Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Post Graduate Study on Road and Transport Engineering

Thesis Proposal on:

Economic Consequences of Delay in Road Maintenance and Rehabilitation in Addis Ababa City

Advisor: Dr. Alemayehu Ambo

By:

Full Name: Solomon G/Mariam…

ID No. GSR/3241/08

Streams: Road and Transport

Sponsored by: MoWIE

Email: solomongmariam100@gmail.com

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Declaration

Am here declare that the work which is being presented in this Thesis entitled, " Economical Evaluation of delay in Road Maintenance in Addis Ababa City" is orginal work of my self.

Name	ID NO.	Signature
Solomon Gebremariam Kahsay	GRS/3241/08 (BSC)	

This is to certify that the above declaration is correct to the best of my knowledge.

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ABSTRACT

An efficient transportation system is of vital importance for the development of a country. In addition, its multiple function of providing access to employment, social, health and education services makes road networks crucial in fighting against poverty by opening up more areas and stimulating economic and social development. There is a problem, however, which is common throughout the world, and that is neglect of maintaining roads. As the road network deteriorates, the whole country loses major assets build up over years, assets created with vast amounts of money, time and effort. Insufficient consideration of maintenance during the road planning and design process is a well-known problem for actors involved in this process and maintenance activities. The problems of performing maintenance activities and their related costs are often subject for discussion. This is not reflected in literatures as published research papers within the subject are very limited. The World Bank has written many papers in this regard! The situations in our country concerning the road condition are not only urgent, it is critical. Therefore, the general objective of this study is to evaluate economically delay in road maintenance using Highway Development and Management Tool (HDM-4) software in case of Addis Ababa city.

KEYWORDS: Road Condition Survey, Road Deterioration, Road Maintenance, Economic Impacts, Highway Development and Maintenance Tool (HDM-4).

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CHAPTER ONE

INTRODUCTION

1.1 Background

A well-organized transportation system has energetic importance for the development of a country. Both the public and private sectors can prepare a good basis for a country's value increase through efficient, effective and sustainable transportation system. It is therefore an imperative for all countries to have a transport policy, which will secure public services and encourage trade and industries. Such policy is important especially to take care of investments on roads to represent and maintain them well and by that also increase the traffic safety (Norwegian Public Roads administration, 1995). It is therefore a national policy all over the world to prevent road traffic fatalities and associated problems including costs to the society. Respectable maintenance is a very important factor in attaining these objectives.

Correctly developed road network in a country attends as a principal foundation for the operative working of transportation and donates in distributing a wide range of economic and social benefits. Acceptable as well as punctual maintenance of the road infrastructure is important to attain and reservation those benefits. The significance of road maintenance is acknowledged by most commentators including key political decision makers (Gunter Zietlow, 1996).

In order to maintain the quality of life in the rural areas, which is of importance in order to have balanced demographics, roads are more or less decisive. In all parts of the world we see that people are moving from rural areas to densely built-up areas because of the availability better transportation facilities. In many countries, there is a policy of encouraging people to develop the rural areas and by doing so avoid the problems of too fast urbanization (Roads Department Botswana, January 2001).

National trunk roads keep a country together and secure that trade and industry flourish throughout the country. Good roads also make a country more competitive both nationally and internationally. In order to establish an efficient road system, it is important to find a right balance amongst using money on construction, maintenance and operation of the roads (Hiep, D. V., 2009). When a maintenance standards is defined, it imposes a limit to the level of deterioration that a pavement is permitted to attain. Consequently, in addition to the capital costs of road construction, the total costs that are incurred by road agencies will depend on the standards of maintenance and improvements applied to road networks.

1.2 Statement of the problem

The rate of pavement deterioration is directly affected by the standards of maintenance applied to repair defects on the pavement surface such as cracking, raveling, potholes, etc., or to preserve the structural integrity of the pavement, thereby permitting the road to carry traffic in accordance with its design function. The overall long-term condition of road pavements directly depends on the maintenance or improvement standards applied to the road and also uncontrolled heavy truck loads.

Availing adequate funding often becomes a contentious issue, and will be influenced by national and political agenda. Insufficient level of expenditure or poor management of the road network often has serious consequences for the contribution made by the road assets. This is why many sources agree that the road maintenance back log is caused by either the shortage of expenditures or lack of proper management or both, it appears that managing the available assets particularly in the developing countries is the main issue.

Maintenance is unlikely to be needed on the entire length of the road at the same time. The secret is to apply maintenance at the right time and in the right place. If interventions are too early or late, money could be wasted. In the case of a new road, its condition deteriorates slowly, only light maintenance is needed. After that time the road enters a critical phase, which may last for some years. To address this subject, this paper will concentrate on evaluating economic impacts of delay in road maintenance in Addis Ababa city with the help of HDM-4 software.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study is to evaluate the economic impact of delay in road maintenance in Addis Ababa city using the Highway Development and Management Tool (HDM-4) software.

1.3.2 Specific objectives

- To carry out pavement condition and traffic surveys on randomly selected road sections;
- To collect data on riding quality of the sampled road sections by using measuring vehicle;
- To determine the required funding levels for the defined maintenance and improvement standards for the road sections;
- To monitor the effect of budget constraints on the long-term network performance trends; and,
- To evaluate the economic impact of delays in road maintenance and improvement in respect of road performance and road user costs.

1.4 Research Questions

- How to collect and document the deterioration data of road networks in the case of AACRA?
- How to determine the riding quality of road networks in case of AACRA in current condition?
- What are the economic impacts of delay in road maintenance and improvement applied to Addis Ababa city's road networks?

1.5 Scope and Limitation of the study

This research performed on Addis Ababa City randomly selected road sections to evaluate economically the delay in road maintenance with the help of HDM 4 software. The research focused only on limited samples and preparation because of unavailability of well documented reconstruction and maintenance backgrounds and other information of the road networks in general.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

All maintenance activities have to be performed at least once a year, if not more frequent. Such activities involves inspections, cleaning of drains, controlling of vegetation and filling of potholes and ruts. Routine maintenance has a lower cost in comparison with any other types of maintenance and new construction projects. On the other hand, maintenance performed immediately to prevent disastrous consequences of damaged road infrastructures. Maintenance departments need unrestricted access to emergency maintenance budgets that allow them to carry out repairs that mitigate immediate dangers. Periodic maintenance and reconstruction are executed less frequently. This type of maintenance includes all sorts of repairs such as resurfacing, overlays, and reconstruction of pavement, base and even sub-base courses, its intervals of maintenance vary according to the demand and may be irregular. Road authorities often allocates a fixed budget on the basis of an inventory that quantifies the assets in terms of age, length, area or volume. The role of management at all levels includes comparing options, organizing activities, making decisions and seeing that they are applied in an efficient and economical way (Ralph, H., 2001).

In many developing countries' economies, while some effort has been made to assess the cost and benefits of good road maintenance, but have not been systematically determined. Insufficient consideration of maintenance during road planning and design processes is a well-known problem for actors involved in this process and maintenance activities. The problems of performing maintenance activities and there related costs are often subject for discussion (Adling, S. & Gupta, A., 2009). This is not reflected in the literature as the published research within the subject is very limited. Efforts have been made to compile the various factors in the road design that generate unnecessary maintenance needs.

The World Bank (WB) as one of the organizations that perform and fund various studies and has assessed the 85 member countries receiving support for their roads, and found that the cost of reconstruction has ranged between three and four times the cost of the preventative maintenance that should have been carried out earlier. Even though the need for maintenance is broadly shared globally, it is still not being adequately addressed. That is why several countries spend just 20-50% of their GDP, what they should be spending on the maintenance of their road network (Harral, C. & Faiz, A., 1988). Burningham, and Stankevich in 2005 identified a number of reasons to explain this low expenditure. Despite the importance of roads maintenance in terms of both their intrinsic value and the role they fulfill, most are poorly managed and badly maintained in the developing world. It is estimated that in Sub-Saharan Africa alone, it would take in the range of £30 billion to repair all the roads requiring immediate rehabilitation and reconstruction. Likewise, for Latin America it is expected that between 1-3% of GDP is being squandered every year due to additional vehicle operating costs **(**VOCs) and rehabilitation produced by inadequate maintenance (Burningham, S. and Stankevich, N., 2005). However the more effective management of the road infrastructure would consequently free up limited capitals and hence contribute to the economic security of such countries (Parkman, C., Madelin, K. & Robinson, R., 2000). According to a previous study performed in Nigeria, postponing road maintenance results in high direct and indirect costs (Emeasoba, U., Ogbuefi, J. & Enugu, C., 2013). If road defects are repaired on time, the cost is usually minimal; if defects are neglected, a whole road section may fully fail, requiring complete reconstruction at three times or more the cost, on average, of maintenance.

Barton & Burns in (2012) stated that "Full range of techniques used are dependent on the nature of the deterioration; this comprises anything from minor potholes or surface patches through to universal pavement construction and drainage upgrades dependent on the source of the damage".

Kenya: in Kenya, because of inadequate maintenance left the main Nairobi – Mombasa road highly vulnerable. In 1997, heavy rain damaged two bridges and several sections of the road. The result was that the users experienced months of national disruptions as long stretches of the road became unusable in the rains and very difficult in dry weather (Ian G. Heggie, 1996).

Tanzania: in Tanzania, failure to improve a simple stream crossing caused damage to three kilometers of road and led to lengthy delays. The result was a bill five times higher than would have been needed to make the original repair (Ian Heggie, 1994).

Southern African Development Communities (SADC)**:** in most SADC countries, a substantial proportion of the road network, typically more than 75%, consists of gravel and earth roads. These relatively low volume roads often fulfill a potentially vital socio-economic function, not only by providing access to rural areas where the bulk of the population live, but also by connecting the productive agricultural areas to the primary road network. Unfortunately, however, despite their vital importance to the wellbeing of the communities that they serve, rural roads in many SADC countries suffer from a number of inherent problems. They often become impassable during the rainy season, gravel wearing courses are abraded by traffic and the weather, dust clouds develop in dry conditions, frequent blading's by motor grader are required to restore riding quality, and regular gravelling places with an unsustainable demand on natural resources (SADC, May 2001).

Recently, there has been a general trend towards increasing the use of the private sectors in road maintenance worldwide, which has been seen by many as a means of encouraging more efficient and effective use of resources. The traditional method was for all administration, management and service provision to be executed by the road owner within the organization. Different countries have experience with reforms, whereby some or all of the functions of the road administrator, manager and service providers, have been contracted out. The majority of road maintenance contracts in use worldwide reflects the different levels of development as well as cultural issues (HDM-4 application manual). The road condition through its life cycle affects road user costs differently to different modes of transport**.** Figure (2.1) below illustrates the effects of road condition on vehicle operating costs for rolling terrain by vehicle type.

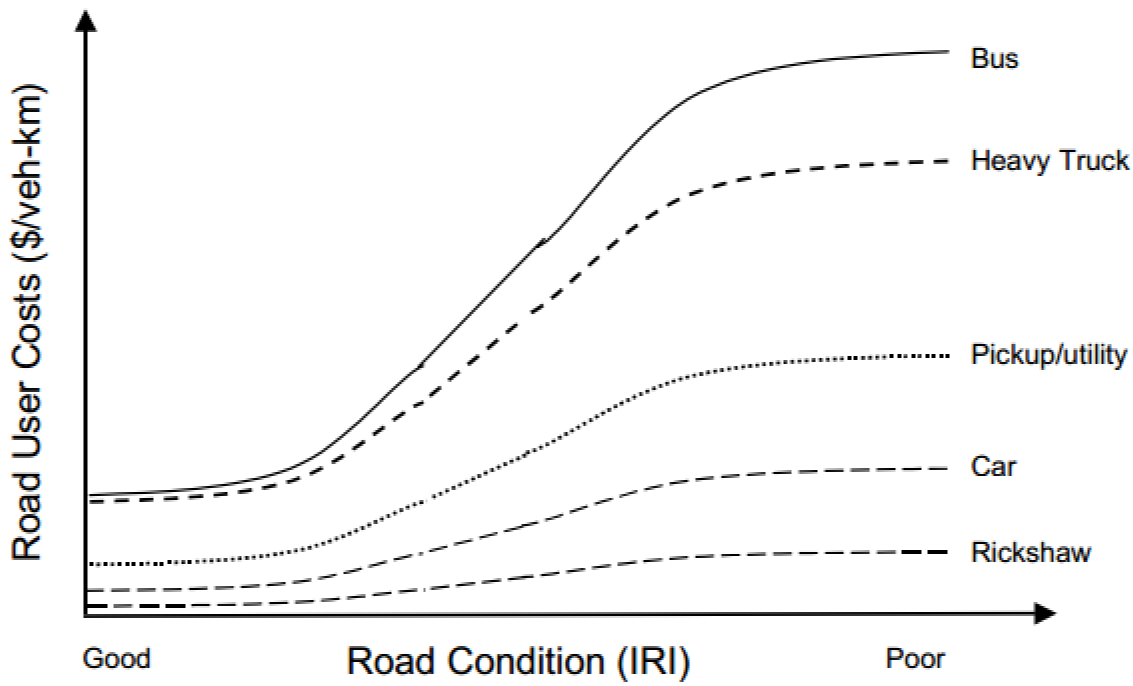

Figure 2- 1 Effects of Road Condition on Vehicle Operating Costs for Rolling Terrain

Source: HDM-4 application manual

2.2 Flexible Pavement Distresses

Classification of distresses according to Federal Highway Administration Distress Identification Manual for the Long-Term Pavement Performance Program (Publication No. FHWA-RD-03-031, June 2003):-

2.2.1 Cracking

A. Fatigue Cracking

Occurs in areas subjected to repeated traffic loadings (wheel paths), can be a series of interconnected cracks in early stages of development. And then it develops into many sided, sharp angled pieces, usually less than 0.3 meter on the longest side, characteristically with a chicken wire/alligator pattern, in later stages with a quantifiable area.

Severity level

Low: an area of cracks with no or only a few connecting cracks; cracks are not sealed; pumping is not evident.

Moderate: an area of interconnected cracks forming a complete pattern; cracks may be sealed; pumping is not evident.

High: an area of moderately or severely interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracking may be sealed; pumping may be evident.

How to Measure

Record square meters of affected area at each severity level. If different severity levels existing within an area cannot be distinguished, rate the entire area at the highest severity present.

Figure 2- 2 fatigue cracking

B. Block Cracking

A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 m^2 to 10 m^2.

Severity levels

Low: cracks with a mean width less than or equals to 6 millimeters; or sealed cracks with sealant material in good condition and with a width that cannot be determined.

Moderate: cracks with a mean width greater than 6 mm and less than or equals to 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent low severity random cracking.

High: cracks with a mean width greater than 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent moderate to high severity random cracking.

How to Measure

Record square meters of affected area at each severity level. If fatigue cracking exists within the block cracking area, the area of block cracking is reduced by the area of fatigue cracking.

Note: an occurrence should be at least 15 m long before rating as block cracking.

Figure 2- 3 block cracking

C. Edge Cracking

Applies only to pavements with unpaved shoulders. Crescent shaped cracks or fairly continuous cracks which intersect the pavement edge and are located within 0.6 meter of the pavement edge, adjacent to the shoulder. Includes longitudinal cracks outside of the wheel path and within 0.6 meter of the pavement edge.

Severity levels

Low: cracks with no breakup and loss of material.

Moderate: cracks with some breakup and loss of material for up to 10 percent of the length of the affected portion of the pavement.

High: cracks with considerable breakup and loss of material for more than 10 percent of the length of the affected portion of the pavement.

How to measure

Record length in meters of pavement edge affected at severity level. The combined quantity of edge cracking cannot exceed the length of the section.

D. Longitudinal Cracking

Cracks predominantly parallel to pavement centerline. Location within the lane (wheel path versus non wheel path) is significant.

Severity levels

Low: a crack with a mean width less than or equals to 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Moderate: any crack with a mean width greater than 6 mm and less than or equals to 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent low severity random cracking.

High: any crack with a mean width greater than 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent moderate to high severity random cracking.

How to Measure

Record separately:

I. Wheel Path Longitudinal Cracking

Record the length in meters of longitudinal cracking within the defined wheel paths at each severity level. Record the length in meters of longitudinal cracking with sealant in good condition at each severity level.

Note: any wheel path longitudinal crack that has associated random cracking is rated as fatigue cracking. Any wheel path longitudinal crack that meanders and has a quantifiable areas is rated as fatigue cracking.

II. Non-wheel Path Longitudinal Cracking

Record the length in meters of longitudinal cracking not located in the defined wheel path at each severity level.

Record the length in meters of longitudinal cracking with sealant in good condition at each severity level.

E. Reflection Cracking At Joints

Cracks in asphalt concrete overlay surfaces that occur over joints in concrete pavements.

Note: the slab dimensions beneath the asphalt concrete surface must be known to identify reflection cracks at joints.

Severity levels

Low: an unsealed crack with a mean width less than or equals to 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Moderate: any crack with a mean width greater than 6 mm and less than or equals to 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent low severity random cracking.

High: any crack with a mean width greater than 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent moderate to high severity random cracking.

F. Transverse Cracking

Cracks that are predominantly perpendicular to pavement centerline.

Severity levels

Low: an unsealed crack with a mean width less than or equals to 6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined.

Moderate: any crack with a mean width greater than 6 mm and less than or equals to 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent low severity random cracking.

High: any crack with a mean width greater than 19 mm; or any crack with a mean width less than or equals to 19 mm and adjacent moderate to high severity random cracking.

How to Measure

Record number and length of transverse cracks at each severity level. Rate the entire transverse crack at the highest severity level present for at least 10 percent of the total length of the crack. Length recorded, in meters, is the total length of the crack and is assigned to the highest severity level present for at least 10 percent of the total length of the cracking. Also record length in meters of transverse cracks with sealant in good condition at each severity level.

Note: the length recorded is the total length of the well-sealed crack and is assigned to the severity level of the crack. Record only when the sealant is in good condition for at least 90 percent of the length of the crack.

If the transverse crack extends through an area of fatigue cracking, the length of the crack within the fatigue area is not counted. The crack is treated as a single transverse crack, but at a reduced length. Cracks less than 0.3 m in length are not recorded.

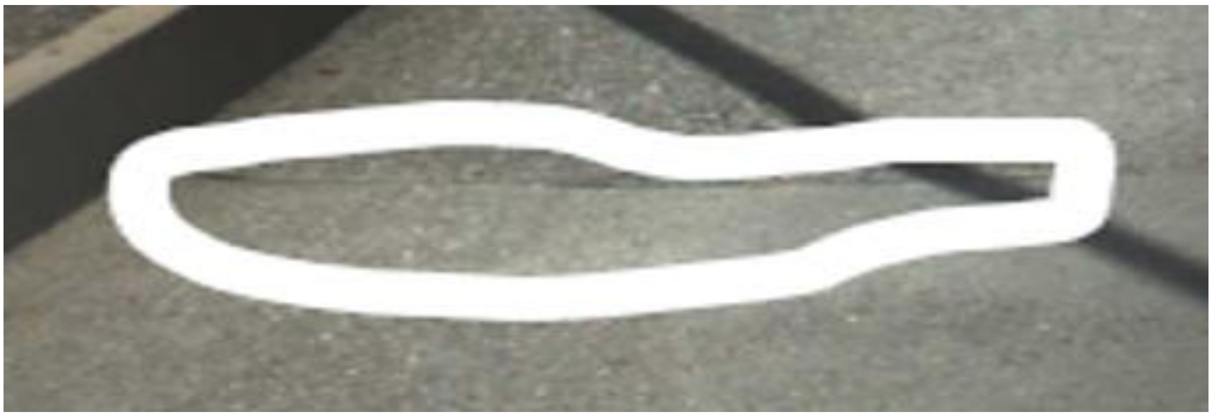

Figure 2- 4 transverse cracking

2.2.2 Patching and Potholes

A. Patch deterioration

Portion of pavement surface, greater than 0.1 m^2, that has been removed and replaced or additional material applied to the pavement after original construction.

Severity levels

Low: patch has, at most, low severity distress of any type including rutting less than 6 mm; pumping is not evident.

Moderate: patch has moderate severity distress of any type or rutting from 6 mm to 12 mm; pumping is not evident.

High: patch has high severity distress of any type including rutting greater than 12 mm, or the patch has additional different patch material within it; pumping may be evident.

How to Measure

Record number of patches and square meters of affected surface area at each severity level.

Note: any distress in the boundary of the patch is included in rating the patch. Rutting or settlement may be at the perimeter or interior of the patch.

B. Potholes

Bowl-shaped holes of various sizes in the pavement surface. Minimum plan dimension is 150 mm.

Severity levels

Low: less than 25mm deep.

Moderate: 25mm to 50mm deep.

High: greater than 50mm deep.

How to Measure

Record number of potholes and square meters of affected area at each severity level. Pothole depth is the maximum depth below pavement surface. If pothole occurs within an area of fatigue cracking the area of fatigue cracking is reduced by the area of the pothole.

Figure 2- 5 potholes

C. Surface Deformation

I. Rutting

A rut is a longitudinal surface depression in the wheel path. It may have associated transverse displacement.

Severity levels

Severity levels could be defined by categorizing the measurements taken. A record of the measurements taken is much more desirable, because it is more accurate and repeatable than are severity levels.

How to Measure

Specific pavement studies (SPS)-3 ONLY. Record maximum rut depth to the nearest millimeter, at 15.25-m intervals for each wheel path, as measured with a 1.2-m straight edge. All other LTPP sections: transverse profile is measured with a Dipstick* profiler at 15.25-m intervals.

II. Shoving

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

Severity levels

Severity levels can be defined by the relative effect of shoving on ride quality.

How to Measure

Record number of occurrences and square meters of affected surface area.

D. Surface Defects

I. Bleeding

Excess bituminous binder occurring on the pavement surface, usually found in the wheel paths. May range from a surface discolored relative to the remainder of the pavement, to a surface that is losing surface texture because of excess asphalt, to a condition where the aggregate may be obscured by excess asphalt possibly with a shiny, glass-like, reflective surface that may be tacky to the touch.

Severity levels

The presence of bleeding indicates potential mixture related performance problems. Extent is sufficient to monitor any progression.

How to Measure

Record square meters of surface area affected.

Note: preventative maintenance treatments (slurry seals, chip seals, fog seals, etc.) sometimes exhibit bleeding characteristics. These occurrences should be noted, but not rated as bleeding.

II. polished Aggregate

Surface binder worn away to expose coarse aggregate.

Severity levels

The degree of polishing may be reflected in a reduction of surface friction.

How to Measure

Record square meters of affected surface area. Polished aggregate should not be rate on test sections that have received a preventative maintenance treatment that has covered the original pavement surface.

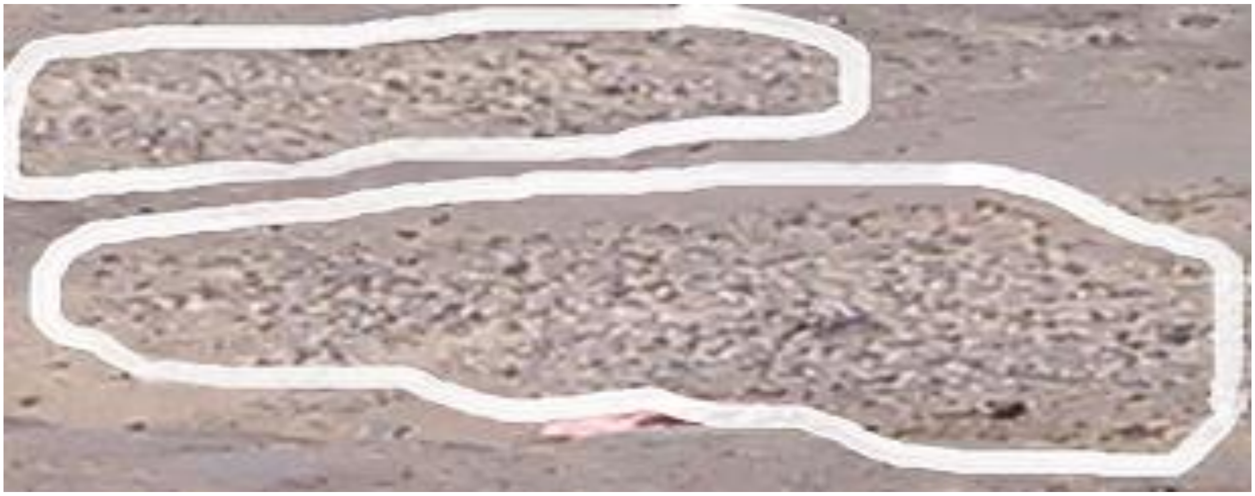

Figure 2- 6 polished Aggregate

III. Raveling

Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder. Raveling ranges from loss of fines to loss of some coarse aggregate and ultimately to a very rough and pitted surface with obvious loss of aggregate.

Severity levels

The presence of raveling indicates potential mixture related performance problems. Extent is sufficient to monitor any progression.

How to Measure

Record square meters of affected surface. Raveling should not be rated on chip seals.

Figure 2- 7 raveling

E. Miscellaneous Distresses

I. Lane to Shoulder Drop off

Difference in elevation between the traveled surface and the outside shoulder. Typically occurs when the outside shoulder settles as a result of pavement layer material differences.

Severity levels

Severity levels could be defined by categorizing the measurements taken. A record of the measurements taken is much more desirable, however, because it is more accurate and repeatable than are severity levels.

II. Water Bleeding and Pumping

Seeping or ejection of water from beneath the pavement through cracks. In some cases, detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

Severity levels

Severity levels are not used because the amount and degree of water bleeding and pumping changes with varying moisture conditions.

How to Measure

Record the number of occurrences of water bleeding and pumping and the length in meters of affected pavement with a minimum length of one meter.

2.3 Pavement Maintenance

2.3.1 Introduction

Preserving and keeping each type of roadway, roadside, structures as nearly as possible in its original condition as constructed or as subsequently improved and the operation of road facilities and services to provide satisfactory and safe transportation, is called road maintenance. Almost everybody uses or is affected by the use of roads. In most countries, roads are the major transport mode for both freight and passengers. Road networks facilitate transport services and reduce the cost of travel and trade, individual roads enhance accessibility to markets and services (Burningham, S. and Stankevich, N., 2005). To achieve continuity of road transport benefits, road assets need to be maintained in good condition. For road projects, sustainability refers to the continuation of transport services and corresponding benefits from the road facilities. The condition of a road will deteriorate over time through use because of the wear and tear of expected and unanticipated traffic, climate change and construction materials' quality.

Road maintenance refers to the processes and resources that are combined to manage road conditions as well as to protect the road assets. It is part of the activities required to ensure an affordable and efficient road system for the sustainability of road transport services. Road maintenance keeps a road network and transport services operating (Parkman, C., et al., 2000). Increasing demand from road traffic will require continued construction and improvement of roads. Substantial economic benefits from road transport cannot be sustained without adequate maintenance, which helps keep a road network in good condition, operating indefinitely without major deterioration overtime, and avoiding economic losses (Emeasoba, et al., 2013).

Different road sections are at different deterioration conditions, despite routine and periodic maintenance, until they are restored to their original smoothness by rehabilitation. Proper maintenance needs tools to identify and plan maintenance tasks, a trained workmanship with selected equipment to carry out the project, and the money to pay for it. Maintenance should be timely, preventing rather than curing significant road deterioration. The requirements for road maintenance differ from country to country and from place to place (John Watson, 1994). Decisions are needed on the level and form of maintenance activity. While for paved and unpaved roads maintenance and its effectiveness may be oriented to the road pavement, for rural roads greater attention is required to off-carriageway works mostly related to the drainage system, halting damage to the road components outside the road surface. In addition, emergency maintenance may be required in response to damage from natural events, especially for bridges, river crossings, and other key road components in vulnerable or remote areas, where failure would sever transport services altogether for a time. Road maintenance is a continuous process, carried out at relatively small-scale and in different locations, and needs a regular and stable source of funding (Barton, J. & Burns, J., 2012).

2.3.2 Pavement Maintenance Issues

- Overloading is a near universal problem in road operations and a difficult one to address.
- The design standards of many roads were not for current traffic loads.
- Budget requests for road maintenance generally must be justified through a prioritization process and delivery of outputs.
- Limited staff capacity impedes effective road maintenance activities irrespective of the level of funding.
- A key issue for execution of maintenance works is the introduction of competitive processes.
- Insufficient road maintenance funding.
- Of fundamental importance in road maintenance funding is a governmental commitment to the concept and benefits of road maintenance, and to its results.
- Increase in the intensity of traffic
- Inadequate thickness of pavement
- Overloading
- Poor road design
- Untimely maintenance
- Limited construction materials
- Lack of institutional capacity

- Need for strong private sector participation
- Limited capacity and number of qualified staff
- Lack of quality contractor
- Lack of advanced technology
- Lack of funding and Natural disasters

Operation and maintenance policies and financing were found to be a significant factor in the likely sustainability of projects, including those in the transport sector. That is why, delay in road maintenance shortens the life of the roads and leads to high operating costs and a high incidence of accidents. So that enhancing capacities for road maintenance is connected to institutional development for the road sector as a whole (Annual Evaluation Review, 2013).

