ADDIS ABABA UNIVERSITY
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Economic Impact of Poor Pavement Maintenance in the City of Addis Ababa

(A Case Study: Megenagna - Meskel Square - Torhayloch Road)

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my advisor Dr. Alemayehu Ambo and has not been presented to any university for similar or any other degree award.

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ABSTRACT

Highway engineers are changing their attention from the construction of new roads to maintenance of the existing network. Pavement maintenance is set activities for ensuring safe, serviceable and sustainable road network till the end of the design life of pavements.

Improper maintenance, on the other hand, has the tendency to adversely affect pavement performances. Declined performance of pavements results in disruption of the traffic stream and for motorists it reduces vehicle performances. The dynamics of road deterioration have much to do with the road maintenance problem.

Maintenance deferment has huge implication in vehicle operation and on national economy. Delayed maintenance ultimately results in reconstruction which will be very expensive for a country like Ethiopia which is promisingly developing at the moment. In this regard, the adverse impact of maintenance deferment is the focus of this research.

This paper characterizes poor maintenance in terms of delayed application of the required maintenance activities and in accurate forecasting of traffic flow. For studying these effects, a principal arterial road along the east-west corridor of Addis Ababa was chosen. The road network starts from Megenagna passes through Meskel Square and terminates at Torhayloch. This network covers about 8.2 kilometer length.

Adequate and regular maintenance requires securing of sufficient funding before repairs and maintenance become an urgent issue. Economic decisions are needed in a highway system to account for the total cost of transportation on the road section: the discounted life-cycle cost of constructing and maintaining the roads and far larger cost of operating vehicles on these roads. This research assesses the economic impact that comes as a result of poor maintenance activities. The research uses Highway Development and Management model to measure the impact quantitatively. The model integrates road network conditions, vehicle characteristics and maintenance programs and finally generates a summary of the economic indicators. The result reveals; in relation to timely maintenance, delayed maintenance brings NPV of Birr -194.79

million and in relation to accurate traffic demand, improper forecasting of traffic flow demand brings NPV of Birr -193.7 million.

In conclusion, it is no wonder that proper maintenance action has the capability to extend the service life of road infrastructures. However, if such maintenance neglect continues, it will not only reduce service levels and accessibility but also hugely increase the whole lifetime cost of the transport infrastructure. This eventually incurs negative impact in overall economic growth of the country.

Key Words: Pavement Performance, Poor Pavement Maintenance, Economic indicators, Economic impact

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LIST OF ACRONYMS

AACRA	Addis Ababa City Roads Authority
AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
AASHTO	American Associate of State Highways and Transportation Officials
BCR	Benefit to Cost Ratio
ERA	Ethiopian Roads Authority
ETB	Ethiopian Birr
EIRR	Economic Rate of Return
HCM	Highway Cost Model
HDM	Highway Development and Management
NPV	Net Present Value
OCC	Opportunity Cost of Capital
PAS	Principal Arterial Street
PSR	Present Serviceability Rating
SAS	Sub-Arterial Street
VOC	Vehicle Operating Cost

CHAPTER ONE

INTRODUCTION

1.1 Background

Road pavements deteriorate as a result of many factors. Most commonly recognized are traffic loading, environmental weathering and effect of inadequate drainage system (H. R. Kerali 2000). No matter how well the pavement is built, it will deteriorate over time based upon the mentioned factors. Before any of these factors bring a significant damage to the pavement structures, it is important to take actions of maintenance.

Pavement performance, therefore, depends on what, when and how maintenance is performed. The rate of pavement deterioration is directly affected by the standard of maintenance applied to repair defects on the pavement surface (Callao and Rodrigo 1999). Adequate maintenance ensures infrastructures in general, road infrastructures in particular, to be sustainable over the design service time.

Highway maintenance is essentially done to preserve the roadway condition so that safe, convenient and efficient movement of people and goods will be addressed. It contributes to deliver a serviceable and sustainable road network system with reference to asset management, integrated transportation, corporate policy and continuous improvement (Walsall 2015).

Deficient maintenance together with poor network management have the capability to let the transportation infrastructures prematurely deteriorate: resulting in spiral increasing of travel and repair costs, deteriorating levels of service and denial of access. Deteriorated pavements drive the potential to reduce vehicle performances for motorists and also disrupt the traffic stream. The dynamics of road deterioration have much to do with the road maintenance problem (Gould, Parkman and Buckland 2013). For healthy and dependable road traffic environment in any country, adequate maintenance is a must to apply (Office of the Road Fund Administration 2001).

In cities like Addis-Ababa, where there is rapid population growth, increased number of motorization, high rate of urbanization, the demand for quality service roads is an urgent question to address.

Journey quality in respect of comfort is likely to decrease along with the neglect to preserve the road condition. Majority of motorists, or drivers, decrease their driving speed as the result of their perception of the roadway condition. Improving the transportation service to comfortable, safe, dependable and efficient state help the city of Addis Ababa to accelerate its development and make it competent city on regional, continental and international levels.

According to (Adlinge and Gupta 2010), the time when the maintenance action is to be carried out is very critical. With this regard the (Nebraska Department of Roads 2002) states that: “The selection of the right maintenance strategy at the right time is of utmost importance for an effective management of highway pavements. The appropriate maintenance strategy will be influenced by the type, severity and extent of the pavement surface distresses and the structural and roughness condition of the pavement’’.

Benefits gained from proper and timely maintenance action do not only end on providing improved customer service but also substantial life cycle cost savings (Johnson 2000).