2.3.3 Types of asphalt Pavement Maintenance

Whether you manage a commercial property, or an entire community of home owners, asphalt pavement maintenance is mandatory. With today's increasing budget constraints, property and facilities managers are looking to stretch every dollar to keep their investment in tip top shape. Typically, emphasis has been placed on fixing roads when there is an issue as opposed to maintaining and preserving existing asphalt. Generally following types of maintenance operations are adopted according to Hand book in Asphalt Pavement Maintenance ref. no. 14.

A. Preventative Maintenance

When we do preventative maintenance we are doing a task before a failure has occurred. That task can be aimed at preventing a failure, minimizing the consequence of the failure or assessing the risk of the failure occurring. This type of maintenance is the most effective to extend pavement life in a cost effective way. Preventative maintenance is a strategy of surface treatments when the asphalt is in relatively good condition. From crack sealing small cracks to sealcoating parking lots, preventative maintenance addresses minor issues before they become serious issues.

To maintain the road infrastructure in a cost effective and efficient manner we are continuously looking for new tools to keep our roads in good condition. Some of the treatments that we currently use includes the following.

Crack and Joint Sealing: is a preventative maintenance treatment that increases pavement life at a minimal cost by keeping water out of the pavement structure. A road that will benefit from Crack and Joint Sealing is typically in good structural condition but exhibits single, well-defined cracks. A roadway that shows signs of raveling, multiple alligator cracking, or greater structural inefficiencies may require a different surface treatment.

Chip Seal (surface treatment): is a thin preventative maintenance overlay consisting of a heavy spray application of asphalt emulsion followed by a single layer of clean, uniform sized crushed stone. The surface treatment will seal the pavement from intrusion of water and reduce oxidation and, weathering of the surface. Pavement skid resistance is also improved with a Chip Seal surface treatment. This type of preventative maintenance treatment is best suited to roads that are still in fair condition, have reasonably well defined cross sections, and are not high traffic streets. Stone chip sealing will usually improve streets from fair condition to good or even very good condition, and is consistent with modern pavement management goals. The typical stone chip seal is expected to last 4-7 years before needing another application or other form of maintenance.

Full Depth Reclamation (FDR) and Stabilization: is a pavement rehabilitation process that pulverizes and reuses the existing pavement and sub-base materials to produce a structurally strong pavement base course. Full Depth Reclamation is a process best suited for failed roadways where heavy pot holes, cracking and rutting exist. Even the most severe pavement problems can be solved using FDR. These roadways deteriorate to a point that conventional maintenance and/or repair and overlay practices become expensive and do not perform well due to the condition of the underlying structure.

Pavement milling (cold planning, asphalt milling, or profiling): is the process of removing at least part of the surface of a paved area such as a road. Milling removes anywhere from just enough thickness to level and smooth the surface to a full depth removal. An asphalt overlay is used after the milling process. An overlay is the paving of a second layer of asphalt over existing asphalt. This is a great alternative to reconstruction because it is considerably less expensive and more convenient then full reconstruction of a road surface.

The success of all of these different treatments is dependent on the condition of the roadway prior to the maintenance. It is very important to apply the Preventative Maintenance before the condition of the road deteriorates beyond fair condition to poor or failed condition. The goal of Preventative Maintenance treatments is to save money over the long term by postponing the need for costly pavement reconstruction. Proactively planning preventative maintenance is the best way to prevent costly corrective or emergency maintenance.

Corrective Maintenance

When we are conducting corrective maintenance the failure has now occurred and we are basically reinstating equipment functionality. To be clear, corrective maintenance can be the result of a deliberate run-to failure strategy. This type of maintenance is performed when the pavement is in need of repair, and is usually more costly. Repairs could be structural overlays, mill and overlays, minor pothole repair, patching, rutting or extensive cracking. Corrective maintenance is also referred to as reactive maintenance.

B. Routine or Periodic Maintenance

Since all types of road are exposed to the adverse climate condition and moving traffic, they would positively wear out. Thus for economy, they need maintenance before further deterioration. Under this category of maintenance generally following works are carried out.

- Up keep of carriage way.
- Maintenance of side drains as clearing of silt and maintain proper slope.
- Maintain of shoulders and sub grade.
- Of other ancillary work such as bridge etc.
- Improvement of highway geometric and traffic controls etc.

C. Emergency Maintenance

Performed during an emergency situation, such as a blowout or severe pothole that needs repair immediately for safety reasons or to allow traffic to utilize the roadway or parking lot. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be performed.

Asphalt Patching

One of the advantages of asphalt pavement is the comparative ease of making effective repairs to distressed areas. There are two types of patching in asphalt pavement maintenance. Such as:-

a) Remove and Replace

The most common forms of distress are fatigue cracking and structural failures. These distresses may be caused by overloading the pavement with vehicular traffic and/or water infiltration to the subgrade. These cracks are visible in the form of alligator cracking, potholes, sags, ruts, depressions and lateral displacement. With these types of distresses, the best option is to remove and replace patch the failed area. This process consists of saw cutting the area where structural damage has occurred, removing the area and patching it back with hot mixed asphalt.

b) Skin or Surface Patching

Another common form of pavement distress is raveling. Raveling is caused by water, ultraviolet rays, and/or gas/oil spills resulting in the asphalt and aggregate to separate and erode away the surface. Depending on the damage, the best option may be to perform skin or surface patch. This process consists of applying a thin hot mixed asphalt patch on the surface of existing pavement where it has been deteriorated or weathered. A variation of skin or surface patching is called fabric skin patching. Fabric skin patches are regular skin patches placed over a fabric inner layer between the patch and original pavement to add longevity to the patch.

2.3.4 Timing Maintenance

A general guide to the condition of a pavement can be obtained from data obtained by inspection. A broad comparison between the conditions of the surface and that of the whole pavement is given in the table below.

Table 2- 1: broad relationship between pavement condition and appearance at the surface

Probable pavement condition	Visible evidence
sound	No cracking. Rutting under a 2 meter straight edge less than 10mm

critical	Either or both of: Cracking confined to a single crack or extending over less than half of the wheel track. Rutting 19mm or less
failed	Either or both of: Interconnected multiple cracking extending over the greater part of the width of the wheel path. Rutting 20mm or greater

Source: Highway Construction & Maintenance, 2nd Edition, John Watson.

The table above illustrates very clearly the sequential nature of pavement deterioration. The engineer seeks to anticipate the onset of critical conditions by the timely carrying out of maintenance work immediately before this condition is reached. Such an approach will obtain the best 'value for money'. Work carried out after critical conditions have been reached tends to be much more expensive to achieve the same increase in pavement life, while work other than superficial measures such as surface dressing carried out while the pavement is still sound will generally have less effect in extending pavement life than would be the case if they were delayed to the onset of critical conditions. In the context of a pavement exhibiting signs of structural distress, the usual treatment is to provide an overlay or to reconstruct. It will occasionally be the case that other remedies are appropriate, and these will be indicated from the inspection survey; but generally these two options will be the only worthwhile ones (John Watson, 1994). The deflection concept provides the necessary thickness and time of application of the overlay. If the required thickness of overlay is unattractively expensive, or if site constraints prevent the application of the required thickness of additional material, reconstruction of the pavement should be considered.

It is generally the case that the larger the standard deflection (deflection as measured and corrected to standard test conditions) the smaller the probability of that pavement achieving a long life, its life being measured as before in terms of the number of standard axles it can support before the onset of the critical conditions. If the pavement is stiffened by the addition of an overlay, its standard deflection will be reduced and the probability of its achieving long life will be increased.

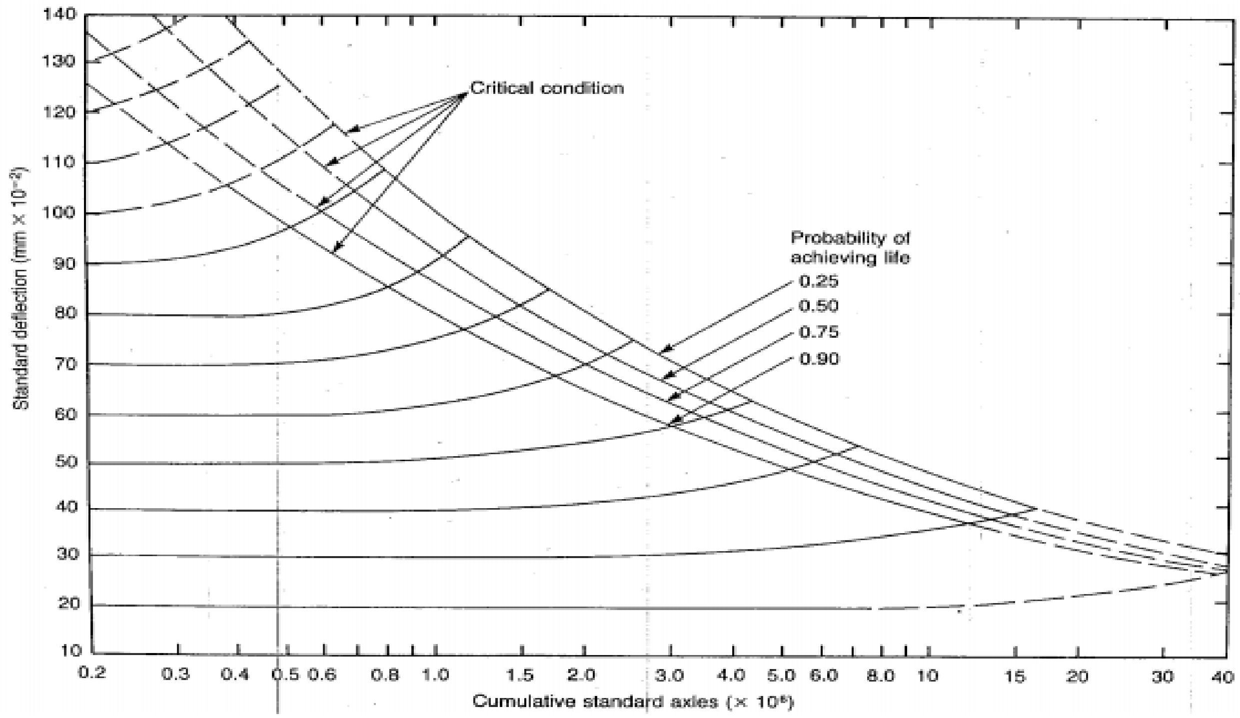

Figure 2- 8 Relationship between standard deflection and life for pavements with bituminous bases

Source: Highway Construction & Maintenance, 2nd Edition, John Watson.

The figure illustrated above should be noted that the pavement life is the whole life of the pavement since it was opened to traffic in its current form, and not an indication of the residual life at the time of the deflection survey (John Watson, 1994). It is however the remaining life which is of the greatest interest to the engineer since it will be the ending of this life that will demand the application of an overlay, or other remedial work. It is therefore useful to estimate the volume of traffic in terms of millions of standard axels that has used the pavement to the time of test.

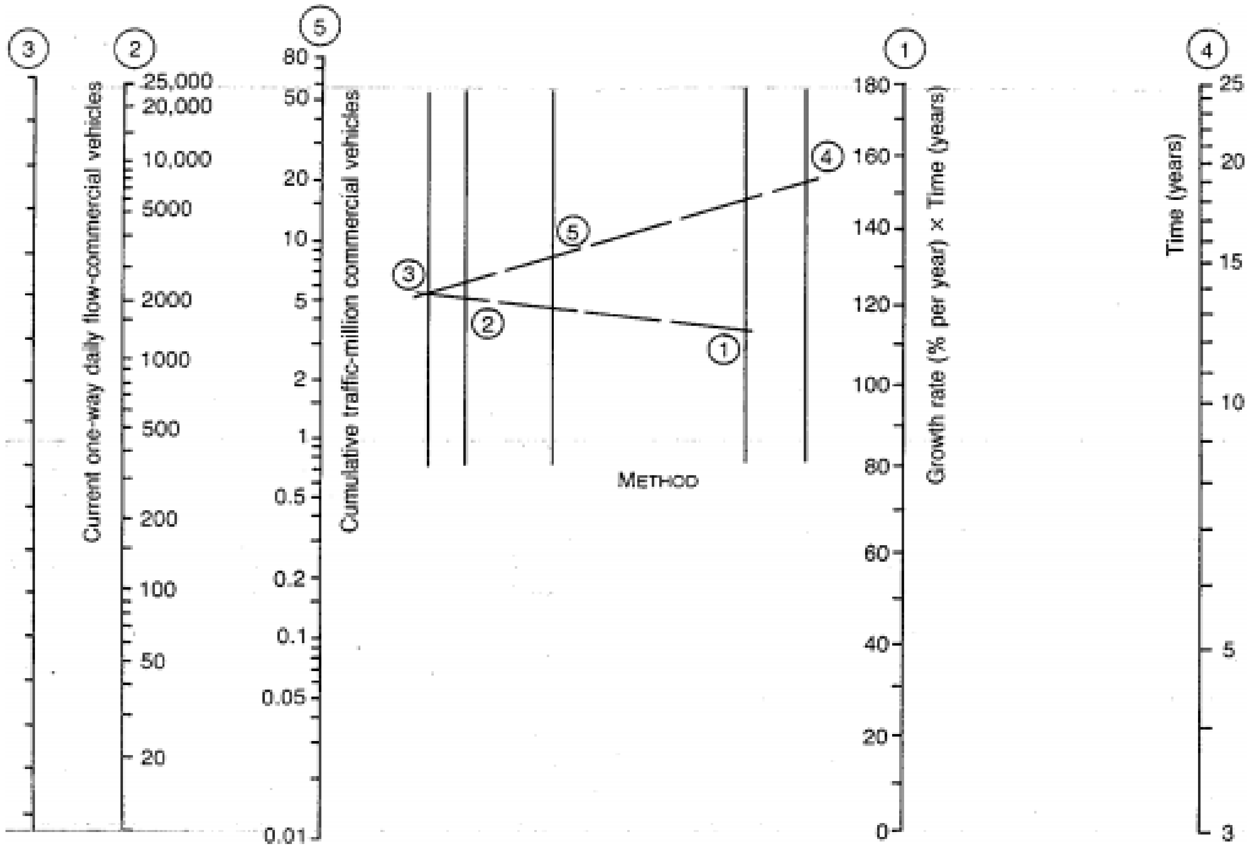

Figure 2- 9 Nomo gram for backward estimation of cumulative traffic

Source: Highway Construction & Maintenance, 2nd Edition, John Watson.

Vehicle damage factor (VDF) = $[0.35/ (0.93^t + 0.082)] - [0.26/ (0.92^t + 0.082)]. [1/3.9^{F/1550}]$

Where t = number of years from the base year to the year in question

F = 24 hour AADF of Commercial vehicles during the year in question

The figure above provides a way of estimating this traffic volume and the equation enables the appropriate vehicle damage factor to be calculated. From these the cumulative number of standard axles may be estimated, and by subtraction the remaining life of the pavement may be obtained from figure 2.1 or other similar diagram appropriate to the pavement's construction.

Maintenance of surfacing upon completion of the surfacing courses, the contractor is required to maintain and water the surface if any traffic is allowed to travel upon the roadway. When traffic is heavy, considerable damage can result if maintenance is not performed daily. It is much better to perform frequent light maintenance on a surfacing course than to wait until considerable rutting, potholing, and segregation occur in which event heavy processing and blading will be required (John Watson, 1994). Testing for density in the top surfacing course shall be deferred until just prior to commencing paving operations.

Good maintenance work and a successfully completed maintenance project depend on good equipment, skillful operation of the equipment, competent, knowledgeable supervision and inspection, and open lines of communications. Maintaining open lines of communication through informal daily meetings between the project inspector and contractor, can greatly improve the success of any project. Hot mix asphalt (HMA) projects, are not always built as original scheduled. Changes may occur because of material supply, equipment breakdown, contractor and subcontractor schedules, and weather conditions. Informal meeting on a regular basis provide a forum for the exchange of information and discussion of problems. To begin the communication process a pre-paving meeting is recommended. The Project Engineer, paving inspectors and testers together with Contractor superintendents, foremen, screed operators, rakers, roller operators and plant operators should be present to go over all activities and plan the entire operation (John Watson, 1994).

2.4 Highway Development and Management Tool (HDM-4)

2.4.1 Introduction

The first move towards producing a road project appraisal model was made in 1968 by the World Bank. The first model was produced in response to terms of reference for a highway design study produced by the World Bank in conjunction with the Transport and Road Research Laboratory (TRRL) and the Laboratoire Central des Ponts et Chaussees (LCPC). Thereafter, the World Bank commissioned the Massachusetts Institute of Technology (MIT) to carry out a literature survey and to construct a model based on information available. The resulting Highway Cost Model

(HCM) produced by MIT (Moavenzadeh 1971, 1972) was a considerable advance over other models used for examining the interactions between the Road Work Costs and Vehicle Operating Costs.

The HCM model highlighted areas where more research was needed to provide a model that was more appropriate to developing country environments with additional relationships specific to that environment. Following this, TRRL, in collaboration with the World Bank, undertook a major field study in Kenya to investigate the deterioration of paved roads as well as the factors affecting vehicle operating costs in a developing countries. The result of this study were used by TRRL to produce the first prototype version of the Road Transport Investment Model (RTIM) for developing countries (Abaynayaka, 1977). In 1976, the World Bank funded further developments of the HCM at MIT that produced the first version of the Highway Design and Maintenance Standards model (HDM) (Harral, 1979).

The results of the TRRL studies were used to develop the RTIM@ model (Parsley and Robinson, 1982), whilst the World Bank developed a more comprehensive model incorporating the findings from all previuos studies and this led to HDM-III (Watanatada et al., 1987). Both models were originally designed to operate on mainframe computers and, as computer technology advanced, the University of Birmingham (Kerali et al., 1985) produced a microcomputer version of RTIM2 for TRRL. Later, the World Bank produced HDM-PC, a microcomputer version of HDM-III (Archondo-Callao and Purohit, 1989). Further development of both models continued with the TRRL producing RTIM3 in 1993 to provide a user-friendly version of the software running as a spreadsheet (Cundill and Withnall, 1995), and in 1994, the World Bank produced two further versions of HDM such as HDM-Q, Incorporating the effects of traffic congestion into the HDM-III program (Hoban, 1987) and HDM Manager, providing a menu-driven front end to HDM-III (Archondo-Callao, 1994).

The various versions of the models have been widely used in a number of countries, and have been instrumental in justifying increased road maintenance and rehabilitation budgets in many countries. The models have been used to investigate the economic viability of road projects in over 100 countries and to optimize economic benefits to road users under different levels of expenditure. As such, they provide advanced road investment analysis tools with broad- based applicability in diverse climates and conditions. However, it was recognized that there was a need for a fundamental redevelopment of the various models to incorporate a wider range of pavements and conditions of use, and to reflect modern computing practice and expectations. The technical relationships contained in the RTIM3 and HDM-III models were in excess of 10 years old by 1995. Although much of the road deterioration models were still relevant, there was a need to incorporate the results of the extensive research that has been undertake around the world in the intervening period. In the case of vehicle operating costs, it was recognized that vehicle technology has improved dramatically since 1980 with the result that typical vehicle operating costs could be significantly less than those predicted by RTIM3 and HDM-III models. It was therefore necessary to update the technical relationships to reflect the state-of-the-art. Whilst most applications of the various models have been utilized in developing countries, in recent years many industrialized countries have begun to make use of the model (Henry G. R. Kerali: Version 1.0). This has resulted in the need for additional capabilities to be included, such as models for:-

- Traffic congestion effects
- Cold climate effects
- A wider range of pavement types and structures
- Road safety
- Environmental effects (Energy Consumption, Traffic Noise and Vehicle Emissions)

It is against this background that the development of HDM 4 was undertaken. The HDM-4 applications have been designed to work with a wide range of data type and quality. The pavement data collected by visual inspection according to condition classes (very good, good, fair, poor condition) can be converted to the HDM-4 model requirements prior to running any of the application. A recent pavement condition survey will prepared for investigating, what percent of the paved road network is in good condition, in fair condition and in poor condition. Data will be collected from ERA and sample traffic surveys will be conducted to countercheck the ERA data.

Road networks provide the basic facilities for storing the characteristics of one or more road sections which is the fundamental unit of analysis. The data entities supported within the road network are sections, links, and nodes. All network data is stored under the road network folder, and facilities are also available for editing, deleting and maintaining this data.

Vehicle fleets facilitate the storage and retrieval of vehicle characteristics required for calculating vehicle speeds, operating costs, travel time costs and other vehicle effects. There is no limit on the numbers or types of vehicles that can be specified. Motorized and non-motorized vehicles are included.

Road works consist a list of maintenance and improvement standards that are followed by road organizations in their network management and development activities.

The data required for HDM-4 analyses can be imported from existing data sources (secondary data) such as pavement management systems (PMS), highway information systems, etc. A data import in to HDM-4 as well as export from HDM-4 is organized according to the data objects described above, that is; road networks, vehicle fleets, and maintenance and improvement standards, and HDM Configuration. The physical attributes of the selected data objects must be exported to a data exchange file format defined for HDM-4. This permits all data required by HDM-4 to be imported directly from any database. Data transformation rules may need to be implemented for converting the data held in the external data base to the format used by HDM-4. For example:-

- Pothole data recorded in percentage area of the pavement surface would need to be converted to the equivalent number of standard pothole units (10 liters by volume).
- Pavement deterioration calibration factors, should inserted as pre-defined default values according to the type of pavement, road class, and other defined factors.
- Other data required for the HDM-4 analyses can be directly stored with in the HDM-4 internal database.

The Highway Design and Maintenance Standards Model (HDM-III), Developed by the World Bank, has been used for over two decades to combine technical and economic appraisals of road projects, to prepare road investment programs and to analyze road network strategies. The International Study of Highway Development and Management (ISOHDM) has been carried out to extend the scope of the HDM-III model, and to provide a harmonized system or approach to road management, with adaptable and user-friendly software tools. This has produced the Highway Development and Management Tool (Henry G. R. Kerali: Version 1.0).

2.4.2 Highway management concepts of HDM-4

When considering the applications of Highway development and Management tool (HDM-4), it is necessary to look at the highway management process in terms of the following functions:-

- Planning
- Programming
- Preparation
- Operation

Clearly, there is a requirement for an objective needs based approach, using knowledge of the content, structure and condition of the roads being managed. It will be seen that the functions of Planning, Programming, Preparation and Operations provide a suitable framework within which a needs based approach can operate (1998). Table 3.1 below shows the management processes of HDM 4.

Table 2- 2: Management Processes

Activity	Time horizon	Staff responsible	Spatial coverage	Data detail	Mode of computer operation
Planning	Long term (strategic)	Senior management and policy level	Network-wide	Coarse/ summary	Automatic
Programming	Medium term (tactical)	Middle-level professionals	Network or sub-network	↓	↓
Preparation	Budget year	Junior professionals	Scheme level/ sections	↓	↓
Operations	Immediate/ very short term	Technicians/ sub-professionals	Scheme level/ sub-sections	Fine/detailed	Interactive

Source: Paterson and Scullion (1990); Paterson and Robinson (1991)

2.4.3 Management cycle

In order to undertake each of these four management functions, an integrated system is recommended. The cycle provides a series of well-defined steps helping the management process through their decision-making activities. The management cycle is typically completed once in each year or in one budgeting period. Figure 3.1 below illustrates the highway management cycle

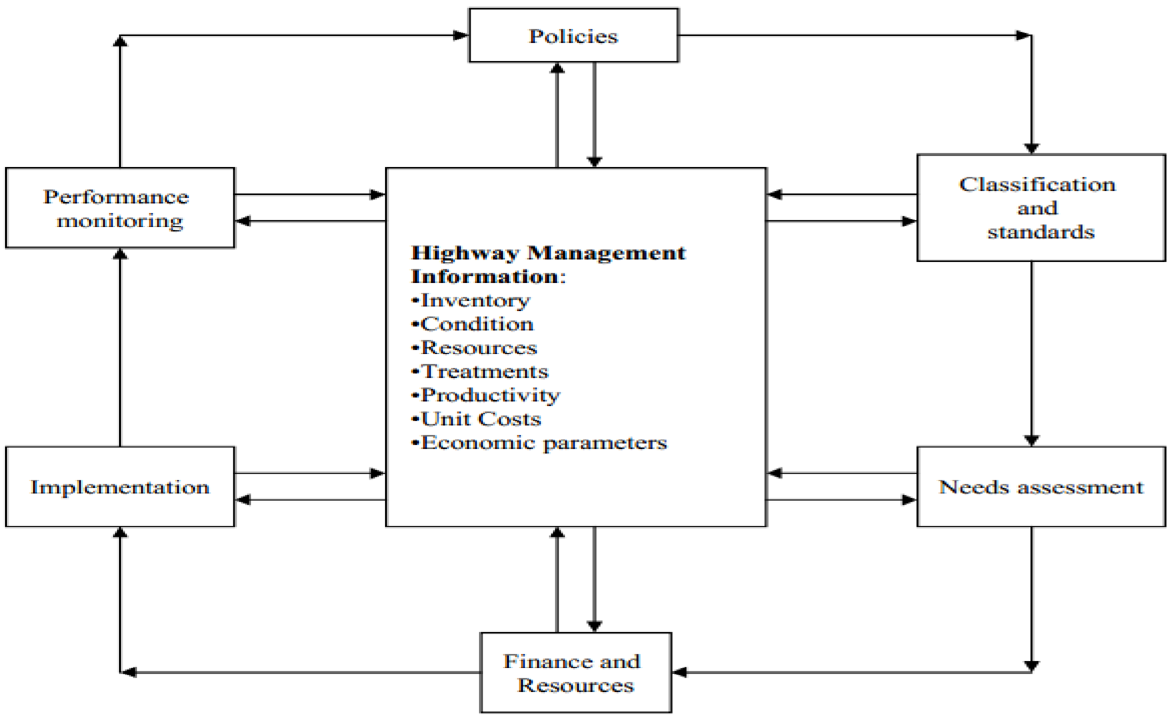

Figure 2- 10: Highway Management Cycle

Source: Robinson et al. 1998

2.4.4 Management functions and the corresponding HDM-4 functions

A. Planning:

i. Strategic analysis system
ii. Network planning system → HDM-4: Strategy Analysis
iii. Pavement management system

B. Programming:

i. Programmed analysis system →

ii. Pavement management system → HDM-4: Programmed Analysis

iii. Budgeting system → HDM-4: Programmed Analysis

C. Preparation:

i. Project analysis system

ii. Pavement management system

iii. Bridge management system → HDM-4: Project Analysis

iv. Pavement/overlay design system

v. Contract procurement system

D. Operation:

i. Project management system

ii. Maintenance management system → HDM-4: Project Analysis

iii. Equipment management system

iv. Financial management/accounting system

2.4.5 Analytical Framework

The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement, which is typically 15 to 45 years:

- Road deterioration
- Road work effects
- Road user effects
- Socio-Economic and Environmental effects

Once constructed, road pavements deteriorate as a consequence of several factors, most notably:

- Traffic loading
- Environmental weathering
- Effect of inadequate drainage systems

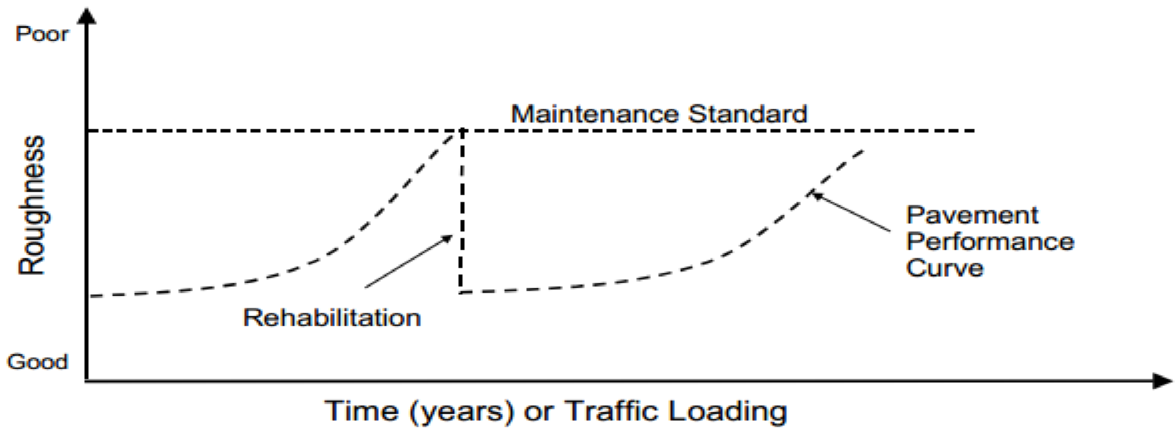

Figure 2- 11: Concept of Life-cycle analysis in HDM-4

Source: HDM-4 Application Manual

The impact of the road condition, as well as the road design standards, on road users are measured in terms of road user costs, and other social and environmental effects. Road users' costs comprise:

- Vehicle Operation costs (fuel, tyres, oil, spare parts consumption; vehicle depreciation and utilization, etc.),
- Costs of travel time – for both passengers and cargo, and
- Costs to the economy of road accidents (loss of life, injury to road users, damage to vehicles and other roadside objects)

In HDM-4, road user effects can be calculated for both motorized transport (buses, trucks, cars, motorcycles, etc.) and non-motorized transport (bicycles, human powered tricycles, animal pulled carts, etc.).

Road User Costs in HDM-4 are calculated by predicting physical quantities of resource consumption and then multiplying these quantities by the corresponding user specified unit costs. It is necessary to ensure that the vehicle resource quantities predicted are in keeping with the range of values observed in the area of application.

Economic benefits from road investments are then determined by comparing the total cost streams for various road works and construction alternatives against a base case (without project or do minimum) alternatives, usually representing the minimum standard of routine maintenance.

HDM-4 software is designed to make comparative cost estimates and economic analyses of different investment options. It estimates the costs for a large numbers of alternatives year by year for a user defined analysis period.

All future costs are discounted to the specified base year. In order to make these comparisons, detailed specifications of investment programs, design standards, and maintenance alternatives are needed, together with unit costs, projected traffic volumes, and environmental conditions (Henry G. R. Kerali: Version 1.0).

2.4.6 HDM-4 Analyzing process

A. Strategy Analysis

The strategy analysis under HDM-4 deals with the entire networks or sub-networks managed by one road organization. In order to predict the medium to long term requirements of an entire road networks or sub networks, HDM-4 applies the concept of a road network matrix comprising categories of the road networks defined according to the key attributes that most influence pavement performance and road user costs. A typical road network matrix could be categorized according to the following:-

- Traffic volume,
- Pavement types,
- Pavement condition,
- Environment or climate zones, and
- Functional classification.

A road network matrix could be modelled using; three traffic categories (high, medium, low), two pavement types (asphalt concrete, surface treatments), and three pavement condition levels (good, fair, poor). The resulting road network matrix for this would therefore comprise (3*2*3=) 18 representative pavement sections. There is no limit to the number of representative pavement sections that can be used in strategy analysis.

B. Program Analysis

Program analysis primarily deals with the prioritization of a defined long list of candidate road projects into a one-year or multi-year program under defined budget constraints. The selection criteria will normally depend on the maintenance, improvement or development standards that a road administration may have defined. This provides the basis for estimating the economic benefits that would be derived by including each candidate project within the budget time frame.

The objective function is to maximize the Net Present Value (NPV) or to select that combination of treatments options for sections that maximizes NPV for the whole subject to the sum of the treatment costs being less than the budget available.

C. Project Analysis

Evaluation of one or more road projects or investment options. The application analysis a road link or section with user selected treatments, with associated costs and benefits, projected annually over the analysis period. Economic indicators are determined for the different investment options (Henry G. R. Kerali: Version 1.0).

Project analysis may be used to estimate the economic or engineering viability of road investment projects by considering the following issues:

- Economic comparisons of project alternatives;
- Life-cycle predictions of road deterioration, road works effects and costs;
- Road user costs and benefits; and Structural performance of road pavements;

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Background

The aim of this study is to evaluate the economic impact of delays in road maintenance and improvement in respect of road performance and road user costs by carry out pavement condition and traffic surveys to collect data on riding quality of the sampled road sections using measuring vehicle and, to determine the required funding levels for the defined maintenance and improvement standards for the road sections to control the effect of budget constraints on the long-term network performance trend and on the economy of the Country in general and to the city of Addis Ababa in particular.

3.2 Research Design

The primary research method for this study is road condition assessment and then identification of the damaged roads which are not maintained will be carried out. This study will be conducted according to the actual data collected on those randomly selected sample road networks and, will focus on the economic impacts of road maintenance delays to the Country in general and to the city of Addis Ababa in particular. Therefore, this research will be a cross-sectional design, quantitative, observational and exploratory study. The Highway Development and Management Tool (HDM-4) software will be used for evaluating and interpreting the quantitative data of the randomly selected road sections of the Addis Ababa city road networks.

3.3 Data collection process

3.3.1 Introduction

The data collection include the primary surveys in the field and the secondary data collection from various sources. This chapter presents the types and sources of secondary data, primary traffic surveys. Based on the objectives and scope of the study, an appropriate methodology has been developed to collect the different types of data and identifying the location (source). In case of secondary data, the past project reports were reviewed for either directly extracting the required data from it (if available) or at least in identifying the sources of required data. Also help of authorities is intended in form of getting necessary permission letters for collecting secondary data from different sources as well as for conducting primary surveys on ground. The data is in different forms like hard copies, scanned reports, AutoCAD drawings, non-editable maps, office documents like Word and Excel etc.

Table 3- 1: Secondary Data Collected

No	Agency/Authority/Association/Gov't Department	Data collected
1	Addis Ababa City Roads Authority	Addis Ababa Road Network Data
2	Addis Ababa Integrated land Information Center	Old Master Plan
3	Addis Ababa Transport Authority	Road Traffic Regulation
4	Central Statistical Agency	Statistical Abstracts
5	Ethiopian Roads Authority	Axle Load Data of all stations

3.3.1.1. Ethiopian Roads Authority

The data on the external freight traffic movement surrounding Addis Ababa is sourced from the Ethiopian Roads Authority from the year 2002 to 2016 from all the radial roads emanating out of city. The total truck traffic (AADT) is summarized and the long-term trend is depicted in the picture below.

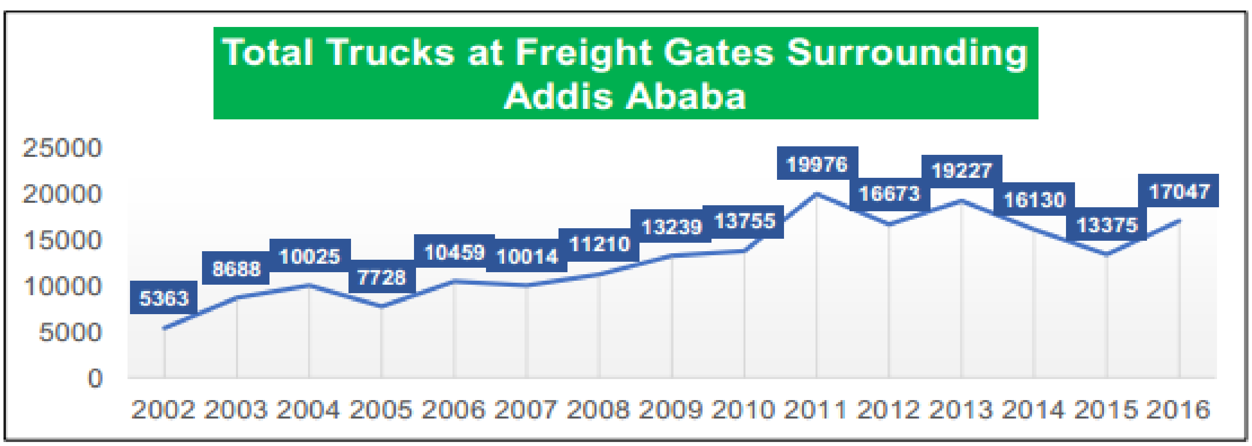

Figure 3- 1: Total Trucks at Freight Gates Surrounding Addis Ababa

(Source: Ethiopian Roads Authority)

Recent truck traffic trend shows there is a dip in the traffic numbers from the year 2014, specifically in the year 2015 which can be majorly attributed to the commencement of traffic operations of the newly built expressway between Addis Ababa and Adama. Until the year 2013, the average share of the truck traffic along the Addis Ababa- Kality (bishoftu) road in overall truck traffic is more than 70% which is very high. And the share of the truck traffic along the Addis Ababa- Kality road is decreased to 30% (from 70%) may be due to the factors like developments happening along other corridors, apart from Kality (bishoftu) road and commencement of new Expressway between Addis Ababa and Adama.

3.3.1.2. Ethiopian Toll Road Enterprise

Ethiopian Toll Road Enterprise is the authority concerned with development and the management of the Expressways in Ethiopia. The approximately 85 km long Addis- Adama expressway connects Addis Ababa to Adama and also is the first expressway in Ethiopia. Since its inception the traffic volume has been growing at a CAGR of 26%. Around 6.67 Lakhs of vehicle passed through Adama Expressway near Tulu Dimtu in the month of October 2017 compared to 4.18 Lakhs of vehicles during October 2015. This huge growth shows that apart from traffic growth, the traffic diversion from Old Modjo road is still active.

3.3.1.3. Addis Ababa Police Commission

The analysis of road accident data (2002-2008 E.C) obtained from Addis Ababa Police Commission indicates that, most accidents in a week have occurred on Thursday whereas Sunday was observed to have least no. of accidents. Based on time of the accident, it has been observed that the time period between **5:00 – 11:00 hrs.’** have recorded the least number of accidents, whereas the time period between **16:00 – 18:00 hrs.’** have almost recorded highest number of accidents.

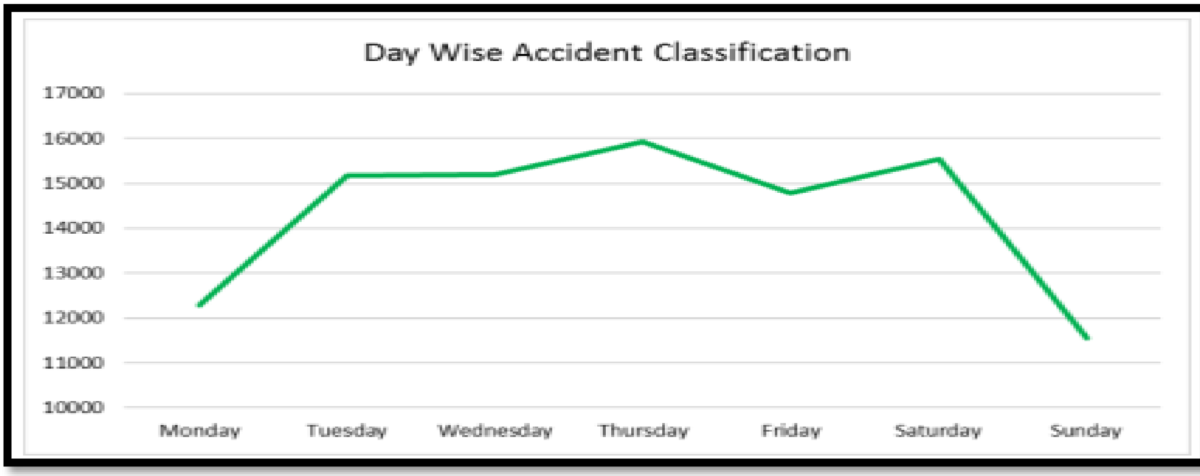

Figure 3- 2: Accidents Classification by Day.

Source: Addis Ababa Police Commission

3.3.1.4. Addis Ababa Trade Bureau

The Addis Ababa Trade Bureau is responsible for the registration and licensing of business establishments. The latest data obtained from the trade bureau illustrates the concentration of business establishments at sub-city level in Addis Ababa. From the graph, it is evident that, the Bole Sub-city accounts for 15 percent of the total establishments and Addis Ketama the sub-city in which Merkato is located accounts for nearly 14 percent of the total establishments. Lideta Sub-city accounts for the least percentage of trade establishments at 5 percent.

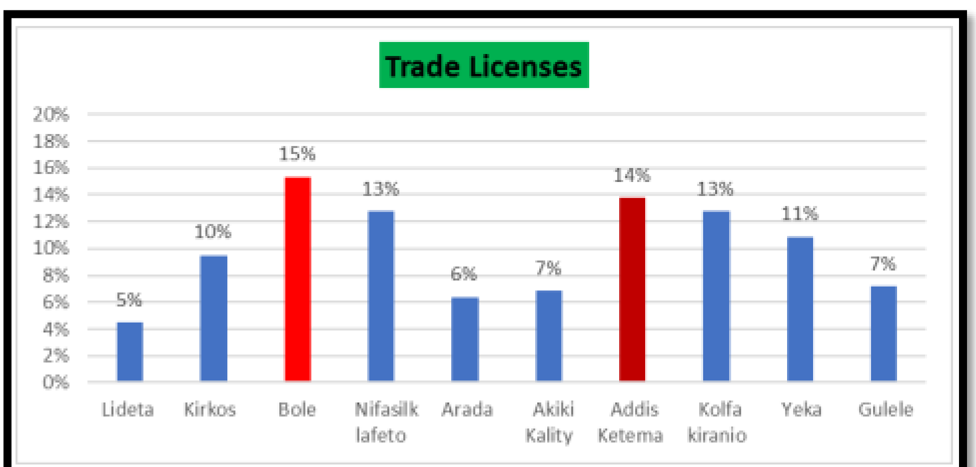

Figure 3- 3: Sub-City wise trade license distribution

Source: Addis Ababa Trade Bureau

3.3.1.5. Addis Ababa City Roads Authority (AACRA)

Addis Ababa City Roads Authority is the manager of the road networks and its associated assets on behalf of the government. Road Asset Management Team is responsible for defining maintenance activities and setting out schedules for the tasks to be done. The process twitch from the road condition survey which includes categorizing roads according to their severity levels and road classes. Usually the roads with higher severity level of deterioration and roads those have higher political pressure get priority. AACRA used matrix method of road condition and traffic priority for their maintenance schedules. Table 3.1 below demonstrate the matrix method used by AACRA.

Table 3- 2: AACRA Matrix Method of road condition and traffic priority

Priority Matrix	Strategic	PAS	SAS	Local
Very Poor	1	2	3	4
Poor	2	5	6	7
Fair	3	8	9	10
Good	11	12	13	14
Very Good	15	16	17	18

Source: AACRA

The analysis of the data obtained from the AACRA until the year 2007E.C. reveals that out of the total network the principal arterial roads have a share of 23 percent whereas Sub-arterial roads have a share of 11 percent. The local streets given the extent of coverage have a major share of 43 percent of the total road network. The collector streets and Ring roads have a share of 20 percent and 3 percent respectively. The figure given below depicts the road classification in Addis Ababa.

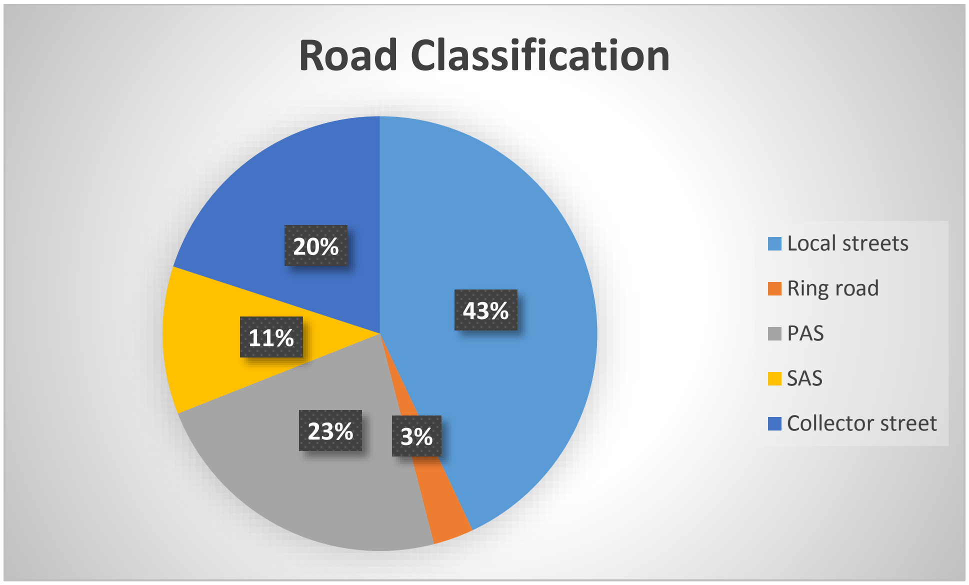

Figure 3- 4: classification of Roads

(Source: AACRA)

3.4 Study Area Description

Addis Ababa is the capital city of Ethiopia and often referred as the "politically capital of Africa" due to its historical and diplomatic significance to the continent. The City is located at the center of the country. The City is extended over 540 sq. km. divided by ten administrative sub cities. The City is the seat of government, Center for education, industry and services and nearly 40% of the GDP is estimated to be generated from this region (ICT, 2012).

Addis Ababa city has been the engine of economic growth in the country and is expected to play a greater role in the years ahead. To enable this, an efficient, effective and economical maintenance system is an important requirement. The delay in road maintenance not only increase the operating times of vehicles within the city, but it also reduces the utilization of the vehicles and therefore increases the cost of transport which will finally burdened on the economics of the city as well as the country.

On time maintenance of the City's road networks are critical if the sector is supposed to contribute its share to the economy and the transport system of the city. This raises the need to understand the current maintenance operation system to increase the efficiency of the road transport and bring down the operation cost of the vehicles.

Addis Ababa is the capital city of Ethiopia. The city is the country's largest political and economic center, also it is the seat of Head Office of African Union and United Nations Economic commission for Africa. It also accommodates many international Aid and Development organization and more than 100 embassies, with an area of 540 sq. km is divided into ten sub-cities for administration purposes.

The city's population is estimated to be 3.2 million (CSA statistical abstract-2014). With the current population growth rate of 2.5%, the city population is estimated to reach 4.5 million after 10 years. And around two-third of the vehicles registered in the nation are in Addis Ababa (FTA statistics on registered vehicles, 2015).

Table 3- 3: Population of Addis Ababa, Ethiopia

Year	Population in million	Average Annual Growth Rate
1961	0.4	-
1967	0.6	7.6
1978	1.1	4.9
1984	1.4	3.5
1994	2.1	4
2000	2.4	2.9
2007	2.7	2.6
2010	2.9	1.6
2011	3	3.4
2012	3.1	3.3
2014	3.2	3.2

Source: CSA statistical abstracts, ICT.

3.4.1 Profile of the City

Addis Ababa, the capital city of Ethiopia hosts more than 20% of the urban population of Ethiopia. It is considered as the diplomatic center of Africa and one of the fastest growing cities on the continent. Its geographic location, combined with its political, historical and socio-economic status have made it a hub to hundreds of thousands of people immigrating in search of employment opportunities and services.

As the capital city and biggest city of Ethiopia, Addis Ababa is well connected by Road. Rail and Air transport networks, to other parts of the country. This city covers an area of 540 sq. km which divided into 10 sub-cities and 116 woredas and its population is currently ranging from 3.5-4.0 million.

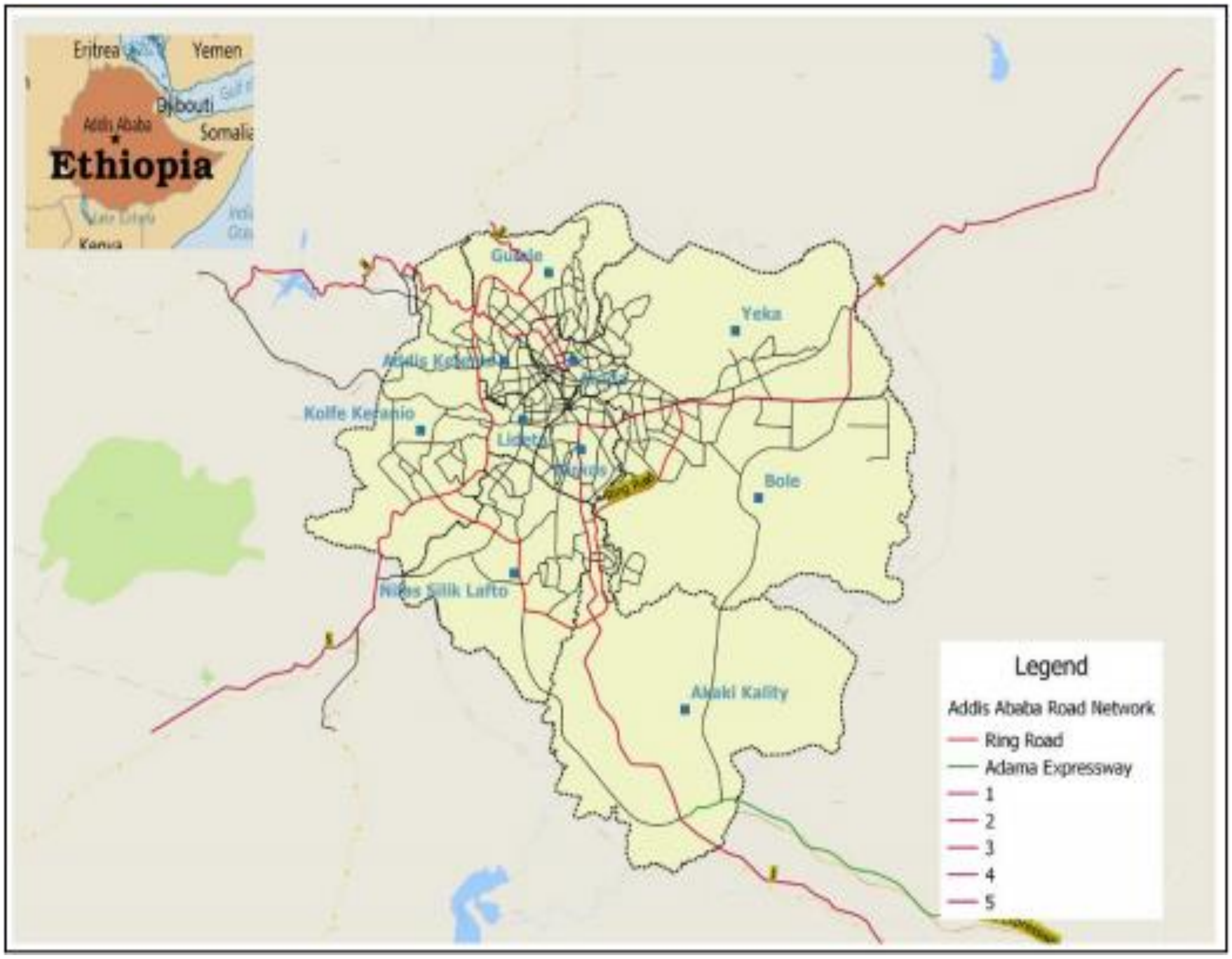

Figure 3- 5: Addis Ababa, Ethiopia

(Source: Addis Ababa City Atlas)

3.4.2 Demographics

According to the CSA estimate, Ethiopia's total population is about 100 million people. Of the total population 16% (16.4 million people) live in urban areas. This number is rising fast due to an annual urban population growth of 4.89%. Ethiopia's urban population is expected to triple by 2037 (World Bank, 2015). Addis Ababa hosts an estimated 3.2 million people, which is a 22%

share of Ethiopia's total urban population. Currently, Addis Ababa is experiencing an annual growth rate of 3.2% and is estimated to reach 4.7 million inhabitants by 2030.

The urban population of Ethiopia is concentrated in few urban centers, predominantly in Addis Ababa. It is one among the fast-growing cities in the World. In between 1961 and1994, its population size has increased by about five times, from about less than half a million to 2.1 million. As per the Central Statistical Agency Report (Census 2007) the last recorded population is estimated to be around 2.7 million. The population growth based on the latest statistics was observed to be 1.6 percent as shown below in table 3-4.

3.4.3 Land Use

The settlement pattern and location of commercial activities spatially provides a basis for understanding the vehicles movement within the city. The land use of the study area as per the Master Plan is given below table 3-5.

Table 3- 4: Sub-city Wise Population distribution in Addis Ababa

No.	Sub-city	Female	Male	Total Population
1	Kolfe keranyo	259,180	240,983	500,163
2	Yeka	216,796	187,540	404,336
3	Nifas Silk Lafto	195,976	172.907	368,883
4	Bole	191,842	168,545	360,387
5	Gulele	161,922	150,174	312,096
6	Addis Ketema	152,839	144,954	297,793
7	Kirkos	137,915	120,120	258,035
8	Arada	131,592	115,088	246,680
9	Lideta	123,515	111,731	235,246
10	Akaki kaliti	108,421	102,959	211,380
	Total population	1,679,998	1,515,001	3,194,999

(Source: Addis Ababa City Atlas)

Table 3- 5: Addis Ababa, Existing Land Use

Land Use	Area in hectare
Administration	894.85

Commercial	761.38
Cultural & Social Welfare	120.15
Education	856.61
Field Crop	13936.49
Green	16569.48
Health	198.19
Infrastructure and Utilities	38.61
Manufacturing & Storage	1758.57
Mixed Residential	880.26
Municipal Services	552.42
Open Spaces	4675.23
Recreation	5227.65
Religious Institutions	558.71
Residential	13130.73
River	1186.02
Road Network	5413.52
Spacial Use	369.77
Transport Terminal	530.11
Urban Agriculture	7499.42

(Source: Addis Ababa City Atlas)

Percentage of some land uses out of the entire land area, Road network comprises 10.42%, Residential land use comprises 25.27% and freight generation land uses namely (commercial, manufacturing and storage) comprises of 5% of the total land use.

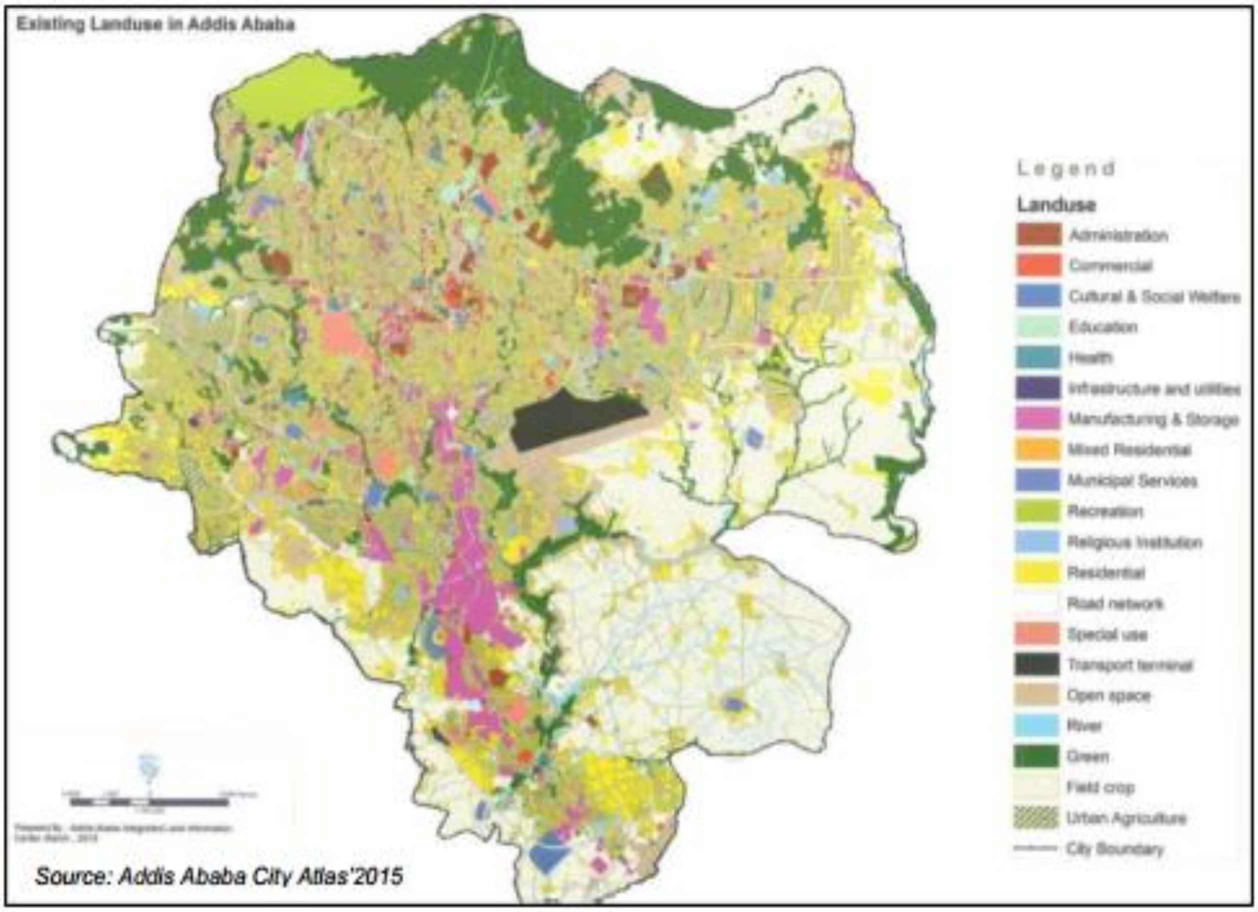

Figure 3- 6: Addis Ababa, Existing Land Use

(Source: Addis Ababa City Atlas)

3.4.4 Road Network

Addis Ababa is the center of Ethiopia, with a radial road network based around the national road system that converges in the city. There are five main road numbers (1, 2, 3, 4 & 5) connecting the city with the other countries and cities. Such as, Road no. 1**,** travels south –east traversing Mojo (dry port) and Adama before turning east and and going through Awash before terminating in the city of Djibouti. The Road no. 2, connects Addis ababa directly to Asmera capital city of Eritrea passing through Debre Birhan, Dessie, Weldiya, Mekelle and Adigrat. The Road no. 3 connects north of Addis Ababa linking it to Debre Markos, Debre Tabor and Gonder Before joining the Road no. 30 into Eritrea. The Road no. 4 traverses west connecting Holeta, Ambo, Nekemte, before bifurcating into Sudan and South Sudan. And it also the principal international route to Nairobi in Kenya and consequently forms part of the Trans Africa Highway route network to Cape town, South Africa. The Road no. 5 connects west traversing Sebeta and Jimma, and further to Sudan, forming the northern section of the Trans Africa Route to Cairo via Khartoum.