On the contrary; poor maintenance scheme, characterized by delay in taking the action of maintenance and inappropriate forecasting of traffic loading and other external factors, put additional costs to road users and society as a whole.

In developing countries, where the traffic growth and axle loading is growing at logarithmic scale, deterioration of highways is very fast (Jain, Jain and Chauhan 2013). During the process of road network maintenance and rehabilitation, road authorities strive to select an optimum maintenance strategy from a number of alternatives. Otherwise it will result in significant financial penalty in the future (Gould, Parkman and Buckland 2013).

According to the (World Bank 1988) policy study, “Economic decisions about a highway system must take into account the total cost of transport on the roads: the discounted life-cycle cost of constructing and maintaining the roads and far larger cost of operating vehicles on these roads. These costs must be estimated on the basis of sound knowledge about road and traffic conditions and the interactions between them, as well as the applicability of different maintenance techniques in different environments.”

The estimation of all costs which are essential for maintaining pavement investment at a desirable specified level of service or at a specified rate of deteriorating service is essential to a proper economic analysis (AASHTO 2007). Basic understanding of various economic principles will aid transportation professionals in anticipating the direction and general magnitude of pavement investment works. Such understanding helps identify key project impacts and leads to more educated and robust decision-making (Kockelman, et al. 2013).

1.2 Statement of the problem

The prime purpose of constructing roadway is to provide the society with safe, efficient, comfortable and environmentally friendly transportation services. A failure to provide these features will bring negative impacts and difficulties on day to day activities of the road users.

Surface deterioration (roughness) of roads in Addis Ababa represents one of the major complaints of the citizens. Riding quality automatically drops to a minimum associated with the conditions of the roadways. As a result of their perception to the roadway condition, journey time increases, travel speed decreases, there will be denial of access and to those who are engaged in business, just in time delivery of goods and services will be impaired. As the problem is lacking immediate solution, productivity of people using the road declines accordingly.

User costs are also based on increased cost of operating vehicles in respect of: vehicle depreciation, fuel and lubricant oil consumption, tire consumption, etc. Vehicles consume more fuel when travelling through poorly maintained road section than normal road condition. Even if drivers choose detours to avoid delays, they will be forced to travel a greater distance which still increases their fuel consumption and other associated factors.

An increase in lifecycle costs is a long term effect of maintenance deferment. A reason more frequently raised from road agencies relating to improper maintenance is limitation of budget. However, much simpler treatments carried out earlier avoid greater costs in the future. Because, as time goes by; roads fail rapidly and maintenance costs increase unbearably to an unaffordable level.

Delays to maintenance also lead to a poorer level of service, which imposes social and environmental costs on users and wider society. Congestion, Vehicle emission, energy consumption, noise and air pollution are the dominant factors associated in this scenario.

Road construction being the most important enabler in social, economic and political development of the country, roadway conditions need to be found on better level of service and quality standard. Urban development and urban economy is directly linked to the standard of the road conditions. Especially for Addis Ababa, capital city of the country and a seat for over 120 missions and embassies, the problem is nonnegotiable.

1.3 Objectives

1.3.1 General Objective

The prime objective of this research is to assess the potential economic impact of poor road maintenance that comes from delay in maintenance and inappropriate forecasting of the traffic demand, associated with pavement deterioration.

1.3.2 Specific Objectives

The research has the following specific objectives.

- To study the existing condition of the subject road surface
- To carry out distress identification work on existing study road section
- To study the rate of deterioration of the existing subject pavement section
- To evaluate the current method of the Addis Ababa City Roads Authority toward maintaining the city’s road infrastructures
- To identify a certain section of a road in Addis Ababa and briefly carryout benefit-cost analysis by considering timely maintenance as without project case and delayed maintenance as with project case in the analysis using the Highway Development and Management (HDM 4) Tool; and
- Based on the outputs of the analysis and discussions, rational recommendations will be forwarded.

1.4 Research questions

In order to do the research, research question need to be developed and reliable answers must be obtained. The following are possible research questions:

- What are the common types of pavement failures in the city of Addis Ababa?

- How often maintenance activities do take place?
- Do maintenance activities take in to account the future demand?
- What are the probable costs that the road users pay as a result of un-maintained roadways?
- What are the economic benefits and costs in timely maintaining of roadways?

1.5 Scope and limitation of the study

The research analyzes the economic impact that arises from poor pavement maintenance action. In the research, it was tried to focus on the time issue and on traffic demand aspect.

Due to time and financial constraint, the research is limited on a particular principal arterial road class of the Addis Ababa City. The road class accommodates large volume of traffic compared to other roads in the city. Among the principal arterial road classes, the selected road section is the Megenagna – Meskel Square – Torhayloch route.

Unavailability of adequate documented information and the unwillingness in giving technical data by the construction firms has limited the preparation of this research to the envisaged level.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Road construction has evolved with the social development of mankind. Interaction of people through trade, commerce and other activities increased as the results of the increased infrastructures, most notably road infrastructure (Garber and Lester 2009). However to attain the desired level of service, the road design should adhere to appropriate standards for design, construction and maintenance procedures (Ethipian Roads Authority 2013).

Transportation, an integral part of the economy and changes are likely to impact the economy in many ways. Many studies claim that transportation investments are the life blood of the economy and serve as engines that fuel economic growth**.** (Kockelman, et al. 2013) stated that, road building and road maintenance, in Sub-Saharan Africa, are among the largest public investments estimated around US $7 billion annually. Their goal is not only to serve the immediate customers but also the community at large - through positive economic impacts.

In Ethiopia; road networks, nowadays, are given much emphasis and also large scale constructions are undertaking in many parts of the country. Road transport, the dominant mode for freight and passenger mobility, accounts 90 to 95 percent of all motorized inter-urban movements in Ethiopia and thus it takes a considerable part in the economic development of the country (Worku 2011).

Huge national assets and resources are invested during the construction as well as the maintenance and rehabilitation of road infrastructure in Ethiopia. Securing effective mode of transport within the country, especially through quality roads, enabled entrepreneurs to get their goods and services to markets in a secure and timely manner, facilitate the movement of workers to the workplace and encourage foreign direct investment (Ondiege, Moyo and Verdi 2013). This investment on transportation infrastructure plays a greater role in the city from travel time saving to job creation and from income growth to property value changes.

2.2 Pavement Distress

2.2.1 Definition

(Hass and Hudson 1978) defined pavement distress as damage or defects visible on the pavement structure. They are symptoms indicating problems of deterioration like cracks, potholes, rutting etc.

Detail information on pavement distress need to be assessed to properly rate and distinguish the individual types, severity levels and extent of the distresses. Authorized agencies routinely gather theses data in the form of condition survey. Collected data are further analyzed to ascertain whether certain types of pavement distress are progressive, leading to eventual failure of the road or whether they are non-progressive (Hajek and Hass 1987).

As (Hass and Hudson 1978) stated “Pavement failure occurs when the accumulated distress reduces the serviceability level below an acceptable level for the users of the facility”. It has long been recognized that pavement distresses are the major factors in causing serviceability loss.

Accumulated damage on pavement sections is, thus, monitored and evaluated for the purpose of ensuring its service life. Maintenance program is developed based on the ongoing performance of the road section and subsequently, it predicts future pavement condition and measures long term needs in accordance with economic objective of the infrastructure (Hass and Hudson 1978).

2.2.2 Flexible Pavement Distress

Flexible pavement is one category of pavement classification on which it has low flexural strength and the load is largely transmitted to the subgrade soil through the lateral distribution of stresses with increasing depth.

Common distresses under flexible pavement are generally grouped in to four major parts (Pavement Management Unit 2003) as follows.

i. Cracking;
ii. Distortion;
iii. Disintegration; and
iv. Slipperiness.

i. **Cracks**: are caused by deflection of the surface over an unstable subgrade, shrinkage of the surface, thermal expansion and contraction of the surface, poorly constructed lane joints or reflection cracking.

The following are examples of cracks that may occur in flexible pavements (Chowdhury 2012).

a. **Alligator / Crocodile Crack** - Interconnected cracks forming a series of small blocks resembling chicken wire. It's usually caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually the cracks lead to disintegration of the surface.

Figure 2-1: Picture of Alligator Crack

b. **Edge Cracking –** Cracks developed about 0.3m from the edge of pavements. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture. There will be settlement or yielding of the base material underlying the cracked area.

Figure 2-2: Picture of Edge Crack

c. **Block Cracking –** Interconnected cracks forming a series of large blocks, usually with sharp corners or angles. They are usually caused by volume change in the asphalt mix or in base or subgrade.

Figure 2-3: Picture of Block Crack

d. **Transverse/ Longitudinal Cracking –**

- **Transversal cracking** - Transverse cracks form at approximately right angles to the centerline of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced. They usually begin as hairline or very narrow cracks and widen with age.

- **Longitudinal Cracking -** Longitudinal cracks are long cracks that run parallel to the center line of the roadway. These may be caused by frost heaving or joint failures or they may be load induced.

e. **Reflective Cracking -** Reflective cracking occurs when a pavement is overlaid with hot mix asphalt concrete and cracks reflect up through the new surface. It is called reflective cracking because it reflects the crack pattern of the pavement structure below

ii. **Distortion**: is the result of weakness in one or more layers of the pavement that has experienced movement after construction. Surface distortions can be a traffic hazard and it may be accompanied by cracking.

The following types of distress are classified as distortion.

a) **Rutting** - is the displacement of pavement material that creates channels in the wheel path. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a subgrade failure.

b) **Corrugation** – is a plastic movement typified by ripples across the pavement surface. The instability of the asphalt concrete surface course may be caused by too much asphalt cement, too much fine aggregate, or rounded or smooth textured coarse aggregate. Corrugations usually occur at places where vehicles accelerate or decelerate.

c) **Shoving** – it is also a form of plastic movement in the asphalt concrete surface layer that creates a localized bulging of the pavement. Locations and causes of shoving are similar to those for corrugations.

d) **Depression** - are small, localized bowl-shaped areas that may include cracking. Depressions cause roughness, are a hazard to motorists, and allow water to collect. Depress It is caused by traffic heavier than that for which the pavement was designed, by poor construction methods, or by consolidation deep within the subgrade.

iii. **Disintegration:** The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the disintegration is not repaired in its early stages, complete reconstruction of the pavement may be needed.

The two most common distresses under this classification are;

a) **Potholes -** Potholes are bowl shaped holes resulting from localized disintegration, due to too little asphalt, too thin asphalt surface, too many fines, too few fines, or poor drainage.

b) **Raveling/ Stripping –** are progressive loss of surface material by weathering and / or traffic abrasion. It is a result of insufficient adhesion between the asphalt cement and the aggregate.

iv. **Slipperiness:** Surface defects that are related to problems in the surface layer that are in this group. The most common types are discussed below (Chowdhury 2012)**.**

a. **Bleeding -** Bleeding is defined as the presence of excess asphalt on the road surface which creates patches of asphalt cement. Excessive asphalt cement reduces the skid-resistance of a pavement, and it can become very slippery when wet, creating a safety hazard. This is caused by excessive high asphalt cement content in the mix, using asphalt cement with too low a viscosity, too heavy a prime or tack coat or an improperly applied seal coat.

b. **Polishing -** Polishing is the wearing of aggregate on the pavement surface due to traffic. It can result in a dangerous low friction surface. A thin wearing course will repair the surface.