The city road network comprises of Arterial, Sub-Arterial, collector and local streets. The peripheral ring road circling around the city has added the most needed orbital road. AACRA had a total road network length of about 1600km covering all the categories. The peripheral ring road a four-lane access controlled highway interlinks the four regional roads and runs from Megenagna in the east up to ambo road. The northern part connecting Ambo road, Gojam road and Dessie road is yet to be completed. Out of the total length of the roads about one-third are Arterial roads. The distribution of road network in length provided by AACRA is given in the table below.

Table 3- 6: Road hierarchy of Addis Ababa

Road Hierarchy	Length(km)
Principal Arterial	376
Sub-arterial	179
Collector streets	320
Rural roads	47
Local streets	681
Total (km)	1603

(Source: AACRA)

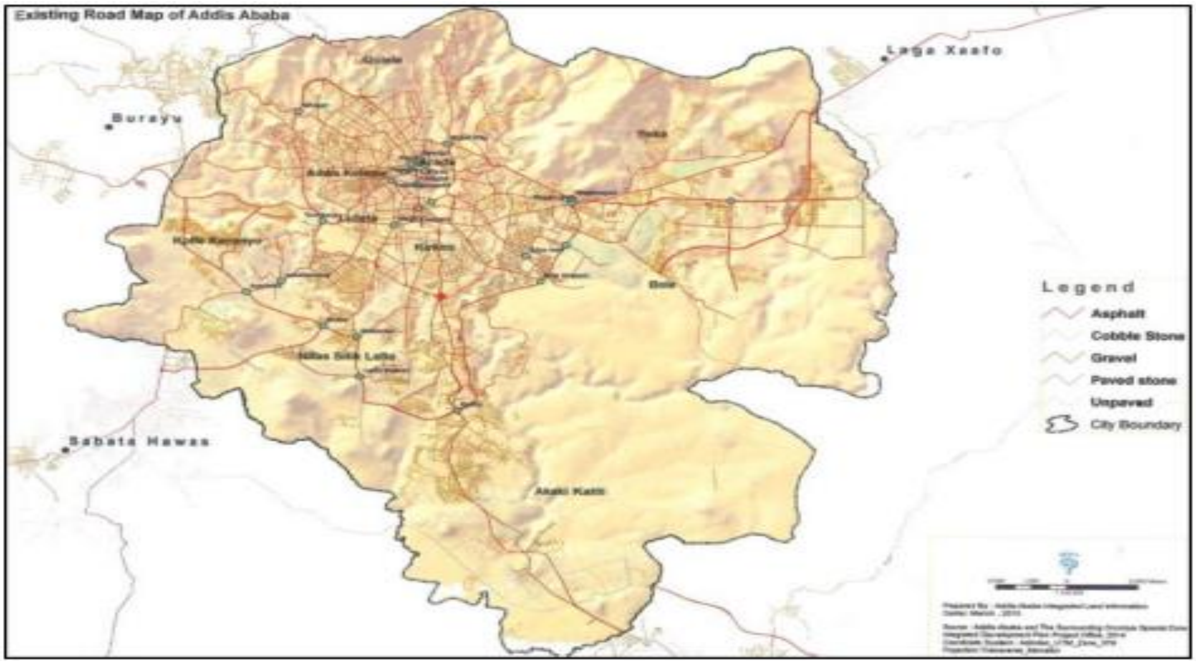

Figure 3- 7: Existing Road Network of Addis Ababa

(Source: Addis Ababa City Atlas)

3.5 Traffic Data Assessment

3.5.1 Introduction

Traffic surveys and studies are an integral component of any transportation study. Appreciation of existing traffic and travel characteristics is extremely important for developing an understanding of the present context and scenario. The main objective of the classified traffic data counts was to assess the traffic characteristics in terms of Average Daily Traffic (ADT), Average Annual Daily Traffic (AADT), Passenger Car Units (PCU) and Traffic compositions (%) on those randomly selected sample road networks. Ethiopian Roads Authority carries out traffic surveys three times a year depending on the country's agricultural activity: high traffic (immediately after harvest i.e. January-April), Low traffic (May-August) and Medium (September-December) and also the adjustment factors and seasonal factors of the ERA traffic survey times of a year 1.31, 1.24, 1.29 and 0.88, 1.22, 0.96 respectively. Traffic counts were conducted for five days a week for 12-hours and two days 24-hour count (one during the middle of the week and the second one during the weekend) depending on the location significance with respect to freight movement and also based on availability of past traffic data.

Table 3- 7: Addis Ababa City Road Classification

Road Classification	Length(km.)	Percentage share
Ring Road	38	8%
Highways	50	11%
PAS 1	42	9%
PAS 2	25	5%
PAS 3	69	15%
PAS 4	128	27%
SAS 1	45	9%
SAS 2	46	10%
Others	31	7%
Total	473	100

(Source: Consultant's Primary Survey 2017)

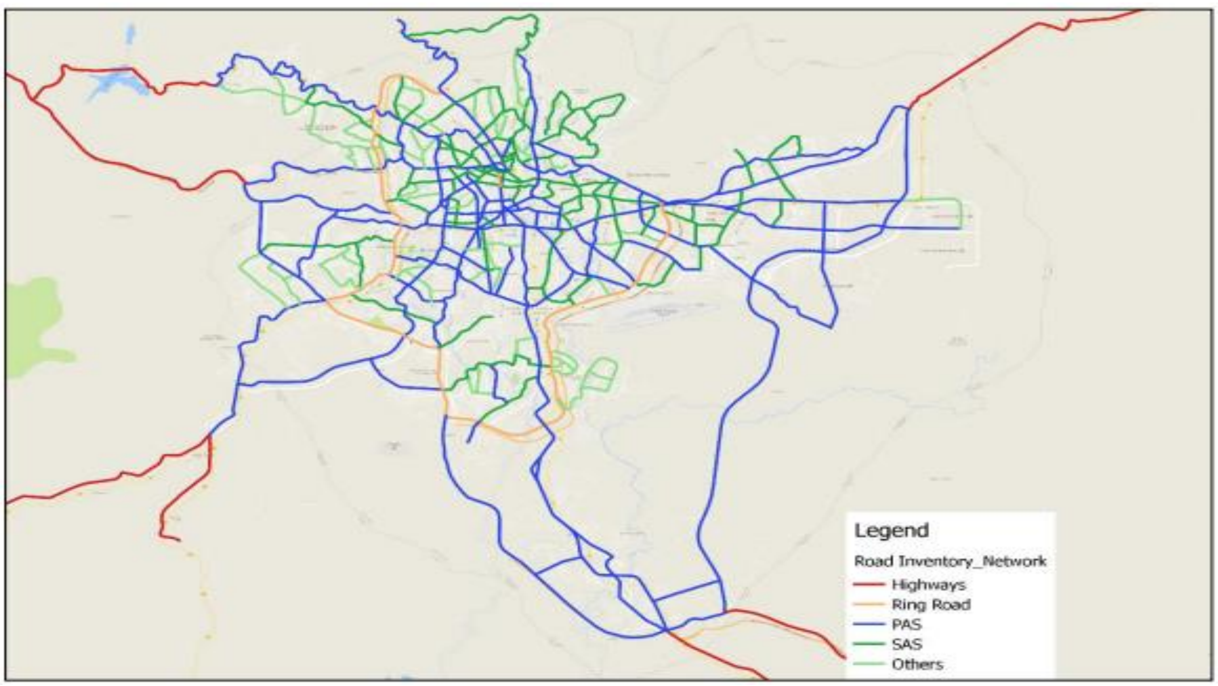

Figure 3- 8: Road Network Inventory Map

(Source: Addis Ababa City Atlas)

3.5.2 Configuration of Roads

The distribution of the road networks show that 68 percent of the road are having divided carriageway and 32 percent of the roads are having undivided carriageway. It was also observed that out of the PAS roads available for freight traffic movement 12 percent of the PAS road network is undivided. The table below illustrates the distribution of roads by carriageway type.

Table 3- 8: Distribution of roads by Carriageway type

Road type	Divided	Undivided
Ring Road	8%	0
Highways	5.60%	4.90%
PAS 1	8.90%	0
PAS 2	5.30%	0
PAS 3	12.80%	1.80%
PAS 4	16.90%	10.20%
SAS 1	5.60%	3.90%
SAS 2	3.30%	6.40%
Others	1.60%	4.90%
Total	68%	32%

(Source: Consultant's Primary Survey 2017)

3.5.3 Type of pavement

The distribution of the road networks of Addis Ababa City by pavement type as shown below in table 3.8, Asphalt surfaces are most popular in Addis Ababa about 97.6 % and about 2% of roads have concrete pavement.

Table 3- 9: Classification of the Addis Ababa roads' by pavement type

Road type	Asphalt	Concrete	Others
Ring Road	6.6%	0.0%	0.0%
Highways	11.1%	0.0%	0.0%
PAS 1	11.3%	0.0%	0.0%
PAS 2	6.7%	0.0%	0.0%
PAS 3	15.4%	1.2%	0.0%
PAS 4	25.7%	0.0%	0.0%
SAS 1	9.5%	0.2%	0.0%
SAS 2	7.0%	0.3%	0.0%
Others	4.30%	0.3%	0.5%
Total	97.6%	2.0%	0.5%

(Source: Consultant's Primary Survey 2017)

3.5.4 Speed Survey

Speed surveys were carried out by the floating car method on the same network as covered in Road Network inventory. The average speed achieved is about 28 km per hour in Addis Ababa.

However, in the city core (around Markato), the achieved travel speeds were low about 5 to 15 km/hr, due to congestion and vehicle encroachments. The classification of the road type by average speed is show in figure below.

Table 3- 10: Average Speed by Road Classification

Road Type	Average Speed km/hr
Ring Road	39.44
Highways	40.33
PAS 1	45
PAS 2	22.24
PAS 3	21.39
PAS 4	25.17
SAS 1	18.66
SAS 2	16.89
Others	17.1
Average Speed in the City	27.36

Source: Consultant's Primary Survey 2017

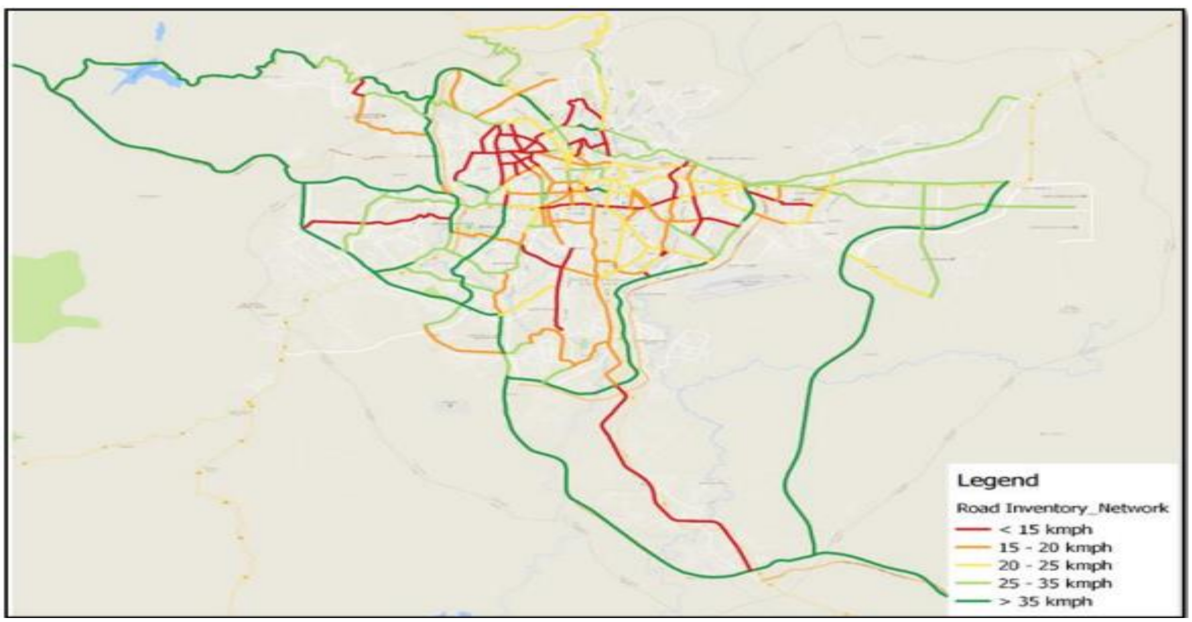

Figure 3- 9: Thematic Map of Journey Speeds
(Source: Addis Ababa City Atlas)

3.5.5 Vehicle Classification

The vehicle attributes and category is prepared according to Ethiopian Road Authority and Highway development and management manual with minor modification. The vehicle category with description of each vehicle group is illustrated below in table 3-11.

Table 3- 11: Vehicle classification

Vehicle Category		Description
Passenger Vehicles	Motor cycle	2-Wheeler
	Bajaj	Auto (3-Wheeler)
	Car	small automobiles
	Land rovers	4WD
	Mini bus	up to 16 passenger seats
	Small bus	up to 25 passenger seats
	Medium bus	up to 45 passenger seats
	Large bus	up to 60 passenger seats
	Articulated bus	over 60 passenger seats
Dual purpose vehicle	Pickup	utility vehicles
Freight vehicles	Light truck	capacity up to 3.5 tons load
	Medium truck	capacity up to 7.5 tons load
	Heavy truck	capacity up to 12 tons load
	Articulated truck	capacity over 12 tons load
Miscellaneous	Hand cart, Animal cart, etc.	

3.5.6 Passenger Car Units

Traffic is composed of various types of vehicles, the range and relative composition of which can vary from location to location. Capacity analysis of a road section represented by a link in traffic modeling software frequently uses a common unit, known as the Passenger Car Unit (PCU), to represent overall traffic. Passenger Car Unit (PCU) is a metric used in Transportation Engineering, to assess traffic flow rate on a highway. A Passenger Car Unit is a measure of the impact that a mode of transport has on traffic variables (such as Headway, Speed and Density) compared to a single standard passenger car. This is also known as Passenger Car Equivalent (PCE). Common Vehicle types are assigned a conversion factor so that an equivalent PCU value can be generated from classified vehicle data. Typical PCU or PCE values sourced from different traffic manuals in Ethiopia and internationally which are presented in the table below. For the data analysis purpose in this study, the PCU (PCE) factors from HDM 4 and ERA are adopted.

Table 3- 12: PCU (PCE) factors for different vehicles

Vehicle Group	Vehicle Category	PCU/PCE factors			
		Ethiopian Roads Authority (ERA)	Transport for London (TFL)	HDM-4	Adopted

Passenger Vehicles	2-Wheeler	0.25	0.4		0.25
	3-Wheeler	0.4	1		0.4
	Cars/Vans/Jeep	1	1		1
	Mini bus		1	1.3	1.3
	Medium bus		2	1.8	1.8
	Articulated bus		3.2	1.8	1.8
Dual purpose Vehicle	Pickup		1	1	1
Freight Vehicles	Isuzu (LCV)		1	1.3	1.3
	2-Axle		1.5	1.5	1.5
	3-Axle		2.3	1.8	1.8
	4-Axle		2.3	2.2	2.2
	5-Axle		2.3	2.2	2.2
	6-Axle		2.3	2.2	2.2
	7-Axle		2.3	2.2	2.2
slow Moving Vehicles	Hand Cart	0.7			0.7
	Animal Cart	2			2

3.5.7 Average Daily Traffic

The average daily traffic observed at the city level: Airport Road with an ADT of 74.708 vehicles has the highest ADT followed by Haile Gebreslasie Street & Cote D'lvoire street with an ADT of 64.057 & 49.616 vehicles respectively. Among the outer cordon locations, maximum traffic in a day was recorded on Sebeta Road with 24,992 vehicles or 26,401 PCUs. The lowest volume was encountered at Sululta Road with 11,018 vehicles or 12,674 PCUs. A total volume of 53,743 vehicles entering into Addis Ababa and 56,278 Vehicles leaving from Addis Ababa were encountered at the outer cordon locations in a day. Along inner cordon, maximum traffic volume was observed at Botswana Street which is 45,321 vehicles. Low traffic volume were recorded at Habte Gyorgis Street 21,420 vehicles. Along Central Cordon, maximum traffic was observed at Airport Road location which is 74,227 vehicles. Whereas, the low traffic volume were recorded at Aba Sebsbe Street location is 32,800 vehicles (Consultant's Primary Survey 2017). Detailed list of traffic count locations along with Average Daily Traffic is presented in the below table () by following ERA traffic surveying method for those randomly selected road networks.

Table 3- 13: Average Daily Traffic of all sample road networks

No.	Road Networks	Small Car	Medium Car	MINI BUS	Medium Bus	Heavy Bus	4WD	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	ADT_o
1	Johannes street	145	10198	8	118	10	937	43	35	20	1	11515
2	Josef Tito street	130	10216	7	108	9	941	45	37	15	1	11509
3	Cameroon street	409	14305	75	54	0	1925	268	10	25	5	17076
4	Roosevelt street	196	7030	68	186	0	1050	557	180	136	60	9463
5	Nigeria street	120	11796	49	50	0	1563	119	30	2	2	13731
6	Intoto Road	74	9297	107	192	0	1048	381	110	190	57	11456
7	Wendimeneh street	116	11776	58	42	0	1567	121	27	3	1	13711
8	Ring Road route 1 section (21)	417	16665	581	356	0	1347	1216	216	182	66	21046
9	Ring Road route 1 section (22)	423	16636	589	430	0	1287	1190	199	215	70	21039
10	Ring Road route 1 section (25)	210	8334	290	168	0	670	607	116	95	40	10530

Table 3- 14: Passenger Car Unit of vehicles on the sample road networks

No.	Road Networks	Small Car	Medium Car	Mini bus	Medium Bus	Heavy Bus	4 WD	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	Total PCU
1	Johannes street	36.25	10198	10.4	212.4	18	937	55.9	52.5	36	2.2	11559
2	Josef Tito street	32.5	10216	9.1	194.4	16.2	941	58.5	55.5	27	2.2	11552
3	Cameroon street	102.25	14305	97.5	97.2	0	1925	348.4	15	45	11	16946
4	Roosevelt street	49	7030	88.4	334.8	0	1050	724.1	270	244.8	132	9923
5	Nigeria street	30	11796	63.7	90	0	1563	154.7	45	3.6	4.4	13750
6	Intoto Road	18.5	9297	139.1	345.6	0	1048	495.3	165	342	125.4	11976
7	Wendimeneh street	29	11776	75.4	75.6	0	1567	157.3	40.5	5.4	2.2	13728
8	Ring Road route 1 sec 21	104.25	16665	755.3	640.8	0	1347	1580.8	324	327.6	145.2	21890
9	Ring Road route 1 sec 22	105.75	16636	765.7	774	0	1287	1547	298.5	387	154	21955
10	Ring Road route 1 sec 25	52.5	8334	377	302.4	0	670	789.1	174	171	88	10958

3.5.8 Traffic Composition

The Traffic Composition observed at the city level: Along the inner cordon, the share of passenger vehicles are found to be 85 percent, whereas the share of freight vehicles and pickups are 5 percent and 10 percent respectively. Among the freight vehicles, the share of LCV (ISUZU), 2 axle trucks, 3 axle trucks and 4&above axle trucks are observed to be 71 percent, 15 percent, 10 percent and 4 percent respectively. Along the Central Cordon the share of passenger vehicles, freight vehicles and pickups was observed to be 84 percent, 5 percent and 11 percent respectively. And with respect to freight vehicles LCV (ISUZU), 2 axle trucks, 3 axle trucks and HGV have a share of 61 percent, 19 percent, 14 percent and 6 percent respectively. Along the Outer Cordon, the composition of passenger vehicles are the highest of the other vehicles which is 65 percent. Whereas, the goods' and pickup vehicles comprises 24 percent and 11 percent respectively. Pickup vehicles are identified separately as they are dual purpose vehicles, behave as both passenger and freight vehicles. And with respect to freight vehicles composition, LCV (ISUZU) occupy the majority share at 46 percent followed by 3 – axle trucks with share of 28 percent and the 4 & above axle trucks share 15 percent and, 2 axle trucks share 11 percent (Consultant's Primary Survey 2017). Particularly, in those randomly selected road networks the traffic compositions are listed in the table below.

Table 3- 15: Traffic Composition (%)

No	Road Networks	Small Car	Medium Car	MINI BUS	Medium Bus	Heavy Bus	4 WD	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	Total %
1	Johannes street	1.25	88.461	0.08	1.023	0.094	8.18	0.4	0.325	0.186	0.009	100
2	Josef Tito street	1.21	88.583	0.06	1.004	0.085	8.14	0.418	0.344	0.139	0.009	100
3	Cameroon street	2.46	83.602	0.47	0.338	0	11.25	1.629	0.063	0.157	0.03	100
4	Roosevelt street	2.08	74.138	0.74	1.968	0	11.06	6.016	1.922	1.425	0.656	100
5	Nigeria street	0.94	85.739	0.38	0.389	0	11.36	0.927	0.234	0.016	0.016	100
6	Intoto Road	0.69	80.992	0.93	1.793	0	9.14	3.325	0.962	1.664	0.504	100
7	Wendimeneh street	0.91	85.719	0.45	0.328	0	11.41	0.944	0.211	0.023	0.008	100
8	Ring Road route 1 section 21	1.98	79.027	2.76	1.718	0	6.39	5.771	1.098	0.925	0.336	100
9	Ring Road route 1 section 22	2.01	78.93	2.8	2.039	0	6.11	5.655	1.013	1.093	0.356	100
10	Ring Road route 1 section 25	1.99	78.994	2.75	1.707	0	6.35	5.762	1.108	0.925	0.406	100

3.5.9 Seasonal Correction Factor Analysis

To arrive at Seasonal Correction Factor (SCF), consultant used the secondary data collected from various sources like Ethiopian Roads Authority (ERA), Ethiopian Fuel Trade Enterprise (EFTE) and fuel companies like NOC & OiLibya. Monthly data is collected from the sources which is mentioned in table (3.16) below.

Table 3- 16: Monthly Seasonal Correction Factors from different sources

Month	EFTE	NOC + OiLibya	ERA	Recommended (Average)
January	0.96	1.07	1.01	1.01
February	0.97	1.06	0.99	1.01
March	0.88	0.95	0.89	0.91
April	0.93	1.03	1.04	1
May	0.94	1	0.95	0.97
June	0.91	1	0.93	0.95
July	1.11	0.98	1.11	1.07
August	1.17	1.02	1.05	1.08
September	1.25	1.04	1.22	1.17
October	1.08	1.03	1.15	1.09
November	1.05	0.95	0.94	0.98
December	0.9	0.91	0.9	0.9
Avg. of Oct. & Nov.	**1.07**	**0.99**	**1.04**	**1.03**

3.5.10 Annual Average Daily Traffic (AADT)

The Annual Average Daily Traffic (AADT) on any road generally varies over different periods of the year depending the cycle of different Socio- Economic activities in the regions through which it passes. Generally during rainy season, vehicles like trucks are lower than other vehicles due to reduction in mining and construction activities. Similarly, traffic varies with respect to different seasons and months. Therefore, in order to have more realistic picture of the traffic on the project road which represents Annual Average Daily Traffic (AADT), it is required to assess seasonal variation in traffic. So that, the Average Daily Traffic (ADT) observed during the survey duration is multiplied by a Seasonal Correction Factor (SCF) to originate at AADT. The Annual Average Daily Traffic (AADT) which is estimated, summarized in the table below.

Table 3- 17: Average Annual Daily Traffic (AADTo)

No	Road Networks	Small Car	Medium Car	Mini bus	Medium Bus	Heavy Bus	4WD	Light Truck	Medium Truck	Heavy Truck	Articu lated Truck	$AADT_o$
1	Johannes street	150	10504	8	122	10	965	44	36	21	1	11861
2	Josef Tito street	134	10523	7	111	9	969	47	38	16	1	11855
3	Cameroon street	422	14734	77	56	0	1983	276	10	26	5	17589
4	Roosevelt street	202	7241	70	192	0	1081	574	185	140	62	9747
5	Nigeria street	124	12150	50	51	0	1610	123	31	2	2	14143
6	Intoto Road	76	9576	110	198	0	1080	393	113	196	58	11800
7	Wendimeneh street	120	12129	60	43	0	1614	125	28	3	1	14123
8	Ring Road route 01 section (21)	430	17165	598	367	0	1387	1253	223	187	68	21678
9	Ring Road route 01 section (22)	436	17135	607	443	0	1326	1226	205	221	72	21671
10	Ring Road route 01 section (25)	216	8584	299	173	0	690	625	120	98	41	10846

The traffic surveys were carried out in the months of October and November, hence the average of these two months are taken as recommended Seasonal Correction Factor to arrive at the AADT.

3.6 Road Condition Survey

Road roughness has been defined as the variation in surface elevation that induces vibration in moving vehicles. In particular, the International Roughness Index (IRI) is a scale for roughness based on the response of a standardized motor vehicle to the road surface. The IRI simulates response to the surface profile, and also considers the effect of vehicle suspension. There are a number of different ways to measure ride quality, but the IRI has become the standard international scale. The IRI was developed in the late 1970's and early 1980's based on initial research in the United States and subsequent research sponsored by the World Bank. It is expressed in units of millimeters per meter or meters per kilometer, with low values indicating smooth roads, and high values indicating rough roads with poor ride quality (Pavement Condition Study Report, pdf.). The Table 3-19 below shows the ranges of IRI and the assumed threshold for pavement surface rating:

Table 3- 18: Road Roughness Condition

Ranges of IRI (mm/m)	Assumed Threshold for Pavement Surface Rating
0 – 2.5	Very Good
2.2 – 5	Good
5 – 8	Fair
8 - 10	Poor
>> 10	Very Poor

Source: AACRA

The IRI measurements were carried out on the sample road networks by using the standardized motor vehicle through the Addis Ababa City Road Authority's Road Asset Management Directorete Staff members. The collected IRI data's are organized and summarized in tables for indicating the roughness conditions of those roads under study. The following tables display the International Roughness Index of the sample road sections from longitudinal profile measurements.

Table 3- 19: Riding Quality of Roosevelt Street

Road Class	*Route*	*Way*	*Section*	*Length (m)*	*Strategic Road*	*Street Name*	*Pavement Type*	*No. Of Lane*	*Carriage way Width(m)*	*Altitude (m)*	*IRI (mm/m)*
P	310	UW	1	65	1	Roosevelt St.	AS	6	11	2301.8	7.71
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2308.1	8.87
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2314.2	6.10
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2324.1	7.78
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2327.7	5.63
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2329.1	7.64
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2333.7	7.42
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2334.3	3.85
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2336.8	4.84
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2338.7	8.09
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2345.3	13.02
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2348	16.03
P	310	UW	1	100	1	Roosevelt St.	AS	6	11	2353.5	14.14

Source: AACRA

Table 3- 20: Riding Quality of Ring Road (section 21)

Road Class	*Route*	*Way*	*Section*	*Length (m)*	*Strategic Road*	*Road/Street Name*	*Pavement Type*	*No. Of Lane*	*Carriage -way Width(m)*	*Altitude (m)*	*IRI (mm/m)*
RS	1	UW	21	100	0	Ring Road	AS	2	8.5	2344.9	11.61
RS	1	UW	21	100	0	Ring Road	AS	2	8.5	2343.3	5.70
RS	1	DW	21	100	0	Ring Road	AS	2	8.5	2355.8	19.19
RS	1	DW	21	100	0	Ring Road	AS	2	8.5	2361.6	36.84

Source: AACRA

Table 3- 21: Riding Quality of Yohanis Street

Road Class	Route	Way	Section	Length (m)	Strategic Road	Road/Street Name	Pavement Type	No. Of Lane	Carriage -way Width(m)	Altitude (m)	IRI (mm/m)
P	304	DW	1	100	1	Yohanis St.	AS	3	8.8	2349.5	17.76
P	304	DW	1	100	1	Yohanis St.	AS	3	8.8	2352	12.53
P	304	DW	2	100	1	Yohanis St.	AS	3	8.8	2351.5	8.70
P	304	DW	2	100	1	Yohanis St.	AS	3	8.8	2350.6	6.59
P	304	DW	2	100	1	Yohanis St.	AS	3	8.8	2350.4	8.39
P	304	DW	2	45	1	Yohanis St.	AS	3	8.8	2348.7	7.29
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2348.6	7.83
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2351.8	6.68
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2356.7	4.38
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2364.8	8.49
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2368.3	8.22
P	304	DW	3	100	1	Yohanis St.	AS	3	8.8	2368.6	5.26
P	304	DW	3	60	1	Yohanis St.	AS	3	8.8	2368.5	10.62
P	304	DW	4	95	1	Yohanis St.	AS	6	9	2366.2	6.34

Source: AACRA

Table 3- 22: Riding Quality of Josef Tito Street

Road Class	Route	Way	Section	Length (m)	Strategic Road	Road/Street Name	Pavement Type	No. Of Lane	Carriage way Width(m)	Altitude (m)	IRI (mm/m)
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2370.3	6.02
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2370.5	15.98
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2371.4	6.44
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2370.1	6.45
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2369.4	4.01
P	304	DW	5	100	1	Josef Tito St.	AS	6	8	2365.7	7.88
P	304	DW	5	110	1	Josef Tito St.	AS	6	8	2362	8.95
P	304	DW	6	100	1	Josef Tito St.	AS	6	12	2363.3	10.96
P	304	DW	6	35	1	Josef Tito St.	AS	6	12	2363	23.08
P	304	DW	7	100	0	Josef Tito St.	AS	6	12	2364.5	9.06
P	304	DW	7	25	0	Josef Tito St.	AS	6	12	2365	26.99

Source: AACRA

Table 3- 23: Riding Quality of Cameroon Street (Upward Direction)

Road Class	*Route*	*Way*	*Section*	*Length (m)*	*Strategic Road*	*Road/Street Name*	*Pavement Type*	*No. Of Lane*	*Carriage-way Width(m)*	*Altitude (m)*	*IRI (mm/m)*
P	303	UW	3	75	1	Cameroon St.	AS	6	12	2333.5	14.78
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2334.5	6.36
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2337.1	5.32
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2338.2	6.36
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2341.3	8.48
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2344.1	4.72
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2343.5	13.03
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2343.3	7.90
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2343.2	12.84
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2342.8	7.26
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2342.3	9.42
P	303	UW	3	100	1	Cameroon St.	AS	6	12	2343.5	14.87
P	303	UW	2	85	1	Cameroon St.	AS	6	12	2345.8	6.54
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2345.8	5.93
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2345.7	5.65
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2344.1	4.17
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2341.9	3.84
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2338.7	3.53
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2336	4.63

P	303	UW	2	100	1	Cameroon St.	AS	6	12	2335.9	3.15
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2335.1	17.34
P	303	UW	2	100	1	Cameroon St.	AS	6	12	2335.7	15.26

Source: AACRA

Table 3- 24: Riding Quality of Cameroon Street (Downward Direction)

Road Class	*Route*	*Way*	*Section*	*Length (m)*	*Strategic Road*	*Road/Street Name*	*Pavement Type*	*No. Of Lane*	*Carriage way Width*	*Altitude (m)*	*IRI (mm/m)*
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2332.4	7.17
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2333.3	6.81
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2331.7	3.17
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2332	3.84
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2334.9	4.27
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2339.1	4.53
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2342.3	4.53
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2344.7	12.18
P	303	DW	2	100	1	Cameroon St.	AS	6	12	2344.3	16.41
P	303	DW	2	85	1	Cameroon St.	AS	6	12	2343	15.23
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2337.8	16.03
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2340.2	9.19
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2339.3	19.53
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2341	10.35
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2341.5	10.16
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2340.2	21.97
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2340.3	9.24

P	303	DW	3	100	1	Cameroon St.	AS	6	12	2337.4	6.70
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2334.2	13.59
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2331.5	8.69
P	303	DW	3	100	1	Cameroon St.	AS	6	12	2328.4	15.19
P	303	DW	3	75	1	Cameroon St.	AS	6	12	2328.3	12.39

Source: AACRA

Table 3- 25: Riding Quality of Wendimeneh Street

Road Class	***Route***	***Way***	***Section***	***Length (m)***	***Strategic Road***	***Road/Street Name***	***Pavement Type***	***No. Of Lane***	***Carriage way Width(m)***	***Altitude (m)***	***IRI (mm/m)***
P	306	UW	3	65	1	Wendimeneh St.	AS	2	4.5	2355	7.00
P	306	UW	3	100	1	Wendimeneh St.	AS	2	4.5	2358.3	4.10
P	306	UW	3	100	1	Wendimeneh St.	AS	2	5.5	2357.4	8.10
P	306	UW	2	35	1	Wendimeneh St.	AS	2	5.5	2358.7	14.10
P	306	UW	2	100	1	Wendimeneh St.	AS	2	5.5	2361	16.30
P	306	UW	2	100	1	Wendimeneh St.	AS	2	5.5	2363.6	7.60
P	306	DW	2	100	1	Wendimeneh St.	AS	2	5.5	2361	6.78
P	306	DW	2	100	1	Wendimeneh St.	AS	2	5.5	2353.3	6.45
P	306	DW	2	35	1	Wendimeneh St.	AS	2	5.5	2354	56.34
P	306	DW	3	100	1	Wendimeneh St.	AS	2	5.5	2353.7	30.23
P	306	DW	3	100	1	Wendimeneh St.	AS	2	4.5	2348.4	4.38
P	306	DW	3	65	1	Wendimeneh St.	AS	2	4.5	2346.6	7.61

Source: AACRA

Table 3- 26: Riding Quality of Nigeria street

Road Class	Route	Direction	Section	Length (m)	Strategic Road	Road/Street Name	Pavement Type	No. Of Lane	Carriage way Width (m)	Altitude (m)	IRI (mm/m)
P	306	UW	1	80	1	Nigeria St.	AS	2	5.5	2363.8	5.80
P	306	UW	1	100	1	Nigeria St.	AS	2	5.5	2365.7	16.80
P	306	UW	1	100	1	Nigeria St.	AS	2	5.5	2366.2	4.60
P	306	UW	1	100	1	Nigeria St.	AS	2	5.5	2366.5	9.20
P	306	DW	1	100	1	Nigeria St.	AS	2	5.5	2364	15.87
P	306	DW	1	100	1	Nigeria St.	AS	2	5.5	2362.8	5.55
P	306	DW	1	100	1	Nigeria St.	AS	2	5.5	2363.5	6.42
P	306	DW	1	80	1	Nigeria St.	AS	2	5.5	2362.1	15.02

Source: AACRA

Table 3- 27: Riding Quality of Ring Road (section 22)

Road Class	Route	Way	Section	Length	Strategic Road	Road/Street Name	Pavement Type	No. Of Lane	Carriage way Width(m)	Altitude (m)	IRI (mm/m)

RS	1	DW	22	100	0	Ring Road	AS	2	8	2363	17.67
RS	1	DW	22	100	0	Ring Road	AS	2	8	2365	15.08
RS	1	DW	22	30	0	Ring Road	AS	2	8	2363.7	5.70
RS	1	UW	22	30	0	Ring Road	AS	2	8	2361.2	17.36
RS	1	UW	22	100	0	Ring Road	AS	2	8	2354.5	21.50
RS	1	UW	22	100	0	Ring Road	AS	2	8	2346.3	14.48

Source: AACRA

Table 3- 28: Riding Quality of Intoto Road (Upward Direction)

Road Class	*Route*	*Way*	*Section*	*Length (m)*	*Strategic Road*	*Road/Street Name*	*Pavement Type*	*No. Of Lane*	*Carriage way Width(m)*	*Altitude (m)*	*IRI (mm/m)*
P	1	UW	14	100	0	Intoto Road	AS	2	4	2717.7	9.60
P	1	UW	14	100	0	Intoto Road	AS	2	4	2711.3	35.03
P	1	UW	14	100	0	Intoto Road	AS	2	4	2698.9	6.78
P	1	UW	14	100	0	Intoto Road	AS	2	4	2686.5	8.66
P	1	UW	14	100	0	Intoto Road	AS	2	4	2676.4	12.21
P	1	UW	14	100	0	Intoto Road	AS	2	4	2664.9	6.53
P	1	UW	14	100	0	Intoto Road	AS	2	4	2655.8	6.86
P	1	UW	14	100	0	Intoto Road	AS	2	4	2650	17.75
P	1	UW	14	100	0	Intoto Road	AS	2	4	2645.5	41.10
P	1	UW	14	100	0	Intoto Road	AS	2	4	2639.7	9.54
P	1	UW	14	100	0	Intoto Road	AS	2	4	2638.4	6.80
P	1	UW	14	100	0	Intoto Road	AS	2	4	2629.5	19.35
P	1	UW	14	100	0	Intoto Road	AS	2	4	2620	11.96

P	1	UW	14	100	0	Intoto Road	AS	2	4	2614.2	16.80
P	1	UW	14	100	0	Intoto Road	AS	2	4	2607.8	3.93
P	1	UW	14	100	0	Intoto Road	AS	2	4	2603.4	3.76
P	1	UW	14	100	0	Intoto Road	AS	2	4	2598.8	7.86
P	1	UW	14	100	0	Intoto Road	AS	2	4	2590.7	5.87
P	1	UW	14	100	0	Intoto Road	AS	2	4	2580.5	5.20
P	1	UW	14	100	0	Intoto Road	AS	2	4	2571.3	8.54

Source: AACRA

Table 3- 29: Riding Quality of Intoto Road (Downward Direction)

Road Class	***Route***	***Way***	***Section***	***Length (m)***	***Strategic Road***	***Road/Street Name***	***Pavement Type***	***No. Of Lane***	***Carriage way Width (m)***	***Altitude (m)***	***IRI (mm/m)***
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2450.4	7.57
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2454	7.83
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2458.3	7.57
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2462	13.58
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2464	7.21
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2466.5	4.39
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2471.8	5.73
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2474.9	9.78
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2483.7	5.20
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2488	6.37
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2489.3	3.79
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2490.3	2.77

RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2496	2.61
RS	1	DW	25	100	0	Ring Road	AS	2	8.5	2505.1	44.21
RS	1	DW	25	60	0	Ring Road	AS	2	8.5	2511.3	3.97

Source: AACRA

3.7 Maintenance Expenditure

The availability of construction materials will often influence the choice between the alternative pavement structures. The prevailing unit cost of the material should be compiled, based either on recent works of similar time and magnitude in the vicinity of the proposed project, or by an analysis of the mobilization, production and haulage costs.

A different pavement structure deteriorates in different ways and requires different levels of maintenance. Therefore good practice to carry out a life cycle cost analysis, anticipating maintenance needs and risk factors and including them in the analysis. In Ethiopia at the present there is insufficient experience of many of the possible structures and their likely maintenance requirements for this to be done with much accuracy. Nevertheless data is being accumulated to assist with this in future and more roads need to be built using alternative pavement structures.

The road user costs or vehicle operating costs are included in the life cycle cost analysis. This is because vehicle operating costs are the highest cost in a transport system and depends on the surface condition or roughness of the road. The roads with smooth surface condition will save vehicle operating costs, which include fuel costs and other costs that affect the national economy.

Addis Ababa City Road Authority's (AACRA) budget for fiscal year 1996/2009 is presented below by using tables and charts :-

Table 3- 30: AACRA Regular budget from the Treasury Department

Year	Adjusted Budget	Actual Expenditure	Over /Under
1996	19,595,135	17,200,091	2,395,044
1997	21,207,181	18,042,738	3,164,443
1998	22,816,086	21,012,027	1,804,060
1999	24,651,822	23,619,936	1,031,886
2000	38,316,045	34,627,527	3,688,518
2001	44,328,877	36,464,272	7,864,605
2002	40,187,310	35,113,607	5,073,703
2003	42,488,214	40,863,544	1,624,670
2004	48,564,890	45,876,755	2,688,135
2005	70,630,335	67,873,390	2,756,945
2006	99,221,850	98,357,403	864,447
2007	142,058,993	133,008,880	9,050,113
2008	170,710,526	155,215,285	15,495,241

2009	191,220,115	127,348,353	63,871,762

Source: AACRA

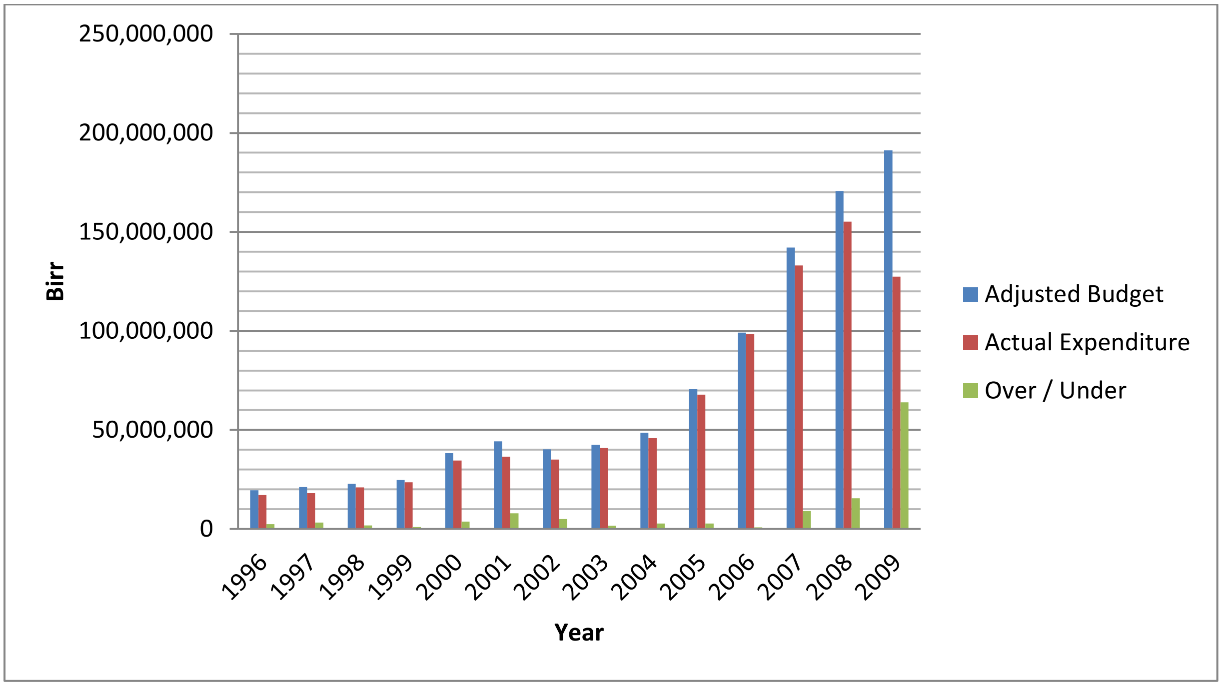

Figure 3- 10: AACRA Regular budget for fiscal year 1996/2009

Table 3- 31: AACRA Capital budget from the Treasury Department

Year	Adjusted Budget	Actual Expenditure	Over / Under
1996	453,543,757	274,954,980	178,588,777
1997	301,343,644	177,714,320	123,629,324
1998	747,622,352	212,484,808	535,137,544
1999	1,068,878,591	634,839,356	434,039,235
2000	1,509,360,181	801,454,909	707,905,272
2001	1,515,267,821	1,307,415,785	207,852,036
2002	1,127,414,794	1,117,319,523	10,095,271
2003	1,190,617,688	1,296,691,238	-106,073,550
2004	1,637,584,929	1,381,041,138	256,543,791
2005	4,409,456,173	3,767,536,070	641,920,104
2006	5,696,691,776	5,418,909,836	277,781,940
2007	6,098,220,000	5,557,167,315	541,052,685
2008	5,469,574,000	4,548,888,406	920,685,594
2009	4,749,241,141	2,694,281,047	2,054,960,094

2010	6,015,585,702	4,073,433,331	1,942,152,372

Source: AACRA

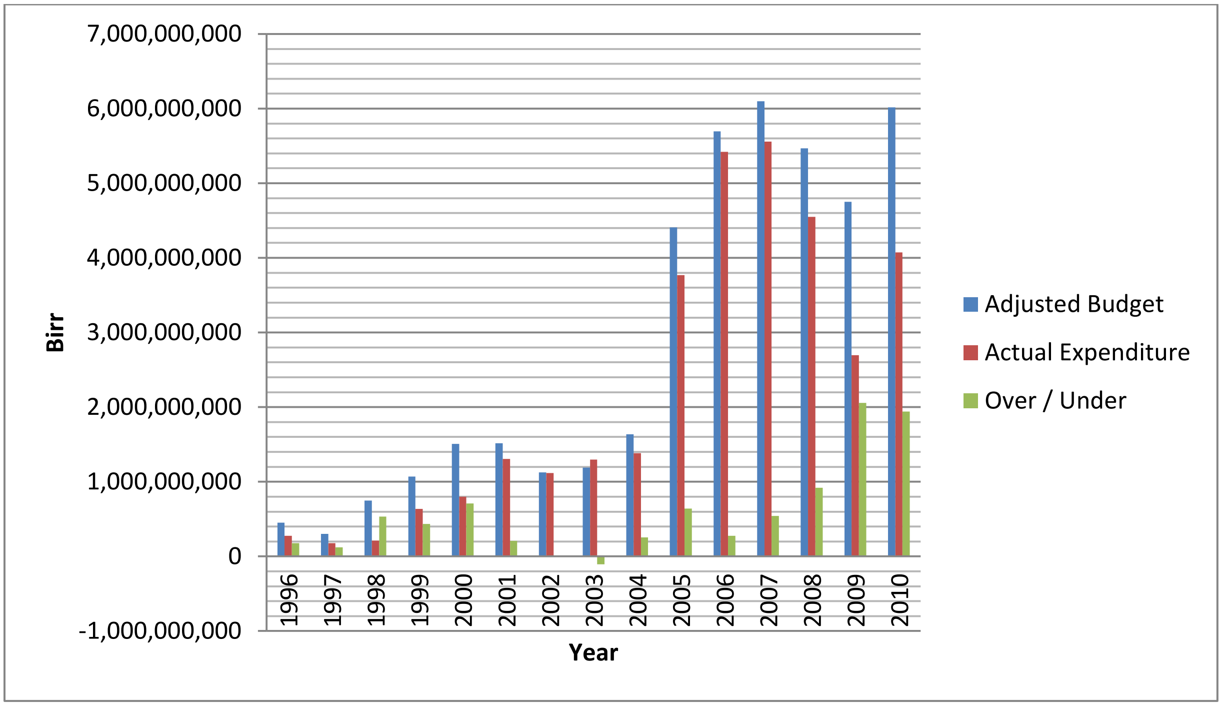

Figure 3- 11: AACRA Capital budget for fiscal year 1996/2009

Table 3- 32: AACRA Budget from Grants Aid

Year	Adjusted Budget	Actual Expenditure	Over / Under
1996	0	26,973,998	-26,973,998
1997	52,497,874	5,100,000	47,397,874
1998	68,616,000	0	68,616,000
1999	67,030,000	7,250,542	59,779,458
2000	65,000,000	17,316,919	47,683,081
2001	0	20,974,002	-20,974,002
2002	0	0	0
2003	0	0	0
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	178,200,378	0	178,200,378
2008	178,200,000	0	178,200,000

2009	5,000,000	0	5,000,000

Source: AACRA

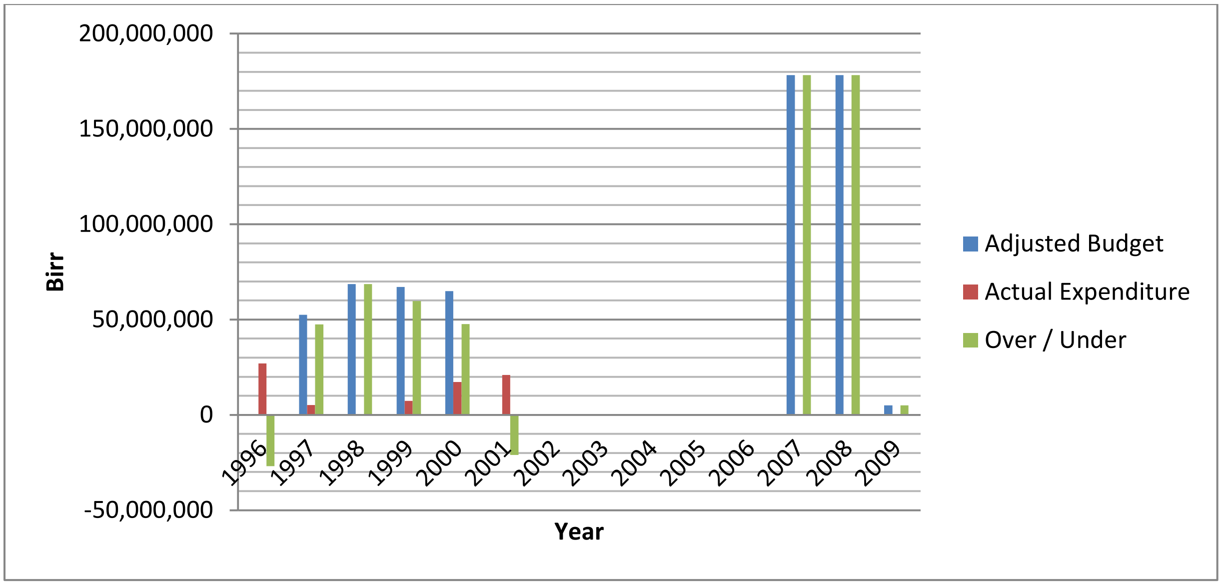

Figure 3- 12: AACRA Grants Aid budget for fiscal year 1996/2009

Table 3- 33: AACRA Capital Budget from Credit

Year	Adjusted Budget	Actual Expenditure	Over / Under
1996	0	0	0
1997	0	0	0
1998	0	0	0
1999	0	0	0
2000	0	0	0
2001	0	0	0
2002	73,050,000	4,559,246	68,490,754
2003	0	0	0
2004	0	0	0
2005	0	0	0
2006	368,119,851	149,964,918	218,154,932
2007	204,200,103	88,604,705	115,595,398
2008	254,200,000	81,179,282	173,020,718
2009	670,000,000	0	670,000,000

Source: AACRA

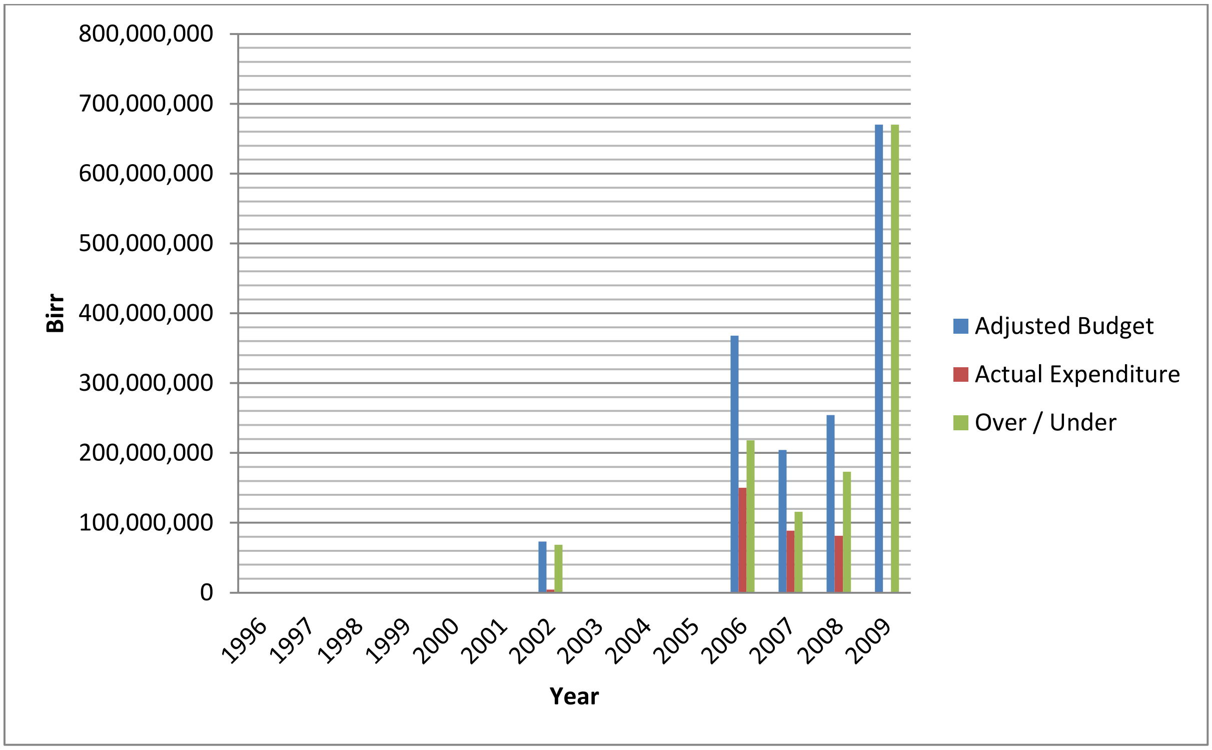

Figure 3- 13: AACRA Capital Budget from Credit for fiscal year 1996/2009

Table 3- 34: AACRA Budget from Road Fund

Year	Adjusted Budget	Actual Expenditure	Over / Under
1996	0	18,850,445	-18,850,445
1997	20,688,000	5,100,000	15,588,000
1998	24,850,737	22,227,729	2,623,008
1999	42,763,256	26,788,260	15,974,996
2000	57,957,886	39,348,650	18,609,236
2001	63,486,000	0	63,486,000
2002	130,504,447	0	130,504,447
2003	45,000,000	44,362,417	637,583
2004	62,601,600	47,030,485	15,571,115
2005	50,370,000	41,602,808	8,767,192
2006	189,207,902	49,771,662	139,436,240
2007	50,400,000	42,004,259	8,395,741
2008	50,400,000	48,440,719	1,959,281
2009	50,400,000	33,282,406	17,117,594

Source: AACRA

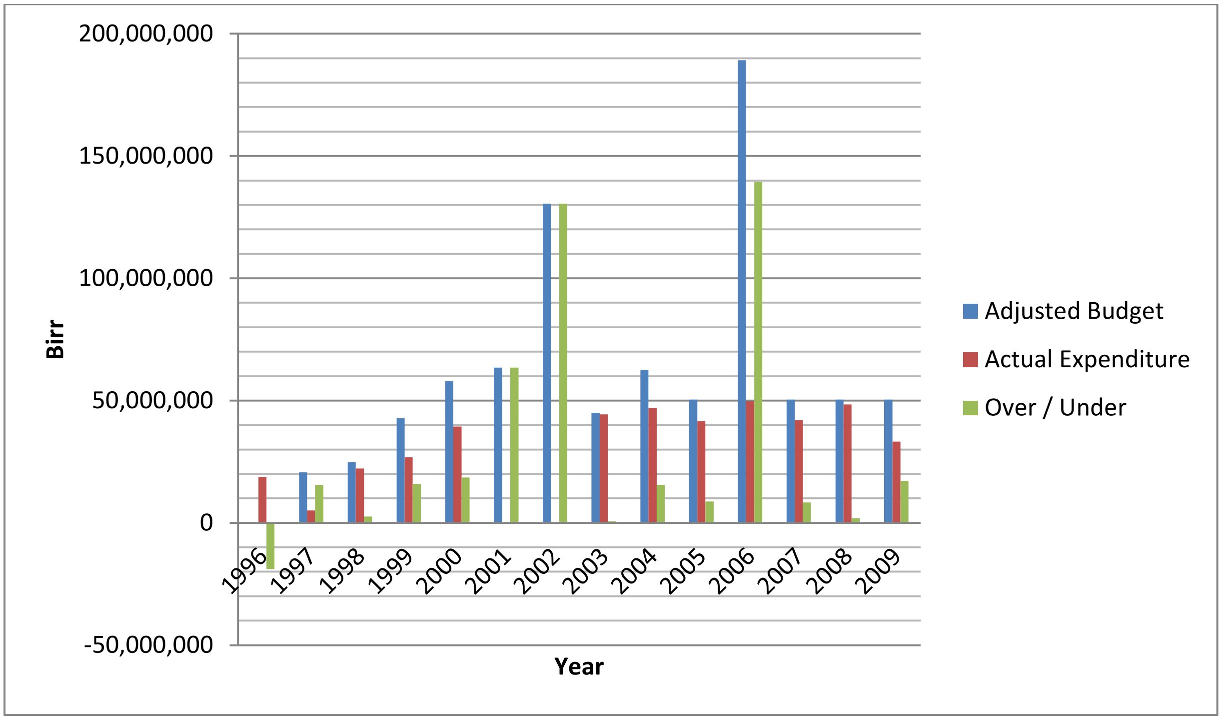

Figure 3- 14: AACRA Budget from Road Fund for fiscal year 1996/2009

3.8 Traffic Analysis

Traffic is the most important factor in pavement design and stress analysis, and constitutes the load imparted on the pavement causing the stresses, strains and deflections in the pavement layers and the subgrade. It is necessary to consider the total number of vehicles that will use the road with the axle loads of these vehicles. And also equivalency factors are used to convert traffic volumes into cumulative standard axle loads. For flexible pavements, traffic classes are defined by ranges of cumulative number of equivalent standard axles.