2.3 Pavement Performance

Pavement condition assessment is a general approach to identify critical areas noted with pavement distresses such as: cracks, potholes, rutting etc. when developing road network maintenance program (Koch and Brilakis 2011). If the road quality could not be established satisfactorily, this should be highlighted in the performance evaluation (Hoban, Riverson and Weckerle 1994).

Pavement performance is defined as the ability of a pavement to satisfactorily serve traffic over time (Ercisli 2015). It should indicate the amount of traffic carried at an acceptable level of service. When this is not well addressed pavements change their condition or serve their intended function with accumulating use. Traffic flow will decrease as a result of this phenomenon and economic activities go down as well (Abell, et al. 2012).

Performance, at project level, is also defined by the distress, loss of serviceability index and skid resistance, loss of overall condition and by the damage that is done by the expected traffic. From view point of road users, pavement provides a particular level of service at any point in time. This leads pavement performance to have a direct link with the concept of present serviceability (Irick 1989).

If the concept of present serviceability is to be useful for describing pavement performance, then users can presumably discern various levels of serviceability among pavements whose physical conditions cover the full spectrum of interest. The present serviceability rate (PSR) of a pavement is a user's judgment of the level of service that a particular pavement provides at a point in time. Table 2-1 below shows the results of the AASHTO PSR indices. Raters were asked to judge present serviceability in 1 of 5 categories (Irick 1989):

Table 2-1: AASHTO Present Serviceability Rating Indices

Categories	Remark
4.0 to 5.0	Very Good
3.0 to 4.0	Good
2.0 to 3.0	Fair
1.0 to 2.0	Poor
0.0 to 1.0	Very Poor

Source: (Irick 1989)

In fact, performance of the pavement depends not exclusively on the design concepts that were used. The success of any design is largely dependent on subsequent construction, maintenance and rehabilitation works. Maintenance phase, such as: the establishment of a program and schedule of repair work, the actual operations of crack filling, patching and so forth, supports the road section in recovering to its good condition.

The major purpose of monitoring pavement performance is to objectively examine and determine the current condition of pavements. Performance improves various features of a project in improving the ongoing and the future planning. It, later, assesses if objectives set out during appraisal have been met (Kerali, McMullen and Odoki 2000).

2.4 Pavement Maintenance

2.4.1 Definition

The term 'maintenance' is defined in a different way by different transportation officials. However, for the aim of formulating analysis towards the effects resulting from poor pavement maintenance, a clear and unambiguous explanation is required.

(INHOFE 2005) defined the term maintenance "as the preservation of the entire highway, including surface, shoulders, roadsides, structures, and such traffic-control devices as are necessary for safe and efficient utilization of the highway".

According to (AASHTO 2007) "Highway maintenance encompasses a program to preserve and repair a system of roadways with its elements to its designed or accepted configuration and to an accepted quality of performance."

Adequate maintenance plans are pre-requisites for sustainable infrastructures (Ondiege, Moyo and Verdi 2013). Different techniques and methodologies are applied just to enhance the life of the pavement and delaying its failure. When roads are nearing the end of their lives, proper maintenance ensures relieving traffic congestion, enhances road safety and also to accommodate increased vehicle axle loads, etc. (H. R. Kerali 2000).

Pavement maintenance basically hold the objective of delivering safe, serviceable and sustainable network, taking in to account the need to contribute to the wider objectives of asset management, integrated transport, corporate policy and continuous improvement (Adlinge and Gupta 2009).

Maintenance reduces the rate at which the pavement deteriorates. The overall long term condition of asphalt road pavement is directly related to the maintenance standard applied to the road. In physical sense, maintenance action consists of set of activities which relate to the problems encounter during the life time of the pavement (Hass and Hudson 1978).

For operational convenience, road maintenance is categorized in to three. Such as;

i. Preventive maintenance;
ii. Corrective maintenance; and
iii. Emergency maintenance.

Figure 2-4 below clearly shows the differences among these three categories of road maintenance operations. As indicated on this picture, the main difference is the condition of the pavement when the treatment is applied.