On the other hand, the mechanism of deterioration of gravel roads differs from that of paved roads. Design of thickness of gravel roads is directly related to the number of vehicles using the road rather than the number of equivalent standard axles as that for paved roads. The traffic volume is therefore used in the design of unpaved roads (gravel roads), as opposed to the paved roads which require the conversion of traffic volumes into the appropriate cumulative number of equivalent standard axles.

Hence the pavement designer must account the amount of traffic load expected over its design life. The traffic loads on pavement can be characterized by:

- Magnitude of wheel load or axle load;
- Axle and wheel configuration (single/dual wheel, single/tandem/tridem axle and spacing with in wheels and axles): as spacing between wheels getting smaller, then their influence areas will overlap and one has to consider the combined effect of all interacting wheel loads instead of dealing with a single wheel load.
- Load repetitions along with the environment, damage pavement overtime. Each individual load from commercial vehicles inflicts a certain amount of unrecoverable damage. This damage is cumulative over the life of the pavement and when it reaches some maximum value the pavement is considered to have reached the end of its useful service life.
- Other considerations include contact pressure, tire pressure, vehicle speed and traffic consideration across the pavement, etc.

3.8.1 Traffic Forecast

Determining traffic growth rate over the design period which is very uncertain process and requires making analysis and forecast of past and future traffic growth, social and economic development trends, etc. In forecasting process, traffic categorized into the following:-

A) Normal Traffic: Traffic that would pass along the existing road or track even if no new or improved pavement were provided. Forecasted by extrapolating data on traffic levels and assume that growth will remain either constant in absolute terms i.e. a fixed number of vehicles per year, or constant in relative terms i.e. a fixed percentage increase. Growth rate can also be related linearly to anticipate Gross Domestic Product (GDP).

B) Diverted Traffic: Traffic that changes from another route (or mode of transport) to the project road because of the improved pavement, but still travels between the same origin and destination.

Origin and destination surveys (O/D survey) should preferably be carried out to provide data on the traffic diversions likely to arise.

C) Generated Traffic: Additional traffic which occurs in response to the provision or improvement of the road. It may arise either because a journey becomes more attractive by virtue of a cost or time reduction or because of the increased development that is brought about by the road investment. Generated traffic is also difficult to forecast accurately and can be easily overestimated. From thorough analysis of economic, social and development trends, determine overall *growth rate* ***r*** for all vehicle categories or separate growth rate r_i for each vehicle category.

Table 3- 35: Traffic Growth Rate (%)

Variables	*Demand Elasticity (e)*		*Growth Rates (%)*		
Years in E.C.	2003-2015	2016-2038	2003-2010	2011-2015	2016-2038
GDP Growth Rate (%)			9.2	9.8	9.5
Private Vehicles:					
Cars	1.2	1.2	11.04	11.76	11.4
4-WD	1.2	1.2	11.04	11.76	11.4
2-wheeler	1.1	1.1	10.12	10.78	10.45
Public Vehicles:					
Mini Bus	1.1	1.1	10.12	10.78	10.45
Medium Bus	1.0	1.0	9.2	9.8	9.5
Heavy Bus	1.0	1.0	9.8	9.8	9.5
Cargo Vehicles:					
Pickup/light truck	1.1	1.0	10.12	10.78	9.5
LCV/ISUZU	1.2	1.1	11.04	11.76	10.45
Medium truck	1.2	1.1	11.04	11.76	10.45
Heavy truck	1.2	1.1	11.04	11.76	10.45
Articulated Truck	1.4	1.3	12.88	13.72	12.35

3.8.2 Axle Load Survey

Axle load survey is carried out together with the traffic count by using portable vehicle weighing devices or weigh in motion (WIM) devices and, each axle of the vehicle weighed and Equivalent Axle Load Factor (EALF) is computed. Each axle of a tandem axle or tridem axle assembly is considered as one repetition and EALF calculated for each axle (ERA Pavement design manual).

Table 3- 36: Average Equivalent Factors for different vehicle types

Class	Type	No. of Axles	Average ESA per vehicle- all loaded	Average ESA per vehicle- half loaded
1	Car	2	-	-
2	Four Wheel Drive	2	-	-
3	Mini-bus	2	0.3	0.15
4	Bus/coach	2	2.0	1.0
5	Small truck/Pickup	2	1.5	0.75
6	Medium truck	2	5	2.5

7	Large 2-axled truck	2	10	5
8	3-axled truck	3	12	6
9	4-axled truck	4	15	7.5
10	5-axled truck	5	17	8.5
11	6-axled truck	6	17	8.5
12	2-axled trailer	2	10	5
13	3 or 4-axled trailer	3 or 4	12	6

Source: ERA Manual

3.8.3 Design Traffic Loading

The data and parameters obtained from the studies discussed in the preceding sections can now be used to estimate the cumulative design traffic volume and loading by using the following steps:-

1**. Adjustment for Lane and Directional Distribution of Traffic:**

Lane Distribution Factor (L)*:* accounts for the proportion of commercial vehicles in the design lane. For two lane highways, the lane in each direction is the design lane, so the lane distribution factor is 100%. For multilane highways, the design lane is the heavily loaded lane (outside lane).

Table 3- 37: Lane Distribution Factors (ERA/AASHTO)

Number of Lanes in each direction	Percent Traffic (ESAL) in design Lane
1	100
2	80 – 100
3	60 – 80
4	50 – 75

Source: ERA Manual

Directional Distribution Factor (D)*:* factor that accounts for any directional variation in total traffic volume or loading pattern. It is usually 0.5 (50%). However, could be adjusted based on actual condition (if there is directional tendency to commercial vehicle distribution (volume or loading); for example if the heavy vehicles in one direction are loaded and come back empty in the other direction).

2. Calculating ($AADT_1$):-

$$AADT_1 = AADT_0\ (1+r)^x$$

$AADT_1$ = Annual Average Daily Traffic (both directions) at year of Road Opening

$AADT_0$ = Initial traffic volume (AADT at the time of traffic count on 2017)

r = Growth Rate (%)

x = time period between the traffic count (2017) and opening year (2021)

AADT1 is used as the Design Traffic Parameter for Gravel Roads (ERA Pavement Design Manual). The projected AADTs in three years calculated and the corresponding two directional volume for each classes of vehicles on each sample road networks illustrated in the table 3-39 below.

3. Cumulative Traffic Volume (T):–

$$T_i = 365\ (L)\ (D)\ AADT_{1i}\ [(1+r_i)^N - 1] / (r_i)$$

Ti = cumulative volume of traffic for the i^{th} commercial vehicle class in the design lane over the design period (adjusted for lane distribution and direction).

r_i = annual growth rate for the i^{th} commercial vehicle class

L = Lane distribution factor;

D = Directional distribution factor (50%)

N = Design Period in years

Selecting a design period of 20 years, the cumulative number of vehicles in each samples of road networks over the designed period is calculated as follows in the table 3-40 below.

4. Design Traffic or Cumulative Equivalent Standard Axle Load (CESAL):– is used to determine the traffic class to be employed for pavement design and it is computed by multiplying the total traffic volume for each vehicle category (T_i) by its corresponding truck factor /Average Equivalent Factors for different vehicle types (TF_i) is calculated as follows in the table 3-41 below.

Design Traffic Load = CESAL=$\sum (T_i \times TF_i)$

Table 3- 38: The Projected AADT (AADT1)

Road Networks	***Small car***	***Medium Car***	***Mini bus***	***Medium Bus***	***Heavy Bus***	***4 WD***	***Light Truck***	***Medium Truck***	***Heavy Truck***	***Articulated Truck***	***$AADT_1$***
Johannes street	202	14521	11	160	13	1334	59	49	28	1	16379
Josef Tito street	181	14548	9	146	12	1340	63	51	22	1	16372
Cameroon street	569	20369	104	74	0	2741	372	13	35	7	24284
Roosevelt street	272	10010	94	252	0	1494	773	249	189	88	13423
Nigeria street	167	16797	67	67	0	2226	166	42	3	3	19537
Intoto Road	102	13239	148	260	0	1493	530	152	264	82	16270
Wendimeneh street	162	16768	81	56	0	2231	168	38	4	1	19510
Ring Road route 01 section (21)	579	23730	806	482	0	1917	1688	300	252	96	29852
Ring Road route 01 section (22)	587	23689	818	582	0	1833	1652	276	298	102	29837
Ring Road route 01 section (25)	291	11867	403	227	0	954	842	162	132	58	14936

Table 3- 39: Cumulative Traffic Volume (Ti)

Road Networks	***Small Car***	***Medium Car***	***Mini-bus***	***Medium Bus***	***Heavy Bus***	***4WD***	***Light Truck***	***Medium Truck***	***Heavy Truck***	***Articu lated Truck***	***Ti (total)***
Johannes street	1556553	124711156	83016	1107487	90778	11457184	456589	373573	217917	13595	140067847
Josef Tito street	1390520	124936738	72639	1007632	81700	11504675	487720	394327	166032	13595	140055578
Cameroon street	4379101	174932803	799030	508355	0	23543624	2864057	103770	269802	67974	207468517
Roosevelt street	2096157	85970438	726391	1742931	0	12834421	5956408	1919748	1452782	842877	113542153
Nigeria street	1654393	185469003	667094	595242	0	24576551	1641051	413598	26684	34958	215078574
Intoto Road	1013983	146177051	1467607	2310940	0	16486134	5243358	1507632	2615008	1013782	177835496
Wendimeneh street	1601025	185148440	800513	501871	0	24637611	1667735	373573	40026	17479	214788271
Ring Road route 01 section (21)	5737008	262022670	7978444	4283409	0	21172470	16717374	2975239	2494931	1188572	324570117
Ring Road route 01 section (22)	5817059	261564722	8098521	5170436	0	20241309	16357144	2735085	2948555	1258488	324191319
Ring Road route 01 section (25)	2881846	131034232	3989222	2019154	0	10532808	8338674	1601025	1307504	716639	162421105

Table 3- 40: Cumulative Equivalent Standard Axle Load - CESAL

Road Networks	*Small Car*	*Medium Car*	*Mini-bus*	*Medium Bus*	*Heavy Bus*	*4WD*	*Light Truck*	*Medium Truck*	*Heavy Truck*	*Articulated Truck*	*CESAL*
Johannes street	-	-	24905	2214975	181555	17185777	684883	1867863	2615008	217517	24992483
Josef Tito street	-	-	21792	2015264	163400	17257013	731580	1971633	1992387	217517	24370585
Cameroon street	-	-	239709	1016710	0	35315435	4296085	518851	3237629	1087583	45712002
Roosevelt street	-	-	217917	3485862	0	19251632	8934612	9598741	17433389	13486024	72408176
Nigeria street	-	-	200128	1190484	0	36864827	2461577	2067991	320205	559328	43664540
Intoto Road	-	-	440282	4621880	0	24729200	7865038	7538162	31380100	16220517	92795178
Wendimeneh street	-	-	240154	1003742	0	36956416	2501602	1867863	480308	279664	43329749
Ring Road route 01 section (21)	-	-	2393533	8566817	0	31758705	25076062	14876195	29939177	19017158	131627647
Ring Road route 01 section (22)	-	-	2429556	10340872	0	30361963	24535716	13675426	35382663	20135815	136862010
Ring Road route 01 section (25)	-	-	1196767	4038309	0	15799211	12508012	8005127	15690050	11466228	68703704

3.8.4 Traffic Classes for Flexible Pavement Design

For identify the traffic classes of pavement an accurate estimate of cumulative traffic is necessary. But it is difficult to achieve due to errors in the surveys and uncertainties with regard to traffic growth, axle loads and axle equivalencies. To a reasonable extent, however, pavement thickness design is not very sensitive to cumulative axle loads and the method recommended in this manual provides fixed structures of paved roads for ranges of traffic as shown in table 3-42. Therefore, the traffic classes of the randomly sampled road networks based on the Cumulative Equivalent Standard Axle Loads (CESAL) presented as in table 3-43.

Table 3- 41: ERA Traffic Classes for Flexible Pavement Design

Traffic Classes	Ranges of ESAs in millions
LV1	< 0.01
LV2	0.01 – 0.1
T1/LV3	0.1 – 0.3
T2/LV4	0.3 – 0.5
T2/LV5	0.5 – 0.7
T3	0.7 – 1.5
T4	1.5 – 3.0
T5	3.0 – 6.0
T6	6.0 – 10
T7	10 – 17
T8	17 – 30
T9	30 – 50
T10	50 – 80
T11	> 80

Source: ERA Manual

Table 3- 42: Traffic Classes for each sample road networks

Road Networks	CESALs	Traffic Class
Johannes street	24,992,483	T8
Josef Tito street	24,370,585	T8
Cameroon street	45,712,002	T9
Roosevelt street	72,408,176	T10
Nigeria street	43,664,540	T9
Intoto Road	92,795,178	T11
Wendimeneh street	43,329,749	T9
Ring Road route 01 section (21)	131,627,647	T11
Ring Road route 01 section (22)	136,862,010	T11
Ring Road route 01 section (25)	68,703,704	T10

Based on the above analysis, the sample road networks under study belongs to the traffic classes (T8, T9, T10 & T11) for flexible pavement design.

3.9 Design Subgrade Soil Strength

The strength of the road subgrade for flexible pavements is commonly assessed in terms of the California Bearing Ratio (CBR) and depends on the type of soil, its density, and moisture content. The type of the subgrade soil is largely determined by the location of the road. However, where the soils within the possible corridor for the road vary significantly in strength from place to place, it is desirable to locate the pavement on the stronger soils if this does not conflict with other constraints. That is why the pavement engineer should be involved in the route selection process. Direct assessment of the likely strength of the subgrade soil under the completed road pavement is often difficult to make. The relationship between strength, density and moisture content for the subgrade soil must be determined in the laboratory, and the density can be controlled within limits by compaction at a specified moisture content. To simplify the estimation of subgrade strength for design, three classifications of subgrade conditions are defined:

1. The water table is high enough during the rainy season to govern the moisture content.
2. The water table is deep, but rainfall can influence the subgrade moisture content under the road.
3. Deep water table and arid climate.

The detail procedure in the ERA Site Investigation Manual is not as elaborated as to give complete curves, but is nevertheless sufficient to conduct the necessary interpolations. This laboratory determination is the first and generally preferred option available to obtain a design CBR (27). A group index of **zero (0)** indicates a "**good**" subgrade material and a group index of **20 or more** indicates a **"poor"** subgrade material. The following Table 3-39 shows the subgrade strength classes for a ranges of California Bearing Ratio (CBR) values estimated in laboratory.

Table 3- 43: Subgrade Strength Classes

Class	CBR Ranges (%)
S1	< 3
S2	3,4
S3	5,6,7
S4	8 – 14

S5	15 – 30
S6	>30

Source: ERA Manual

CHAPTER FOUR

HDM-4 Analysis

4.1 Introduction

This case study presents the economic analysis of maintenance and rehabilitation alternative standards for ten sample paved road networks. The objective of this case study is to evaluate economically the effect of delay in road maintenance and improvement standards on road performance and road user costs. The existing road networks exhibits significant levels of roughness and surface distress. This case study evaluates several possible maintenance and rehabilitation alternatives. Traffics and condition data are available from surveys undertaken in 2017. For analysis purposes the road networks data, vehicle fleet characteristics, geometry, pavement condition, and traffic volume are presented below in the following tables.

Table 4- 1: Road networks Data

No	Street/Road Section	Road Class	Altitude (m)	No. of lanes	Length (m)	Carriage-way Width	IRI mm/m	Road Condition
1	Yohanis street	Principal	2354.23	3	1300	8.81	8.51	Poor
2	Josef Tito street	Principal	2365.84	3	970	9.45	11.44	Very Poor
3	Cameroon street	Principal	2337.76	6	2160	24	9.38	Poor
4	Rosevelt street	Principal	2315.95	3	1265	11	8.55	Poor
5	Nigeria street	Principal	2364.34	4	380	11	9.91	Poor
6	Intoto Road	Principal	2685.28	2	2000	4	12.21	Very Poor
7	Wendimeneh street	Principal	2356.56	4	500	10.34	14.08	Very Poor
8	Ring Road route 01 section (21)	Ring Road	2348.35	4	200	17	18.34	Very Poor
9	Ring Road route 01 section (22)	Ring Road	2360.15	4	230	16	15.3	Very Poor

10	Ring Road route 01 section (25)	Ring Road	2457.65	2	1460	8.5	8.84	Poor

Source: AACRA

Table 4- 2: Vehicle Fleet Characteristics and their Economic Costs

Vehicle Type	Car	L/Rover	Small Bus	Large Bus	Small Truck	Medium Truck	Heavy Truck	Truck Trailer
Physical Characteristics								
• Operating Weight (kg)	1,200	1,600	5,200	9,000	5,500	13,000	22,000	28,000
• Axles per Vehicle (No.)	2	2	2	2	2	2	3	5
• Tires per Vehicle (No.)	4	4	4	6	4	6	10	18
Utilization								
• Annual Run (km)	20,000	40,000	50,000	60,000	50,000	60,000	65,000	65,000
• Annual Hours	500	900	1,600	1,800	1,600	1,800	2,100	2,100
• Average Service Life (yrs.)	12	12	15	15	12	15	15	15
• Private use (%)	85	20	15	-	-	-	-	-
• Passenger Occupancy (No.)	3	3	20	45	2	2	2	2
• Work Related Trips (%)	15	80	85	100	100	100	100	100
Unit Costs (Economic)								
•Annual Overhead (Birr)	0	0	66,000	88,000	33,000	33,000	55,000	66,000
•Annual Interest Rate (%)	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23
Time Value								
• Passenger Working Time	2.06	2.06	1.47	1.47	-	-	-	-
• Passenger Nonworking Time	0.72	0.72	0.52	0.52	-	-	-	-
• Cargo	-	-	-	-	0.13	0.30	0.36	0.77

Source: Ethiopian Road Authority (ERA)

Table 4- 3: Economic Costs of vehicles

Vehicle Type		Engine Size	One New Vehicle (Birr)	One Tire (Birr)	One Liter Fuel (Birr)	Fuel Type	One Liter Lubricant (Birr)	Maintenance Labor Cost (Birr/hr.)	Crew Cost (Birr/hr.)
Car	Toyota Corolla (sedan)	1300	617,938	1,833	15	petrol	69.35	54.87	36.47
Large Car	Mitsubishi (Pajaro)	4200	2,060,091	4,000	14.4	diesel	60.27	47.55	36.17
Small Bus	Mitsubishi	Dawo	1,464,063	7,083	14.4	diesel	60.27	36.66	27.18
Large Bus	Iveco	150E 18	2,070,313	13,167	14.4	diesel	60.27	49.54	43.95
Pickup	Toyota (D/CAB)	3000	907,604	2,917	15	petrol	69.35	47.55	39.27
Small Truck	Mitsubishi (70 quintals)	8.25-20140PR	1,453,125	6,750	14.4	diesel	60.27	26.86	25.57
Medium Truck	Iveco (246 quintals)	AT380T38H	2,460,938	13,167	14.4	diesel	60.27	49.24	38.72
Large Truck	Scania 400 quintals)	360 HP Turbo	2,656,250	13,333	14.4	diesel	60.27	44.14	46.93
Truck and Trailer	M. Truck + trailer (170 + 235 q)	360 HP Turbo	3,345,099	14,750	14.4	diesel	60.27	30.47	44.56

Source: Woineshet and Teferra (WT) Consult, Addis Ababa

Table 4- 4: Financial Cost of vehicles

Vehicle Type		Engine Size	One New Vehicle (Birr)	One Tire (Birr)	One Liter Fuel (Birr)	Fuel Type	One Liter Lubricant (Birr)	Maintenance Labor Cost (Birr/hr.)	Crew Cost (Birr/hr.)
Car	Toyota Corolla (sedan)	1300	1,378,000	2,200	18.6	petrol	90.16	60.36	40.12
Large Car	Mitsubishi (Pajaro)	4200	4,594,000	4,800	17.75	diesel	80.23	52.31	39.79
Small Bus	Mitsubishi	Dawo	1,874,000	8,500	17.75	diesel	80.23	40.33	29.9
Large Bus	Iveco	150E 18	2,650,000	15,800	17.75	diesel	80.23	54.49	48.35
Pickup	Toyota (D/CAB)	3000	2,387,000	3,500	18.6	petrol	90.16	52.31	43.2
Small Truck	Mitsubishi (70 quintals)	8.25-20140PR	1,860,000	8,100	17.75	diesel	80.23	29.55	28.13
Medium Truck	Iveco (246 quintals)	AT380T38H	3,150,000	15,800	17.75	diesel	80.23	54.16	42.59
Large Truck	Scania (400 quintals)	360 HP Turbo	3400000	16,000	17.75	diesel	80.23	48.55	51.62
Truck and Trailer	M. Truck + trailer (170 + 235 q)	360 HP Turbo	4281727	17,700	17.75	diesel	80.23	33.52	49.02

Source: Woineshet and Teferra (WT) Consult, Addis Ababa

4.2 Locate the Case Study Data

This case study is presented as a section analysis. The road sections are selected from the Addis Ababa City Road Networks, stored in the Road Network folder. The Vehicles using the road sections will be selected from the Addis Ababa City Vehicle Fleet, stored in the Vehicle Fleet folder. The data for this case study are located in the projects folder in the case studies workspace and the name of the case study is ***Economical Evaluation of Delay in Road Maintenance***.

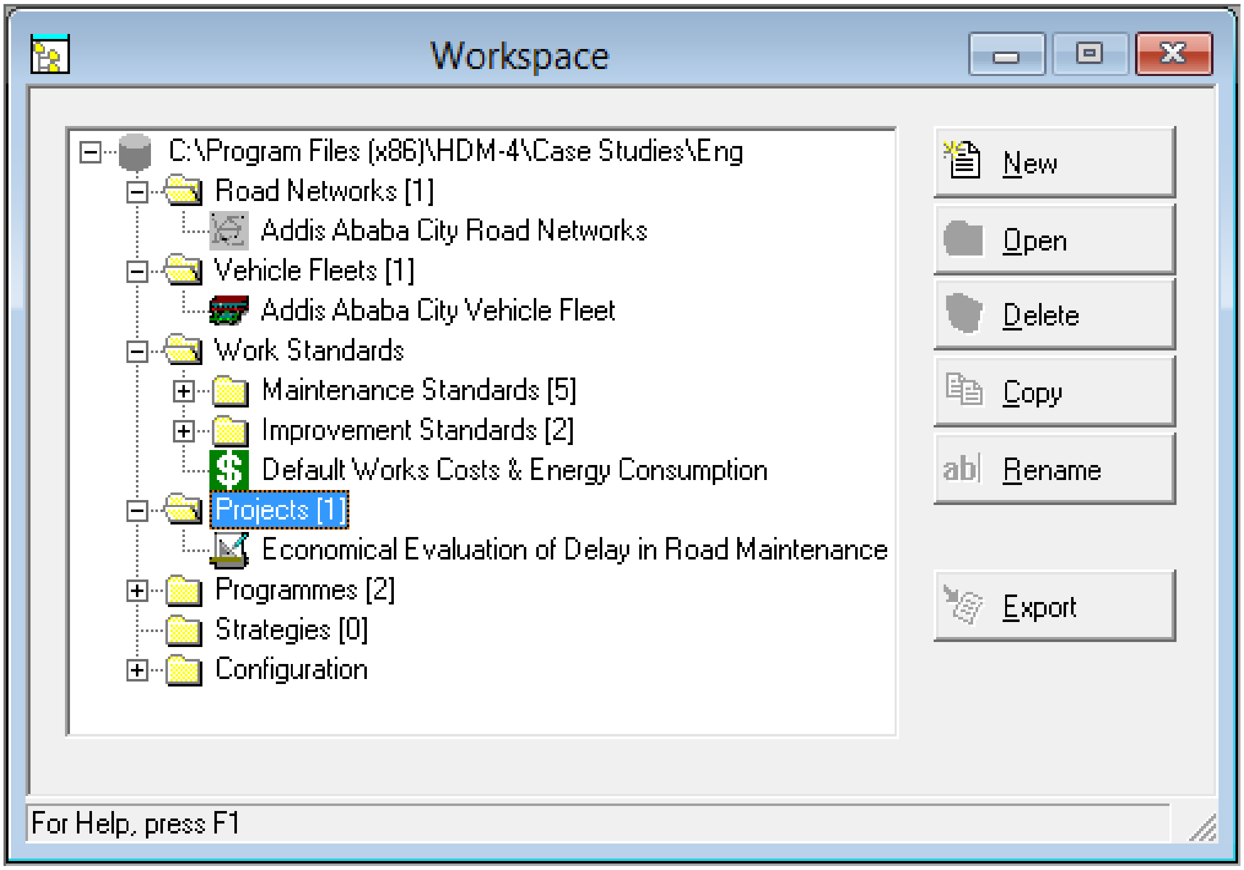

Figure 4- 1: case study data
Source: HDM-4 software

4.3 Review the Case Study Input Data

The case study input data's are reviewed under the HDM-4 project work flow. The project start year has been defined as 2018 with the analysis period (duration) specified as 23 years. The project analysis in this case, as the task is to compare, for all ten road sections, the maintenance and improvement alternatives against the base alternative.

4.3.1 General

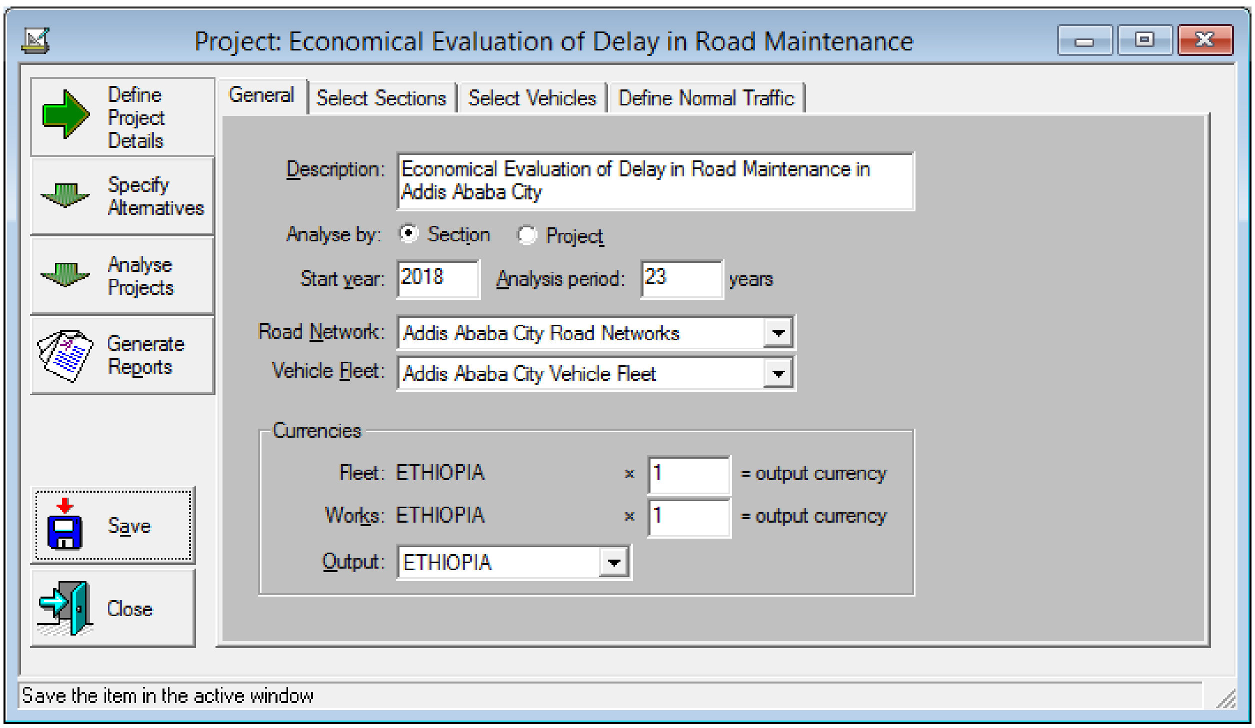

Figure 4- 2: Project title and type of analysis required
Source: HDM-4 software

The road sections within the Addis Ababa City Road Networks and vehicle types from the Addis Ababa City Vehicle Fleet to be used for the analysis are selected under the Select Sections and Select Vehicles tabs respectively, as discussed below:

4.3.2 Select Section

The road section is the basic entity for all calculations of pavement deterioration, construction and maintenance costs, and economical analysis. For this case study, ten sections are considered based on those physical attributes (road class, climate, carriageway width, geometry, pavement condition, traffic flow, and loading) for each section as shown below in figure 4-3.

4.3.3 Select vehicles

In this step, the vehicle types from the Addis Ababa City Vehicle Fleet folder are selected to assign for each road section as shown below in figure 4-4.

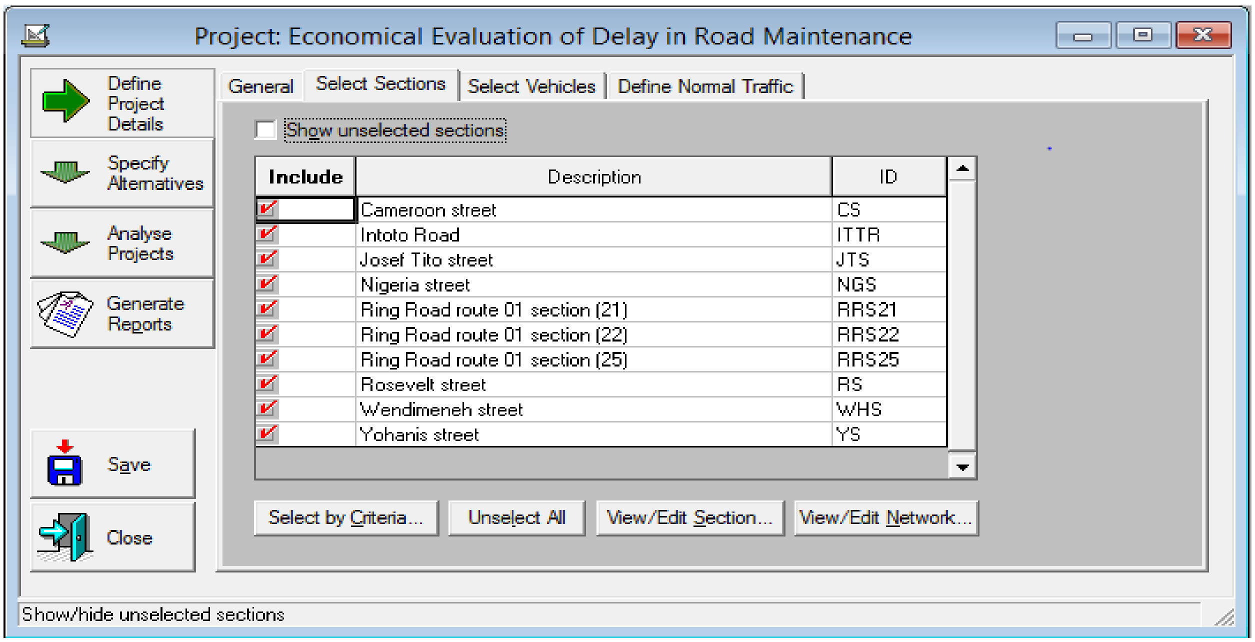

Figure 4- 3: select sections
(Source: HDM-4 software)

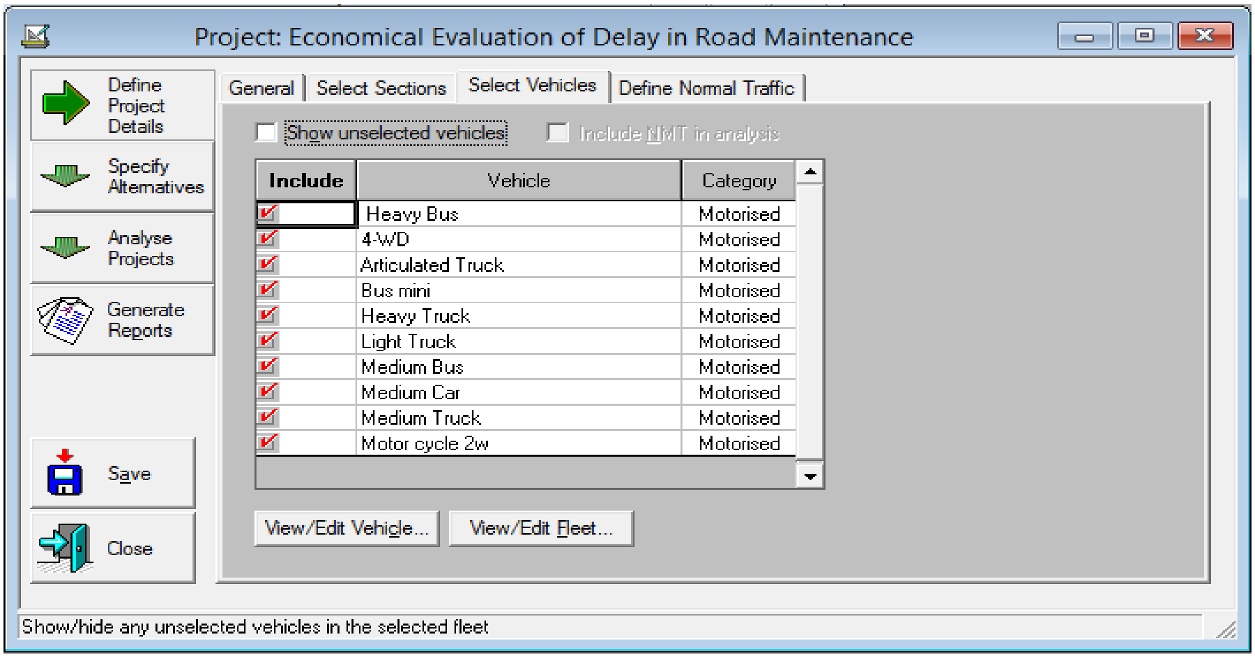

Figure 4- 4: select vehicles tab page

Source: HDM-4 software

4.3.4 Define Normal Traffic

In this stage, the traffic volume (AADT) on each road section in the specified year is listed and the base AADT held by section is automatically assigned to the Define Normal Traffic tab page as presented below in figure 4-5.

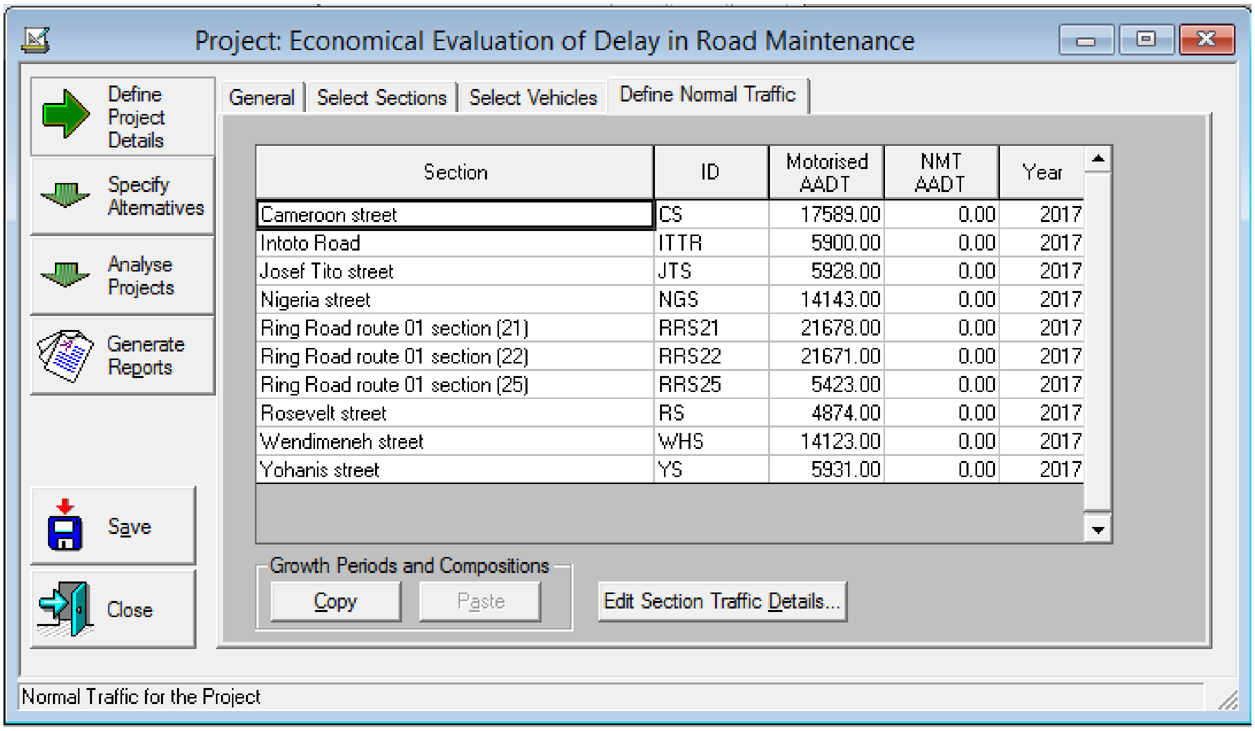

Figure 4- 5: define normal traffic tab page

Source: HDM-4 software

4.3.5 Alternatives

The economic feasibility of the project is assessed by comparison against a base-line project alternative (that is, a without project alternative). The project alternatives are:-

- Without project:
  - ✓ Maintain existing paved road every five years.
- With project
  - ✓ Maintain existing paved road every three years,
  - ✓ Maintain existing paved road every two years,
  - ✓ Maintain existing paved road every years, and
  - ✓ Improvement (pavement reconstruction)

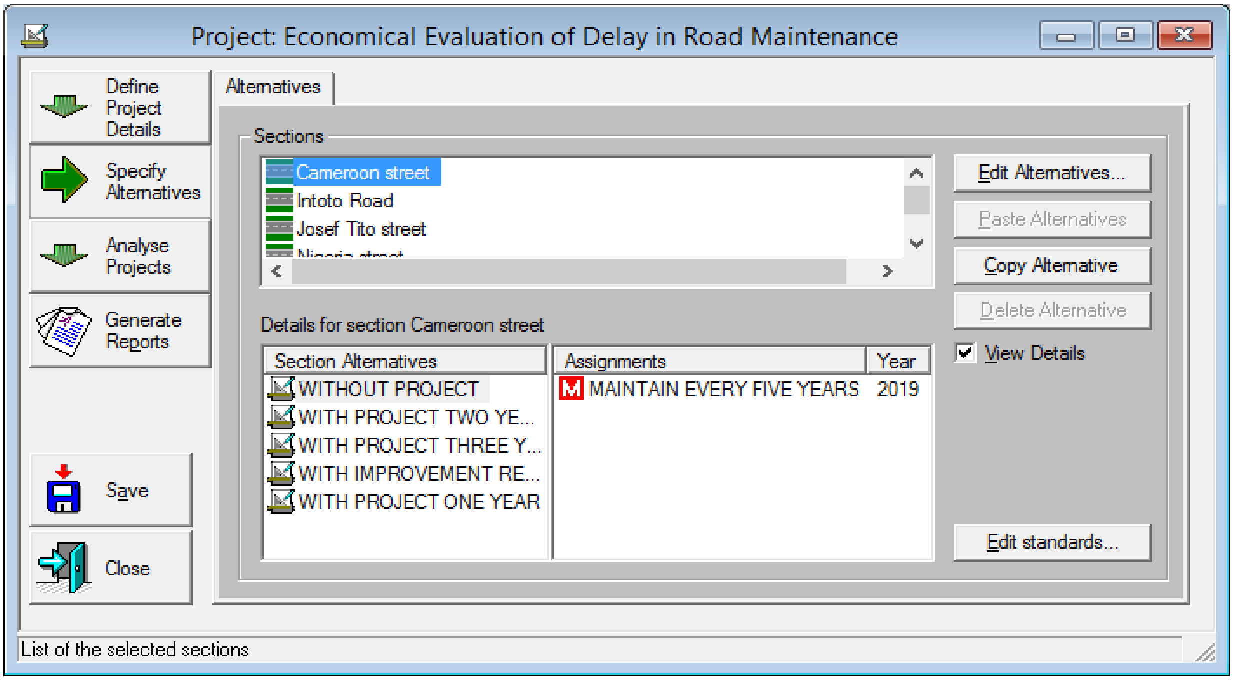

Figure 4- 6: alternative tab page
Source: HDM-4 software

4.4 Run HDM-4 and Examine the Results

The costs and benefits of the on time maintenance of paved road (with project alternative will be compared with the maintenance every five years (base option/without project-alternative).

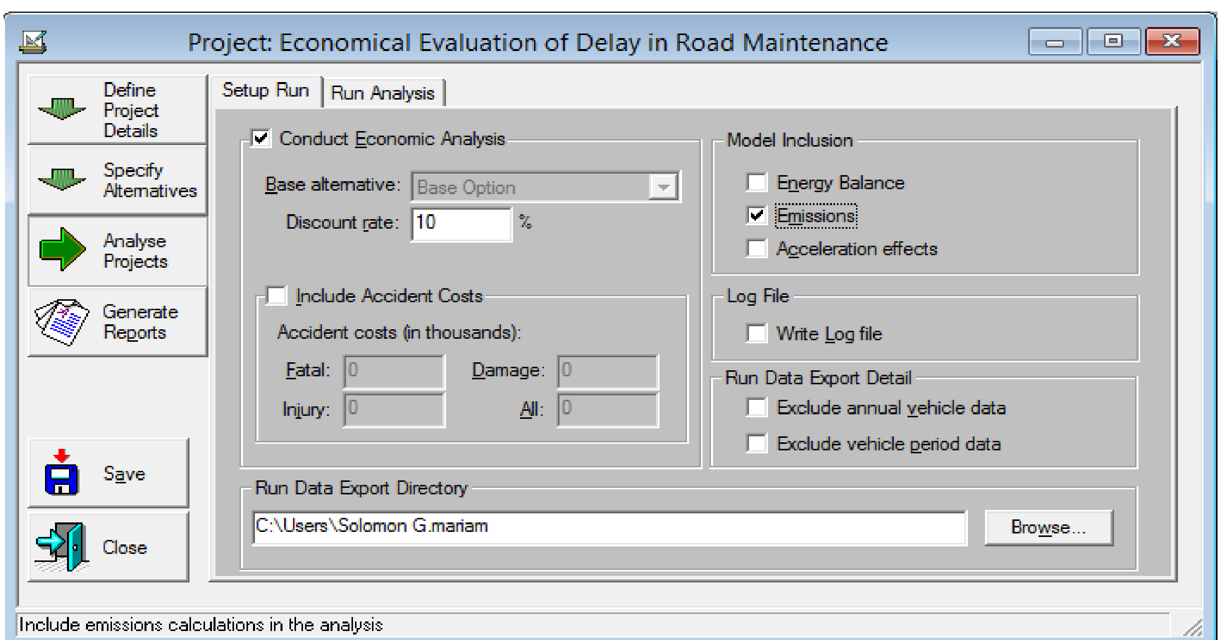

Figure 4- 7: alternative tab page
Source: HDM-4 software

4.4.1 Cost Stream

The economic analysis summary report gives a summary of Costs, and discounted Net Present Value (NPV) in detail by road section (by section). For this case study, the overall NPV is reported as 1305.3 million of Birr with improvement alternative. The breakdown by section indicates that all sections give positive NPV value only ***with improvement/reconstruction project alternative*** as shown below in table 4-5 but with other alternatives give negative NPV values as shown in detail on appendix A.

Net Present Value = Total Discounted Benefit *minus* Total Discounted Cost

NPV = TDB – TDC

Table 4- 5: Discounted NPV of the road sections with improvement

Section ID	***Section Description***	***TDB (millions of Birr)***	***TDC (millions of Birr)***	***Discounted NPV (millions of Birr)***
YS	Yohanis street	84.969	0.042	84.927
JTS	Josef Tito street	70.275	0.031	70.244
CS	Cameroon street	454.38	0.07	454.31
RS	Rosevelt street	81.893	0.041	81.852
NS	Nigeria street	69.54	0.012	69.528
ITTR	Intoto Road	170.832	0.065	170.767
WHS	Wendimeneh street	94.214	0.016	94.197
RRS21	Ring Road route 01 section (21)	69.684	0.006	69.678
RRS22	Ring Road route 01 section (22)	75.244	0.007	75.236
RRS25	Ring Road route 01 section (25)	134.587	0.047	134.54

Source: HDM-4 Software

The generated report of this case study gives total discounted benefits and total discounted costs of with each project alternative of all sections as shown in appendix A and appendix B. However, the Benefit Cost Ratio (B-CR) values of the ***with improvement project alternative*** only gives positive values greater than one as shown below in table 4-6 but the rest project alternatives gives negative values and/or less than one as shown in detail on appendix A and B.

Benefit Cost Ratio = Total Discounted Benefit over Total Discounted Cost

B-CR = TDB/TDC

Table 4- 6: Benefit Cost Ratio (B-CR) values of the road sections with improvement

Section ID	***Section Description***	***TDB (millions of Birr)***	***TDC (millions of Birr)***	***B-CR***
YS	Yohanis street	84.969	0.042	2023.07
JTS	Josef Tito street	70.275	0.031	2266.94
CS	Cameroon street	454.38	0.07	6491.14
RS	Rosevelt street	81.893	0.041	1997.37
NS	Nigeria street	69.54	0.012	5795
ITTR	Intoto Road	170.832	0.065	2628.18
WHS	Wendimeneh street	94.214	0.016	5888.4
RRS21	Ring Road route 01 section (21)	69.684	0.006	11614
RRS22	Ring Road route 01 section (22)	75.244	0.007	10749.14
RRS25	Ring Road route 01 section (25)	134.587	0.047	2863.55

Source: HDM-4 Software

The ***Saving in Road User Costs (RUC)*** of all road sections with and without project alternatives are analyzed by the HDM-4 Software. So that, For Cameroon street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic of Motorized Vehicle Operation Cost and Motorized Time Cost is 451.384 and 1.125 million birr respectively, and on Generated traffic 1.862 and 0.006 million birr respectively.

For Intoto Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 169.517 and 0.676 million birr respectively, and on Generated traffic 0.636 and 0.003 million birr respectively.

For Josef Tito Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 69.657 and 0.229 million birr respectively, and on Generated traffic 0.388 and 0.002 million birr respectively.

For Nigeria Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 69.159 and 0.106 million birr respectively, and on Generated traffic 0.274 and 0.001 million birr respectively.

For Ring Road route (01) section (21) with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 68.697 and 0.823 million birr respectively, and on Generated traffic 0.162 and 0.003 million birr respectively.

For Ring Road route (01) section (22) with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 74.019 and 1.097 million birr respectively, and on Generated traffic 0.125 and 0.002 million birr respectively.

For Ring Road route (01) section (25) with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 132.187 and 1.734 million birr respectively, and on Generated traffic 0.655 and 0.010 million birr respectively.

For Rosevelt Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 81.33 and 0.203 million birr respectively, and on Generated traffic 0.358 and 0.001 million birr respectively.

For Wendimeneh Street Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and Motorized Time Cost is 93.618 and 0.233 million birr respectively, and on Generated traffic 0.360 and 0.002 million birr respectively.

For yohanis Street with improvement project alternative the total Saving in Road User Cost for the design period on normal and diverted traffic under Motorized Vehicle Operation Cost and

Motorized Time Cost is 84.336 and 0.198 million birr respectively, and on Generated traffic 0.433 and 0.002 million birr respectively.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

According to HDM-4 Software generated reports, the Economic Analysis Summary of this case study shows, in the current condition of the road sections need improvement alternatives when it is comparison with the other project alternatives. Because the Net Present Values of with improvement option was only have a positive value which means the total discounted benefit is greater than the total discounted cost of all the sampled road sections for the analyzed period of time. Whereas with the other maintenance project alternatives the total discounted cost is greater than total discounted Benefit so that only the improvement project alternative will be viable for those sample road sections.

It is evident that maintenance of road assets will produce different impacts on road users cost and parts of society. The generated report under cost stream of this study confirms that impacts of road maintenance and improvement on road user costs. Which is the sample road sections comes with positive impacts with every year maintenance and with improvement project alternatives by saving the road user costs in terms of vehicle operation cost and travel time cost.

Deterioration in road conditions will cause an increase in vehicle operating costs, this was the most significant impact that could be quantified. And also deterioration in road condition will cause increases in travel time as vehicles travel slower on roads in poorer condition. This effect could, however, be more than offset by less disruption to journeys due to reduced road maintenance. The possible effects on road user journey times from potential breaks in those road networks can cause significant local issues and affect economic activities of the Addis Ababa.

There is a problem which is common throughout the world, the delay of maintaining our roads. Construction or reconstruction of roads are expensive, but without maintaining the roads properly, they deteriorate very quickly. If nothing is done, our roads with a design life of decades can need replacing or major repair work after just a few years. That deterioration will very fast infect road transport in general where the costs will rise, which again will infect the economy of the transporters. The transporters will transfer their expenses to the customers and the economy of the whole country will suffer. As the road network deteriorates, the whole country loses major assets build up over years, assets created with vast amounts of money, time and effort.

Even small budgets for maintenance make a difference with proper planning and the right priorities. The situation in Addis Ababa concerning the road condition is not only urgent, it is critical. It is important to know the costs involved in road maintenance and the costs of not maintaining the roads. The money which is saved in the maintenance budget by not maintaining the roads, is ultimately paid by the users and the society. I as professional person have to sell the message that maintaining roads are of decisive importance for a country. It is also important to involve the local communities and the users which are those who first will experience the result of bad roads.

5.2 RECOMMENDATION

The aim of this case study was to establish a trustworthy starting point for future work, and identify what any future work might involve in road maintenance practices. Evidence from this study suggests that, in general, highway managers in Addis Ababa City Road Authority (AACRA) are still struggling to produce a comprehensive and evidence-based justification for current levels of road maintenance or to describe the wider impacts to society of reductions in maintenance funding.

The developing a comprehensive understanding of the quantifiable impacts of road maintenance needs to be progressed with care. The long-term effect of road maintenance and the fact that savings now will increase costs later if the delay in our road maintenance practices as today are to continue to be adopted.

It is important to involve the local communities in the maintenance problems totally dependent on good condition road network systems. The Addis Ababa City Road Authorities should use time and effort to inform local politicians and businessmen on how to solve the maintenance challenge, because good functioning roads became an important issue in a local election. And also cooperating the AACRA with those road user organizations have given good results in Addis Ababa city road networks in order to put the questions about maintenance in focus. I have recommend that our maintenance engineers in AACRA have to be share their knowledge with the road users they are responsible for those road systems to come up with good arguments.

Good road network condition make a city more competitive both nationally and internationally. Consequently properly maintained road networks serves as a principal foundation for the effective functioning of transportation and contributes in delivering a wide range of economic and social benefits. Adequate as well as on time maintenance of our road infrastructures are essential to achieve and preserve those road user benefits. However, in order to establish an efficient road maintenance system, it is important to find a right balance amongst using money on construction, maintenance and operation of our roads.

The another important part is sharing knowledge of maintenance methods and practices and to learn from each other's successes and mistakes of our day to day maintenance practices. As a result I think we can come up with the cheap and simple methods that is improved road maintenance systems. And then sharing this methods to the road authorities and people working in this area by organizing seminars and conferences.

In AACRA there is no well-organized road data defines the background condition of the road networks like the last reconstruction or new construction year, last rehabilitation (overlay) year, last resurfacing (resealing), last preventative treatments and others. So that I recommend to have this road authority a good management and decision support systems are necessary and must be developed, and then there is a need to establish a Road Data Bank and a Road Maintenance Management system. As a result the road authority can decide what, where and when should be done to keep our road networks in economically efficient condition.

In order to minimize the construction costs, maintenance costs and vehicle operation costs or road user costs the maintenance projects should be provided on the right time. The design should be modified according to the expected maintenance in order to implement the most economic strategies. And it would be more efficient to concentrate any future analysis on the categories that are historically shown to have greater exposure to changes in overall budgets.

References

1. Ralph, H., (2001). Reinvesting the (Pavement management) Wheel. In Fifth International Conference on Managing Pavements. Seattle, Washington, page (1-67). Available at: http://Asphalt.org/Downloads/Haaslecture.pdf.
2. Adling, S. & Gupta, A., (2009). Pavement Deterioration and its causes. Mechanical and Civil Engineering, page (9-15). Available at: www.iosrjournals.org.
3. Harral, C. & Faiz, A., (1988). Road Deterioration in Developing Counties: Causes & Remedies.
4. Burningham, S. and Stankevich, N., (2005). Why road Maintenance is Important and How to get it done. (June), page (1-10). Available at: https://openknowledge.worldbank.com/handle/10986/11779 (Accessed September 29, 2014).
5. Parkman, C., Madelin, K. & Robinson, R., (2000). Managing Change to Improve the Delivery of Road Maintenance, Available at: http://r4d.dfid.gov.uk/pdf/outputs/R68891.pdf.
6. Emeasoba, U., Ogbuefi, J. & Enugu, C., (2013). Sustainable Socio-Economic Development in Nigeria: A case for Road Infrastructure Maintenance. Journal of Environment and Earth Science, 3(5), page (129-137). Available at: file://C:/Users/cvjs8/Downloads/5725-7821-1-PB (1).pdf.
7. Barton, J. & Burns, J., (2012). Road Maintenance Review International Comparison, Available at: file:///C:/Users/cvjs8/Downloads/wra-uk-road-maintenance-review-international-comparison-41111.pdf.
8. Ian G. Heggie: Management and Financing of Roads. An Agenda for reform. World Bank Technical Paper No. 275, 1996.
9. Ian Heggie: Commercializing Africa’s Roads. Transforming the Role of the public Sector. SSATP Working Paper No. 10, published by the World Bank in 1994.
10. Sustainable Solutions for Surfacing Low Volume Roads in the SADC Region. Paper presented at TT- conference in Arusha in Tanzania in May 2001 by Mr. Charles Øverby, NPRA.

11. US Department of Transportation, Federal Highway Administration: Distress Identification Manual for the Long-Term Pavement Performance Program. Publication No. FHWA-RD-03-031, June 2003.

12. Annual Evaluation Review, Linked Document E, Issues in Road Maintenance, 2013.

13. Hand book in Asphalt Pavement Maintenance. Available at: http://www.stonington-ct.gov/sites/pavement_maintenance.

14. Proactively planning preventative maintenance. Available at: http://www.sunlandasphalt.com/maintenance/asphalt-repairs.

15. John Watson: Highway Construction and Maintenance. Second edition at Longman Group Limited 1994.

16. Henry G. R. Kerali: Hand book in Overview of Highway Development and Management Tool (HDM-4) Version 1.0.

17. Addis Ababa City Atlas 2015. Addis Ababa, Ethiopia.

18. Wallman, C. G., Wretling, P. & Oberg, G. (1997). Effects of Winter Road Maintenance (Report no. 423A). Linkoping, Sweden: VTI.

19. Consultant's Primary Survey (2017). Addis Ababa, Ethiopia.

20. Anne Balcerac de Richecour and Ian G. Heggie: African Road Funds: What Works and Why? SSATP Working Paper No. 14, published by the World Bank in 1995.

21. Gunter Zietlow: Financial and Institutional Reform of Road Maintenance. Published by International Road Federation in 1996.

22. Handbook in Impact Assessment of Road Projects. Published by Norwegian Public Roads administration in 1995.

23. Guideline for Planning and Environmental Impact Assessment of Road Infrastructure in Botswana. Roads Department Botswana January 2001.

24. Hiep, D. V., (2009). PhD Thesis Optimization of Pavement Designs &/or Maintenance Strategies using Gradient Search with Option Evaluation Systems. Engineering, page 134. Available at: http://www.lpcb.org/index.php/compenent/docman/doc_view/927-2009-japan-optimizing-pavement-investment-using-the-gradient-method?Itemid=32.

25. Henry G. R. Kerali: Overview of HDM-4, Version 1.0; published by Association mondiale de la Route and World Road Association.

26. Austroads (2009), Guide to Road Safety Part 6: Road Safety Audits. Austroads Incorporated, Sydney, Australia.

27. Ubaka, D. (2011). Presentation at National Roads Maintenance Review-Wider economic issues, impacts, costs and benefits meeting for Workstream 7, Perth, 18th August 2011.