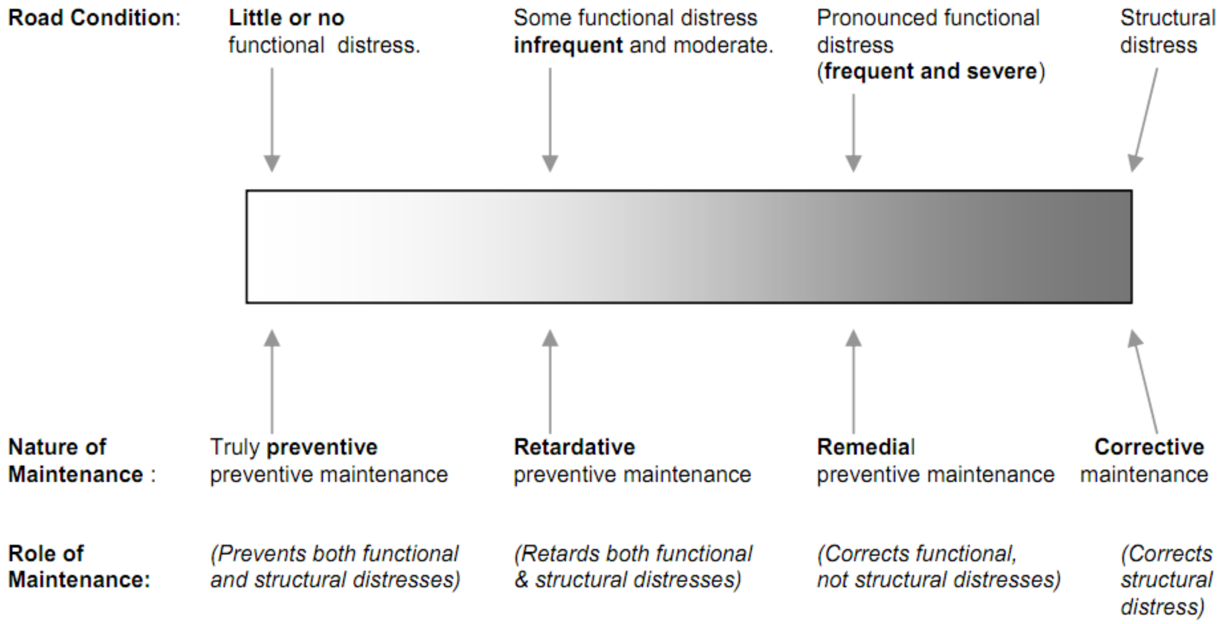

Figure 2-4: Maintenance Spectrum

Source: (Labi and Sinha 2003)

2.4.2 Maintenance Management

According to the definition given by (Hass and Hudson 1978), “A maintenance management system is an operational methodology for managing or directing and controlling maintenance resources for optimum benefit.”

Since maintenance activities thrive for keeping a structure in a serviceable state, the type and degree of maintenance emphasizes various serviceability levels of a pavement. The economic and efficient practice with regard to serviceability level is ensured through maintenance phase in the pavement management system.

Maintenance management and pavement management concepts are two complementary ideas. They reinforce and supplement each other rather than interfere. Pavement maintenance management is, thus, a necessary tool for analyzing and predicting the effects of various maintenance policies.

Figure 2-5 below shows the functional extent of maintenance management in the pavement system (Hass and Hudson 1978).

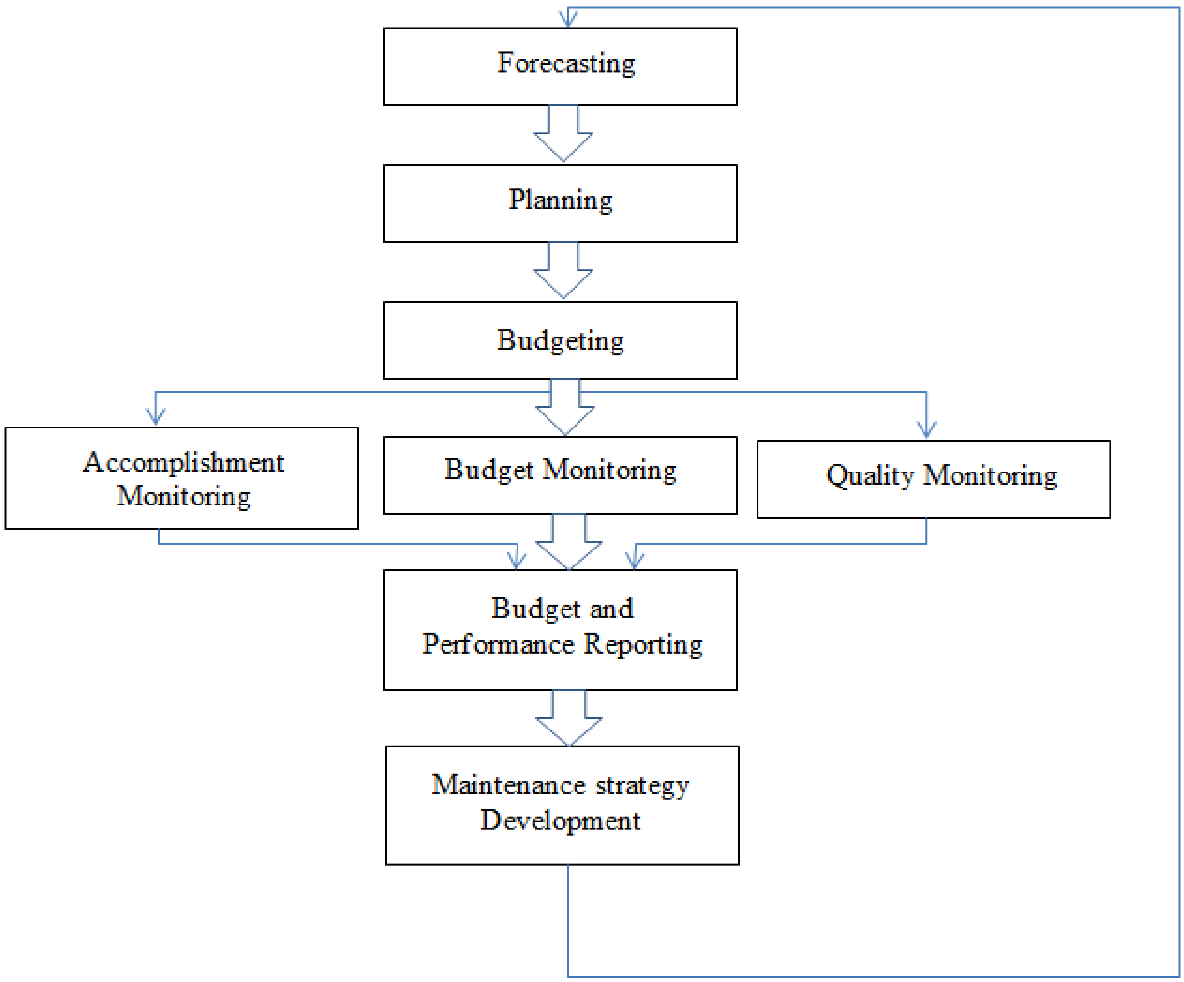

Figure 2-5: The Essential Functions of Maintenance Management

2.4.3 Poor Pavement Maintenance

(Whelan and McCurdy 1996) arguably states that the biggest technical challenge facing highway engineers today is not the construction of new roads but maintenance of the existing network. Pavements must be selected for maintenance when they are still effective; before the need is apparent to the casual observers in order to avoid the rapid deterioration after certain limit (Gedafa 2006). Sustainability of transport infrastructure is threatened by inadequate maintenance together with insufficient enforcement of transport regulations. Recurrence of pavement damage and further disruption to traffic soon after completion of repair work is becoming more common nowadays.

Without proper maintenance the high value of any road network can be quickly eroded and road users and society can experience significant adverse impacts if a road condition is in poor state. Inadequate maintenance affects not only the present generation but places undue burden on future generation (World Road Association 2014).

It is no wonder that proper maintenance action has the capability to extend the service life of infrastructures. However, if such maintenance neglect continues, it will not only reduce service levels and accessibility but also hugely increase the whole life costing of the transport infrastructure (John Clifton, et al. 2016). Thus benefits, returns, satisfaction, or progress towards stated objectives to be acquired through the work of maintenance could not be achieved.

This paper characterizes poor maintenance in terms of time and load aspect. The subsequent sections discuss these two factors in a greater detail.

2.4.3.1 Delayed Maintenance

It is quite known that maintenance activities are continual processes performed in order to retard or correct the deterioration of infrastructure facilities. With special focus to road projects, this aim can adequately be achieved only if the work is done according to the established time of work, before major rehabilitation is needed on the road section.

“Timing” of maintenance activities refers to the frequency of application or the distress occurrence threshold to trigger application (Labi and Sinha 2003). Timely attention is much vital for effectively addressing the purpose of maintenance in the way it keeps road assets in a good state of repair and reduce or delay further degradation. On the other hand, inappropriate repair (with regard to time issue) can actually accelerate the rate of distress development. This is because once pavements start to deteriorate; they deteriorate rapidly beyond the point where maintenance is effective.

It is also important to investigate any tradeoffs between maintenance and the frequency of capital investments. Timely attention to maintenance reduces the expenditure needed to sustain the road system in the long term, saves significant future costs (World Road Association 2014). “While this incurs earlier costs it can avoid greater costs in the future and therefore reduce net present costs to the highway authority. Also, planned programs of work can allow for more efficient procurement and consequently reduce unit costs. Any assessment of costs and benefits arising from changes in highway maintenance spending; need to take these effects into account" (Gould, Parkman and Buckland 2013).

2.4.3.2 Traffic Demand

Traffic demand is "the amount of traffic volume (flow rate) that occurs on pavement facilities under some given set of travel conditions." When not constrained by a highway's capacity, the actual flow rate measured on the highway will equal its demand.

Transport demand is characterized by its variability in time and space and further differentiated according to trip purpose and type of passenger (Zegras and Litman 1997).

Ensuring accurate quantity and stability of current and future demand for traffic products have significant influence on the construction and improvement of available traffic capacities, which in turn provides conditions for new increase in transport demand.

Traffic forecasts are used to determine the capacity of transport infrastructure. Both the over- and underestimation of traffic levels can have severe implications. (Welde and Odeck 2011). In the case of traffic underestimation, the capacity relief on the congested links could turn out to be lower than planned, inefficient and inaccurate sizing of the road comes as a result. Social viability of such projects declines resulting in implementation of non-viable projects. The end result may be inefficient resource allocation because, if the income estimates in the transportation models are underestimated, traffic may also be underestimated.

Ever increasing levels of pavement loading is a source of concern to highway pavement managers, as average daily loads on highway pavements continue to increase year after year. This demand results in more traffic flowing through the road network, which increases the structural strength deterioration rate and therefore worsen the actual structural strength of the network (Labi and Sinha 2003). It has a degrading effect on the condition of the road. Heavy traffic in particular weakens structural strength and accelerates deformation and the creation of ruts, while traffic in general affects negatively the road texture, and accelerates the creation of ruts and cracks.

Longer period of economic growth explains for higher traffic levels than estimated. Because transport is a derived demand, accurate estimation of traffic flow relies on the forecasts of a range of other parameters (Boyce and Bright 2003).

2.5 Economic Evaluation

(Odoki and Kerali 2000) discuss that "Economic evaluation by its definition is to check whether the project is economically viable or not. It investigates technical standards and strategies to be followed by a particular investment decision".

Economic evaluation comprises series of approaches to know if the stated objectives are met. The evaluation gives directions for specific recommendations about improving aspects of the project design that can be used to improve the ongoing and future planning (Kerali, McMullen and Odoki 2000).