28. Austroads (2009), Guide to Road Safety Part 1: Road Safety Overview. Austroads Incorporated, Sydney, Australia.

29. Ethiopian Roads Authority (2003), Pavement Design Manual Volume I Flexible Pavement.

30. Rogers, M. P. & Gargett, T. (1991). A skidding resistance standard for the national road network. Highways and Transportation, 38 (4): 10-16

31. Asphalt Industry Alliance (2011). Annual Local Authority Road Maintenance (ALARM) Survey. London, UK: Asphalt Industry Alliance.

32. Bennet, C. R. & Greenwood, l. (2004). HDM-4 Highway Development and Management. Volume 7. Modeling road user and environmental effects in HDM-4. Washington DC, USA: the World Bank.

33. Highways Agency (2009). Design Manual for Roads and Bridges. Volume 14. Economic assessment of road maintenance. London, UK: Highways Agency.

34. Ramdas, V. Thomas, C., Lehman, C. & Young, D. (2007). Highway Service Level (PPR251). Wokingham, UK: Transport Research Laboratory.

35. Robinson, R.,Hide, H., Hodges, J.W., Rolt, J. & Abaynayaka, S.W. (1975). A Road Transport Investment Model for Developing Countries (LR675).Workingham, UK: Transport Research Laboratory.

APPENDICES

Appendix A: Benefit Cost Ratios

Table A- 1: Benefit cost ratio of Cameroon Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.115	0.000	0.000	-0.115	-1.000	No Solution
WITH PROJECT THREE YEAR	0.050	0.000	0.000	-0.050	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.070	454.380	0.000	454.310	6,503.526	No Solution
WITH PROJECT ONE YEAR	0.272	0.000	0.000	-0.272	-1.000	No Solution

Source: HDM-4 Software

Table A- 2: Benefit cost ratio of Intoto road

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.107	0.000	0.000	-0.107	-1.000	No Solution
WITH PROJECT THREE YEAR	0.047	0.000	0.000	-0.047	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.065	170.832	0.000	170.767	2,640.132	No Solution
WITH PROJECT ONE YEAR	0.252	0.000	0.000	-0.252	-1.000	No Solution

Source: HDM-4 Software

Table A- 3: Benefit cost ratio of Josef Tito Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.052	0.000	0.000	-0.052	-1.000	No Solution
WITH PROJECT THREE YEAR	0.023	0.000	0.000	-0.023	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.031	70.275	0.000	70.244	2,239.179	No Solution
WITH PROJECT ONE YEAR	0.122	0.000	0.000	-0.122	-1.000	No Solution

Source: HDM-4 Software

Table A- 4: Benefit cost ratio of Nigeria Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.020	0.000	0.000	-0.020	-1.000	No Solution
WITH PROJECT THREE YEAR	0.009	0.000	0.000	-0.009	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.012	69.540	0.000	69.528	5,657.520	No Solution
WITH PROJECT ONE YEAR	0.048	0.000	0.000	-0.048	-1.000	No Solution

Source: HDM-4 Software

Table A- 5: Benefit cost ratio of Ring Road route 01 section 21

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.011	0.000	0.000	-0.011	-1.000	No Solution
WITH PROJECT THREE YEAR	0.005	0.000	0.000	-0.005	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.006	69.684	0.000	69.678	10,772.446	No Solution
WITH PROJECT ONE YEAR	0.025	0.000	0.000	-0.025	-1.000	No Solution

Source: HDM-4 Software

Table A- 6: Benefit cost ratio of Ring Road route 01 section 22

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.012	0.000	0.000	-0.012	-1.000	No Solution
WITH PROJECT THREE YEAR	0.005	0.000	0.000	-0.005	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.007	75.244	0.000	75.236	10,114.655	No Solution
WITH PROJECT ONE YEAR	0.029	0.000	0.000	-0.029	-1.000	No Solution

Source: HDM-4 Software

Table A- 7: Benefit cost ratio of Ring Road route 01 section 25

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.078	0.000	0.000	-0.078	-1.000	No Solution
WITH PROJECT THREE YEAR	0.034	0.000	0.000	-0.034	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.047	134.587	0.000	134.539	2,849.358	No Solution
WITH PROJECT ONE YEAR	0.184	0.000	0.000	-0.184	-1.000	No Solution

Source: HDM-4 Software

Table A- 8: Benefit cost ratio of Rosevelt Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.067	0.000	0.000	-0.067	-1.000	No Solution
WITH PROJECT THREE YEAR	0.030	0.000	0.000	-0.030	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.041	81.893	0.000	81.852	2,000.735	No Solution
WITH PROJECT ONE YEAR	0.160	0.000	0.000	-0.160	-1.000	No Solution

Source: HDM-4 Software

Table A- 9: Benefit cost ratio of Wendimeneh Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.027	0.000	0.000	-0.027	-1.000	No Solution
WITH PROJECT THREE YEAR	0.012	0.000	0.000	-0.012	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.016	94.214	0.000	94.197	5,825.315	No Solution
WITH PROJECT ONE YEAR	0.063	0.000	0.000	-0.063	-1.000	No Solution

Source: HDM-4 Software

Table A- 10: Benefit cost ratio of Yohanis Street

Alternative	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E - C)	NPV/Cost Ratio (NPV/C)	Internal Rate of Return (IRR)
Base Option	0.000	0.000	0.000	0.000	0.000	0.000
WITH PROJECT TWO YEAR	0.069	0.000	0.000	-0.069	-1.000	No Solution
WITH PROJECT THREE YEAR	0.030	0.000	0.000	-0.030	-1.000	No Solution
WITH IMPROVEMENT REHABILITATION	0.042	84.969	0.000	84.927	2,019.999	No Solution
WITH PROJECT ONE YEAR	0.164	0.000	0.000	-0.164	-1.000	No Solution

Source: HDM-4 Software

Appendix B: Economic Analysis Summary

Table B- 1: with Improvement Rehabilitation vs Base Alternative of all Sections

Section: Cameroon street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.13	0.00	0.00	1,110.29	3.14	0.00	0.00	0.00	1,113.29
Discounted	0.07	0.00	0.00	453.25	1.13	0.00	0.00	0.00	454.31

Section: Intoto Road

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.12	0.00	0.00	399.05	1.65	0.00	0.00	0.00	400.58
Discounted	0.06	0.00	0.00	170.15	0.68	0.00	0.00	0.00	170.77

Source: HDM-4 Software

Section: Josef Tito street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.06	0.00	0.00	188.90	0.69	0.00	0.00	0.00	189.53
Discounted	0.03	0.00	0.00	70.04	0.23	0.00	0.00	0.00	70.24

Section: Nigeria street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.02	0.00	0.00	166.11	0.37	0.00	0.00	0.00	166.46
Discounted	0.01	0.00	0.00	69.43	0.11	0.00	0.00	0.00	69.53

Section: Ring Road route 01 section (21)

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.01	0.00	0.00	145.62	1.96	0.00	0.00	0.00	147.57
Discounted	0.01	0.00	0.00	68.86	0.83	0.00	0.00	0.00	69.68

Source: HDM-4 Software

Section: Ring Road route 01 section (22)

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.01	0.00	0.00	149.13	2.25	0.00	0.00	0.00	151.36
Discounted	0.01	0.00	0.00	74.15	1.10	0.00	0.00	0.00	75.24

Section: Ring Road route 01 section (25)

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.09	0.00	0.00	345.53	4.72	0.00	0.00	0.00	350.16
Discounted	0.05	0.00	0.00	132.84	1.74	0.00	0.00	0.00	134.54

Section: Rosevelt street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.08	0.00	0.00	205.32	0.56	0.00	0.00	0.00	205.80
Discounted	0.04	0.00	0.00	81.69	0.20	0.00	0.00	0.00	81.85

Source: HDM-4 Software

Section: Wendimeneh street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.03	0.00	0.00	221.51	0.74	0.00	0.00	0.00	222.23
Discounted	0.02	0.00	0.00	93.98	0.23	0.00	0.00	0.00	94.20

Section: Yohanis street

Alternative: WITH IMPROVEMENT REHABILITATION vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.08	0.00	0.00	223.33	0.65	0.00	0.00	0.00	223.90
Discounted	0.04	0.00	0.00	84.77	0.20	0.00	0.00	0.00	84.93

Source: HDM-4 Software

Table B- 2: With Project One Year vs Base Alternative of all Sections

Section: Cameroon street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.68
Discounted	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.27

Section: Intoto Road

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.63
Discounted	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.25

Section: Josef Tito street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30
Discounted	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.12

Source: HDM-4 Software

Section: Nigeria street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.12
Discounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05

Section: Ring Road route 01 section (21)

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Section: Ring Road route 01 section (22)

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Source: HDM-4 Software

Section: Ring Road route 01 section (25)

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.46
Discounted	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.18

Section: Rosevelt street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.40
Discounted	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.16

Section: Wendimeneh street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.16
Discounted	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06

Source: HDM-4 Software

Section: Yohanis street

Alternative: WITH PROJECT ONE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.41
Discounted	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.16

Table B- 3: With Project Three Year vs Base Alternative of all Sections

Section: Cameroon street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.11
Discounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05

Section: Intoto Road

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.10
Discounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05

Source: HDM-4 Software

Section: Josef Tito street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05
Discounted	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02

Section: Nigeria street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02
Discounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Section: Ring Road route 01 section (21)
Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Discounted	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: HDM-4 Software

Section: Ring Road route 01 section (22)
Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Discounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Section: Ring Road route 01 section (25)

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.08
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Section: Rosevelt street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Source: HDM-4 Software

Section: Wendimeneh street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03
Discounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Section: Yohanis street

Alternative: WITH PROJECT THREE YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Table B- 4: With Project Two Year vs Base Alternative of all Sections

Section: Cameroon street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.26
Discounted	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.12

Section: Intoto Road

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.24
Discounted	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.11

Section: Josef Tito street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.12
Discounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05

Section: Nigeria street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05
Discounted	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02

Section: Ring Road route 01 section (21)

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02
Discounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Source: HDM-4 Software

Section: Ring Road route 01 section (22)

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03
Discounted	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01

Section: Ring Road route 01 section (25)

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.18
Discounted	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.08

Section: Rosevelt street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.15
Discounted	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07

Source: HDM-4 Software

Section: Wendimeneh street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
Discounted	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03

Section: Yohanis street

Alternative: WITH PROJECT TWO YEAR vs Base Alternative

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.16
Discounted	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07

Source: HDM-4 Software

Appendix C: Comparison of Cost Streams

Table C- 1: Comparisons of Improvement with Base Alternative Cost of Cameroon Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.111	0.000	0.000	0.000	0.000	0.000	-0.111
2020	0.000	0.000	0.000	56.806	0.004	0.000	56.810
2021	0.000	0.000	0.000	71.068	0.009	0.000	71.077
2022	-0.075	0.000	0.000	97.327	0.188	0.000	97.591
2023	0.075	0.000	0.000	119.904	0.231	0.000	120.060
2024	0.000	0.000	0.000	129.567	0.249	0.000	129.816
2025	0.000	0.000	0.000	138.507	0.266	0.000	138.773
2026	0.075	0.000	0.000	147.709	0.455	0.000	148.089
2027	-0.075	0.000	0.000	157.904	0.488	0.000	158.467
2028	0.000	0.000	0.000	169.250	0.550	0.000	169.800
2029	0.075	0.000	0.000	180.935	0.591	0.000	181.450
2030	0.000	0.000	0.000	191.629	0.630	0.000	192.259
2031	0.000	0.000	0.000	202.435	0.638	0.000	203.073
2032	0.000	0.000	0.000	213.913	0.716	0.000	214.629
2033	0.000	0.000	0.000	225.957	0.761	0.000	226.718
2034	0.000	0.000	0.000	129.381	0.519	0.000	129.899
2035	0.075	0.000	0.000	-1.506	-0.002	0.000	-1.584
2036	0.000	0.000	0.000	-1.651	-0.004	0.000	-1.655
2037	-0.075	0.000	0.000	-2.092	-0.003	0.000	-2.020
2038	0.075	0.000	0.000	-1.882	-0.005	0.000	-1.962
2039	0.000	0.000	0.000	-1.995	-0.005	0.000	-2.000
2040	0.000	0.000	0.000	-2.590	-0.005	0.000	-2.595

Source: HDM-4 Software

Table C- 2: Comparisons of Improvement with Base Alternative Cost of Intoto Road

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.051	0.000	0.000	0.000	0.000	0.000	-0.051
2020	0.000	0.000	0.000	15.706	0.039	0.000	15.745
2021	0.000	0.000	0.000	18.962	0.052	0.000	19.014
2022	-0.035	0.000	0.000	20.453	0.080	0.000	20.567
2023	0.035	0.000	0.000	21.445	0.084	0.000	21.494
2024	0.000	0.000	0.000	22.891	0.090	0.000	22.981
2025	0.000	0.000	0.000	24.478	0.098	0.000	24.576
2026	0.035	0.000	0.000	26.120	0.103	0.000	26.188
2027	-0.035	0.000	0.000	27.860	0.114	0.000	28.008
2028	0.000	0.000	0.000	29.796	0.123	0.000	29.920
2029	0.035	0.000	0.000	31.839	0.133	0.000	31.937
2030	0.000	0.000	0.000	33.596	0.178	0.000	33.774
2031	0.000	0.000	0.000	35.459	0.156	0.000	35.616

2032	0.000	0.000	0.000	37.360	0.168	0.000	37.528
2033	0.000	0.000	0.000	37.354	0.176	0.000	37.531
2034	0.000	0.000	0.000	20.632	0.184	0.000	20.816
2035	0.035	0.000	0.000	-0.478	-0.005	0.000	-0.518
2036	0.000	0.000	0.000	-0.539	-0.007	0.000	-0.546
2037	-0.035	0.000	0.000	-0.732	-0.013	0.000	-0.710
2038	0.035	0.000	0.000	-0.875	-0.066	0.000	-0.975
2039	0.000	0.000	0.000	-1.106	-0.018	0.000	-1.124
2040	0.000	0.000	0.000	-1.173	-0.019	0.000	-1.191

Source: HDM-4 Software

Table C- 3: Comparisons of Improvement with Base Alternative Cost of Josef Tito Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				

2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.025	0.000	0.000	0.000	0.000	0.000	-0.025
2020	0.000	0.000	0.000	4.874	0.001	0.000	4.876
2021	0.000	0.000	0.000	5.401	0.002	0.000	5.403
2022	-0.017	0.000	0.000	6.147	0.003	0.000	6.167
2023	0.017	0.000	0.000	7.108	0.006	0.000	7.098
2024	0.000	0.000	0.000	8.625	0.035	0.000	8.660
2025	0.000	0.000	0.000	9.801	0.038	0.000	9.839
2026	0.017	0.000	0.000	10.450	0.041	0.000	10.474
2027	-0.017	0.000	0.000	11.171	0.044	0.000	11.232
2028	0.000	0.000	0.000	11.980	0.048	0.000	12.027
2029	0.017	0.000	0.000	12.808	0.054	0.000	12.845
2030	0.000	0.000	0.000	13.591	0.058	0.000	13.649
2031	0.000	0.000	0.000	14.329	0.061	0.000	14.390
2032	0.000	0.000	0.000	15.190	0.066	0.000	15.255
2033	0.000	0.000	0.000	16.004	0.070	0.000	16.074
2034	0.000	0.000	0.000	16.901	0.074	0.000	16.975
2035	0.017	0.000	0.000	16.572	0.079	0.000	16.635
2036	0.000	0.000	0.000	8.668	0.082	0.000	8.750
2037	-0.017	0.000	0.000	-0.142	-0.001	0.000	-0.126
2038	0.017	0.000	0.000	-0.157	-0.001	0.000	-0.175
2039	0.000	0.000	0.000	-0.168	-0.001	0.000	-0.169
2040	0.000	0.000	0.000	-0.250	-0.073	0.000	-0.322

Source: HDM-4 Software

Table C- 4: Comparisons of Improvement with Base Alternative Cost of Nigeria Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.010	0.000	0.000	0.000	0.000	0.000	-0.010
2020	0.000	0.000	0.000	5.268	0.001	0.000	5.269
2021	0.000	0.000	0.000	7.270	0.002	0.000	7.272
2022	-0.007	0.000	0.000	8.273	0.003	0.000	8.283
2023	0.007	0.000	0.000	8.743	0.004	0.000	8.739
2024	0.000	0.000	0.000	9.347	0.004	0.000	9.351
2025	0.000	0.000	0.000	10.009	0.004	0.000	10.014
2026	0.007	0.000	0.000	10.769	0.005	0.000	10.767
2027	-0.007	0.000	0.000	11.523	0.015	0.000	11.544
2028	0.000	0.000	0.000	12.358	0.016	0.000	12.374
2029	0.007	0.000	0.000	13.251	0.018	0.000	13.262
2030	0.000	0.000	0.000	14.066	0.019	0.000	14.085
2031	0.000	0.000	0.000	14.928	0.020	0.000	14.948
2032	0.000	0.000	0.000	15.815	0.021	0.000	15.837
2033	0.000	0.000	0.000	16.765	0.131	0.000	16.895
2034	0.000	0.000	0.000	9.888	0.138	0.000	10.026
2035	0.007	0.000	0.000	-0.179	-0.001	0.000	-0.186
2036	0.000	0.000	0.000	-0.322	-0.001	0.000	-0.322
2037	-0.007	0.000	0.000	-0.343	-0.001	0.000	-0.338
2038	0.007	0.000	0.000	-0.527	-0.020	0.000	-0.554
2039	0.000	0.000	0.000	-0.386	-0.001	0.000	-0.387
2040	0.000	0.000	0.000	-0.407	-0.001	0.000	-0.408

Source: HDM-4 Software

Table C- 5: Comparisons of Improvement with Base Alternative Cost of Ring Road route 01 section 21

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.005	0.000	0.000	0.000	0.000	0.000	-0.005
2020	0.000	0.000	0.000	8.335	0.056	0.000	8.391
2021	0.000	0.000	0.000	8.659	0.059	0.000	8.718
2022	-0.003	0.000	0.000	9.146	0.061	0.000	9.211
2023	0.003	0.000	0.000	9.511	0.065	0.000	9.572
2024	0.000	0.000	0.000	10.151	0.069	0.000	10.220
2025	0.000	0.000	0.000	10.930	0.168	0.000	11.098
2026	0.003	0.000	0.000	11.567	0.183	0.000	11.747
2027	-0.003	0.000	0.000	12.347	0.196	0.000	12.546
2028	0.000	0.000	0.000	13.194	0.208	0.000	13.401
2029	0.003	0.000	0.000	13.989	0.225	0.000	14.211
2030	0.000	0.000	0.000	14.801	0.239	0.000	15.040
2031	0.000	0.000	0.000	15.510	0.254	0.000	15.764
2032	0.000	0.000	0.000	9.183	0.222	0.000	9.406
2033	0.000	0.000	0.000	-0.181	-0.005	0.000	-0.186
2034	0.000	0.000	0.000	-0.186	-0.003	0.000	-0.190
2035	0.003	0.000	0.000	-0.047	0.000	0.000	-0.051
2036	0.000	0.000	0.000	-0.057	-0.004	0.000	-0.061
2037	-0.003	0.000	0.000	-0.250	0.000	0.000	-0.247
2038	0.003	0.000	0.000	-0.302	-0.012	0.000	-0.317

2039	0.000	0.000	0.000	-0.319	-0.005	0.000	-0.323
2040	0.000	0.000	0.000	-0.359	-0.019	0.000	-0.378

Source: HDM-4 Software

Table C- 6: Comparisons of Improvement with Base Alternative Cost of Ring Road route 01 section 22

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.006	0.000	0.000	0.000	0.000	0.000	-0.006
2020	0.000	0.000	0.000	9.579	0.136	0.000	9.715
2021	0.000	0.000	0.000	10.026	0.143	0.000	10.168
2022	-0.004	0.000	0.000	10.445	0.150	0.000	10.599
2023	0.004	0.000	0.000	11.016	0.159	0.000	11.171
2024	0.000	0.000	0.000	11.683	0.164	0.000	11.847

2025	0.000	0.000	0.000	12.471	0.179	0.000	12.650
2026	0.004	0.000	0.000	13.295	0.191	0.000	13.482
2027	-0.004	0.000	0.000	14.186	0.207	0.000	14.397
2028	0.000	0.000	0.000	15.164	0.222	0.000	15.386
2029	0.004	0.000	0.000	16.094	0.248	0.000	16.338
2030	0.000	0.000	0.000	17.006	0.263	0.000	17.269
2031	0.000	0.000	0.000	10.056	0.230	0.000	10.286
2032	0.000	0.000	0.000	-0.180	0.000	0.000	-0.180
2033	0.000	0.000	0.000	-0.043	0.000	0.000	-0.043
2034	0.000	0.000	0.000	-0.046	-0.004	0.000	-0.050
2035	0.004	0.000	0.000	-0.059	0.000	0.000	-0.063
2036	0.000	0.000	0.000	-0.253	-0.011	0.000	-0.264
2037	-0.004	0.000	0.000	-0.292	-0.005	0.000	-0.293
2038	0.004	0.000	0.000	-0.310	0.000	0.000	-0.314
2039	0.000	0.000	0.000	-0.333	-0.013	0.000	-0.346
2040	0.000	0.000	0.000	-0.381	-0.006	0.000	-0.387

Source: HDM-4 Software

Table C- 7: Comparisons of Improvement with Base Alternative Cost of Ring Road route 01 section 25

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.038	0.000	0.000	0.000	0.000	0.000	-0.038
2020	0.000	0.000	0.000	6.835	0.068	0.000	6.903
2021	0.000	0.000	0.000	8.889	0.086	0.000	8.975
2022	-0.025	0.000	0.000	12.542	0.153	0.000	12.721
2023	0.025	0.000	0.000	16.318	0.206	0.000	16.498
2024	0.000	0.000	0.000	18.497	0.230	0.000	18.726
2025	0.000	0.000	0.000	19.751	0.246	0.000	19.997
2026	0.025	0.000	0.000	21.135	0.266	0.000	21.375
2027	-0.025	0.000	0.000	22.559	0.285	0.000	22.869
2028	0.000	0.000	0.000	24.178	0.335	0.000	24.513
2029	0.025	0.000	0.000	25.839	0.361	0.000	26.175
2030	0.000	0.000	0.000	27.358	0.384	0.000	27.742
2031	0.000	0.000	0.000	28.918	0.410	0.000	29.327
2032	0.000	0.000	0.000	30.546	0.434	0.000	30.980
2033	0.000	0.000	0.000	32.250	0.462	0.000	32.711
2034	0.000	0.000	0.000	32.770	0.488	0.000	33.258
2035	0.025	0.000	0.000	18.190	0.322	0.000	18.486
2036	0.000	0.000	0.000	-0.139	-0.003	0.000	-0.142
2037	-0.025	0.000	0.000	-0.158	-0.001	0.000	-0.133
2038	0.025	0.000	0.000	-0.225	-0.004	0.000	-0.254
2039	0.000	0.000	0.000	-0.248	-0.004	0.000	-0.252
2040	0.000	0.000	0.000	-0.275	-0.004	0.000	-0.280

Source: HDM-4 Software

Table C- 8: Comparisons of Improvement with Base Alternative Cost of Rosevelt Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.033	0.000	0.000	0.000	0.000	0.000	-0.033
2020	0.000	0.000	0.000	4.843	0.001	0.000	4.844
2021	0.000	0.000	0.000	5.638	0.002	0.000	5.639
2022	-0.022	0.000	0.000	6.790	0.003	0.000	6.815
2023	0.022	0.000	0.000	8.472	0.005	0.000	8.455
2024	0.000	0.000	0.000	11.221	0.031	0.000	11.252
2025	0.000	0.000	0.000	13.515	0.041	0.000	13.556
2026	0.022	0.000	0.000	14.546	0.044	0.000	14.568
2027	-0.022	0.000	0.000	15.465	0.047	0.000	15.535
2028	0.000	0.000	0.000	16.457	0.051	0.000	16.508
2029	0.022	0.000	0.000	17.525	0.055	0.000	17.558
2030	0.000	0.000	0.000	18.439	0.058	0.000	18.497
2031	0.000	0.000	0.000	19.402	0.062	0.000	19.464
2032	0.000	0.000	0.000	20.336	0.066	0.000	20.403
2033	0.000	0.000	0.000	20.720	0.070	0.000	20.790
2034	0.000	0.000	0.000	11.882	0.072	0.000	11.954
2035	0.022	0.000	0.000	0.840	0.002	0.000	0.820
2036	0.000	0.000	0.000	-0.082	-0.001	0.000	-0.083
2037	-0.022	0.000	0.000	-0.138	-0.001	0.000	-0.117
2038	0.022	0.000	0.000	-0.150	-0.002	0.000	-0.174
2039	0.000	0.000	0.000	-0.219	-0.048	0.000	-0.267
2040	0.000	0.000	0.000	-0.187	-0.002	0.000	-0.189

Source: HDM-4 Software

Table C- 9: Comparisons of Improvement with Base Alternative Cost of Wendimeneh Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				
2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.013	0.000	0.000	0.000	0.000	0.000	-0.013
2020	0.000	0.000	0.000	9.514	0.010	0.000	9.523
2021	0.000	0.000	0.000	10.361	0.010	0.000	10.371
2022	-0.009	0.000	0.000	10.924	0.011	0.000	10.944
2023	0.009	0.000	0.000	11.470	0.012	0.000	11.473
2024	0.000	0.000	0.000	12.332	0.012	0.000	12.345
2025	0.000	0.000	0.000	13.196	0.013	0.000	13.210
2026	0.009	0.000	0.000	14.111	0.015	0.000	14.117
2027	-0.009	0.000	0.000	15.099	0.026	0.000	15.133
2028	0.000	0.000	0.000	16.196	0.017	0.000	16.213
2029	0.009	0.000	0.000	17.455	0.019	0.000	17.465
2030	0.000	0.000	0.000	18.519	0.109	0.000	18.628
2031	0.000	0.000	0.000	19.552	0.117	0.000	19.668

2032	0.000	0.000	0.000	20.740	0.125	0.000	20.865
2033	0.000	0.000	0.000	21.979	0.133	0.000	22.112
2034	0.000	0.000	0.000	12.975	0.140	0.000	13.115
2035	0.009	0.000	0.000	-0.319	0.000	0.000	-0.328
2036	0.000	0.000	0.000	-0.360	-0.017	0.000	-0.378
2037	-0.009	0.000	0.000	-0.521	-0.001	0.000	-0.513
2038	0.009	0.000	0.000	-0.553	-0.002	0.000	-0.564
2039	0.000	0.000	0.000	-0.562	-0.001	0.000	-0.563
2040	0.000	0.000	0.000	-0.596	-0.001	0.000	-0.598

Source: HDM-4 Software

Table C- 10: Comparisons of Improvement with Base Alternative Cost of Yohanis Street

Year	Increase in Road Agency Costs			Decrease in MT VOC	Decrease in MT Time Cost	Net Exogenous Benefit	Net Benefit
	Capital	Recurrent	Special				

2018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	0.033	0.000	0.000	0.000	0.000	0.000	-0.033
2020	0.000	0.000	0.000	4.521	0.000	0.000	4.521
2021	0.000	0.000	0.000	5.363	0.001	0.000	5.364
2022	-0.023	0.000	0.000	6.677	0.002	0.000	6.701
2023	0.023	0.000	0.000	8.763	0.004	0.000	8.744
2024	0.000	0.000	0.000	11.399	0.011	0.000	11.409
2025	0.000	0.000	0.000	13.144	0.016	0.000	13.160
2026	0.023	0.000	0.000	14.053	0.017	0.000	14.048
2027	-0.023	0.000	0.000	15.028	0.051	0.000	15.102
2028	0.000	0.000	0.000	16.080	0.055	0.000	16.134
2029	0.023	0.000	0.000	17.236	0.059	0.000	17.272
2030	0.000	0.000	0.000	18.213	0.063	0.000	18.275
2031	0.000	0.000	0.000	19.274	0.067	0.000	19.341
2032	0.000	0.000	0.000	20.385	0.071	0.000	20.456
2033	0.000	0.000	0.000	21.509	0.076	0.000	21.585
2034	0.000	0.000	0.000	21.398	0.080	0.000	21.478
2035	0.023	0.000	0.000	11.375	0.082	0.000	11.435
2036	0.000	0.000	0.000	-0.140	-0.001	0.000	-0.141
2037	-0.023	0.000	0.000	-0.151	-0.002	0.000	-0.130
2038	0.023	0.000	0.000	-0.223	-0.001	0.000	-0.247
2039	0.000	0.000	0.000	-0.244	-0.001	0.000	-0.245
2040	0.000	0.000	0.000	-0.332	-0.002	0.000	-0.334

Source: HDM-4 Software