With regard to road infrastructures, economic evaluation and screening is mostly put for the reason of optimizing road spending based on rational and well-explained criteria (Hoban, Riverson and Weckerle 1994). Particularly in pavement design, alternative costs and benefits are assigned to predict outputs, in terms of material, construction, maintenance, and others. Then the total cost and benefit of the project will be assessed in the evaluation process (Hass and Hudson 1978).

When roadways deteriorate they put extra costs on the road users. Transportation operations will ultimately drops down as a result of this. It is understood that deferment of road maintenance work leads to higher costs to the road user in addition to its effect on the loss of the limited resource outlay to preserve the road network asset of the country (Office of the Road Fund Administration 2001). Economic evaluation considers all the agency costs together with user costs and provides management with a basis for decision making.

2.5.1 Economic Principles

Principles of engineering economy to transport projects are applicable at two levels. First is at the management decision required to determine the feasibility and timing of the project. Second is to maximize economy once the project is certified as a feasible project.

Basic engineering economy principles are summarized as follows (Hass and Hudson 1978):

- Economic analysis provides the basis for a management decision but does not itself represent a decision. Again, it has no relationship to the source of financing a project. Such financing considerations can either limit the number of feasible projects or the amount of particular projects.
- An economic evaluation should consider all possible alternatives, within the constraints of time and other planning and design resources. This includes the need for comparing alternatives not only with a base or existing situation but also with each other.
- All alternatives should be compared over the same time period. This time period should be chosen so that the factors involved in the evaluation can be forecast with some reasonable degree of reliability. Uncertainties can be considered in the decision made to choose the best alternative.
- The economic evaluation of pavements should include agency costs and user costs. The major costs that public agency may consider in the economic evaluation includes:
    - ➢ Agency costs
        - ✓ Initial capital cost of construction
        - ✓ Future capital cost of construction/rehabilitation
        - ✓ Maintenance costs, recurring throughout the design period
        - ✓ Salvage return or residual value at the end of the design period
    - ➢ User costs
        - ✓ Travel time
        - ✓ Vehicle Operation
        - ✓ Accidents
        - ✓ Discomfort
        - ✓ Time delay and extra vehicle operating costs during major maintenance

According to (Labi and Sinha 2003), effectiveness in the evaluation resides either by seeking the maximum benefits for a given level of investment (maximum benefit approach) or by seeking the least cost for effective treatment of problems (least cost approach). The least cost approach is considered more appropriate for evaluation of maintenance investments.

2.5.2 Economic Indicators

Economic indicators are fundamental components on determining how the economy is performing. This section on the whole reviews approaches to the economic analysis of transport projects, focusing on road maintenance projects and providing a detailed illustration of how to conduct an appraisal. They measure the overall performance of projects that economic decision passes through these indicators whenever a project or investment is going to undertake. The major indicator used in road projects is briefly are discussed below.

Net Present Value (NPV)

Net present value of a project is a change in an investment economy/cash flow where time value of money is taken in to consideration. It equals to the present value of net cash inflows generated by a project less the initial investment on the project.

$$\mathbf{NPV = PV - I} \qquad \dots .. (2.1)$$

Where: NPV = Net Present Value

PV = Present Value

I = Initial Investment

Net Present value can be defined by taking all future cash flows discounted at a rate to determine the present value (Asma Arshad 2012). It is calculated as:

$$\mathbf{NPV} = -CF_o + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots\dots\dots\dots + \frac{CF_n}{(1+r)^n} \qquad \dots .. (2.2)$$

Where: NPV = Net Present Value

CF_o = Initial investment/ cash flow at the beginning

CF_n = Cash flow at a respected year

r = Discounting rate

n = Time in years

In NPV analysis, the cash flows are reinvested at a constant rate. The higher the discount rate, the lower the present value of the future cash flows.

The final result of the analysis describes the value of investment in amount and if the project shows a positive result then that project is accepted as net present value shows more value than the project’s initial cost (Asma Arshad 2012).

NPV is superior and most preferable to the original approach which is the consideration of benefit-cost ratios, because it has no serious flaws. Furthermore, the method of NPV unambiguously ranks mutually exclusive projects, and it can differentiate between projects of different scale and time horizon (Spears 2017). It is a very simple and most reliable measure in capital budgeting. The decision maker will have an objective picture from the result of the analysis (Peter Temple 2003).

Analysis Year

Analysis year is the time horizon considered during the service life of the pavement. It is commonly accepted to cover a time period until the pavement needs major rehabilitation (West 2014). Figure 2-6 clearly shows the overall time horizon over which analysis period of pavement structure covers.

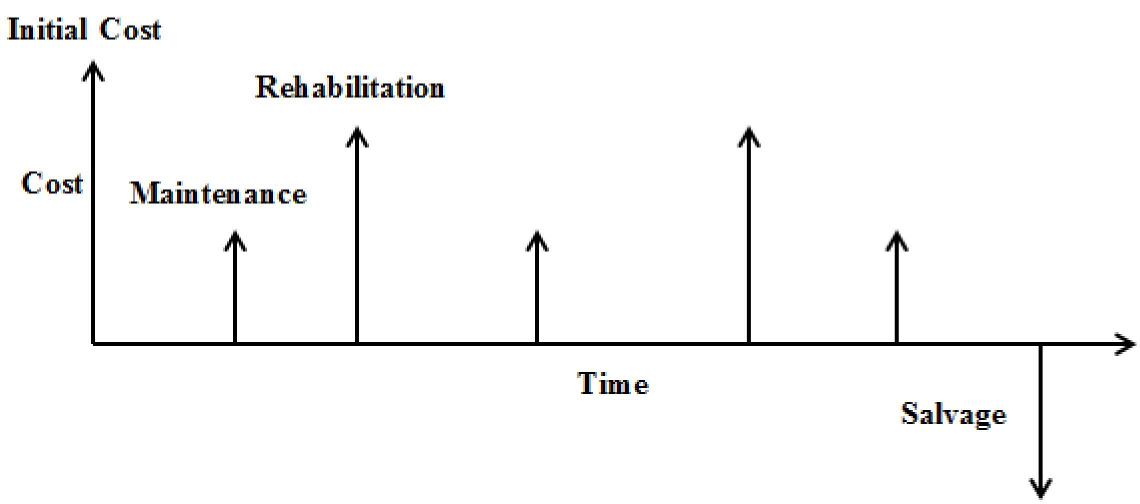

Figure 2-6: Time horzon over which pavement construction covers
(Source: (West 2014))

“Rehabilitation techniques include restoration treatments and structural overlays. It is inferred that for asphalt pavements, rehabilitation includes structural overlays with or without milling, and for concrete pavements includes a wider range of activities such as full-depth slab removal and replacement, under-sealing, dowel-bar retrofit, HMA overlays, and bonded concrete overlays. No distinction is made as to which activities are considered “major” rehabilitation. (Musselman 2015)”

Discount rate

Highway projects incur costs at various stages of their lifecycles, including initial construction costs, rehabilitation, maintenance, and salvage. To assess the costs of a project, an analyst must equate costs from present years and future years into like terms. Discounting transforms future costs and benefits occurring at different years to a common point in time.

A discount rate translates future values influenced by the time value of money to constant terms. A real discount rate reflects only the effects of the time value of money and results in a lower, current number when multiplied by a higher future value. The NPV of investments is adjusted to constant terms using a discount rate, shown as Equation (2.2).

Salvage Value

Salvage value refers to the net worth of the pavement at the end of the analysis period (West 2014). The salvage value is a negative vector in the calculation of the NPV. It has an alternative often has two components. A "residual value" refers to the value received from liquidated the investment (for example, selling the asset via recycling). The investment may also have still function, and thus should be credited with "serviceable life" value. The salvage value would thus be the sum of these components. The NPV of salvage for pavements is often considered to be insignificant because it is discounted for several decades (Musselman 2015).

2.6 Highway Development and Management Tool (HDM-4)

2.6.1 Introduction

The Highway Development and Management model, also referred to as HDM-4 is a computer model developed by the World Bank, primarily used as a planning and programming tool for highway expenditures and maintenance standards. The model consists of various applications which are useful for analysis of road management and investment alternatives. It has been used to investigate the economic viability of road projects in over hundred countries and to optimize economic benefit to different road users under different level of expenditure (Bennett and Paterson 2000).

Early versions of HDM (HCM and HDM-II) relied on simple empirical regression models that were built on field data collected at specific study sites. However, these simple models lacked transferability because they could not show how the results would change when there was a change in the assumed conditions. In the development of HDM-III and HDM-4, a high degree of transferability across different technological and climatic conditions was built into the model. HDM-4 in particular comprises new features such as;

- Effects of traffic congestion on speed, fuel, tires and maintenance costs
- Non-motorized transport modeling
- Traffic safety impact
- Vehicle emissions impact

The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. It performs comparative cost estimates and economic analysis of different investment options in a more advanced way than the traditional project appraisal method (H. R. Kerali 2000). The model estimates the costs for a large number of alternatives year by year for a user defined analysis period, discounting future costs, in which detailed specifications of investment programs, design standards and maintenance alternatives are needed, together with unit costs, projected traffic volumes and environmental conditions.

"In HDM-4, maintenance standards are used to represent the targets or levels of condition and response that are aimed to be achieved. Maintenance standards define the maintenance works required to maintain the road network at the target level. Each maintenance standard consists of a set of one or more works items. Each work item is defined in terms of the road surface class to which it applies an intervention level, an operation type, and the resultant effect on the pavement. Routine and periodic maintenance are the two kinds of maintenance treated in HDM-4. Both maintenances can be carried out based on scheduled and condition-responsive except inlays, in which it is always defined in terms of condition-responsive works" (Odoki and Kerali 2000).

Besides economic evaluation, HDM-4 undertakes technical evaluation using four sets of models:

- Road Deterioration (RD): Predicts pavement deterioration for bituminous, concrete and unsealed roads;
- Work Effects (WE): Simulates the effects of road works on pavement condition and determines the corresponding costs;
- Road User Effects (RUE): Determines costs of vehicle operations, road accidents and travel time; and

- Social and Environmental Effects (SEE): Determines the effects of vehicle emissions and energy consumption.

2.6.2 HDM-4 Application

The highway management process is considered as a cycle of activities that are undertaken within each of the management functions of planning, programming, preparation and operations. Upon considering HDM-4 application, it is advantageous to view the highway management process in terms of Strategic analysis, Program analysis and Project analysis.

(i) Strategy Analysis

Strategy analysis may be used to analyze a chosen network as a whole, to prepare medium to long range planning estimates of expenditure needs for road development and conservation under different budget scenarios. Strategic planning of medium to long term road network expenditures requires that a road organization should consider the requirements of its entire road network asset. Thus, strategy analysis deals with entire networks or sub-networks managed by one road organization.

In order to predict the medium to long term requirements of an entire road network or sub-network, HDM-4 applies the concept of a road network matrix comprising categories of the road network defined according to the key attributes that most influence pavement performance and road user costs. Road user costs, per see, comprise:

- Vehicle operation costs (fuel, tyres, oil, spare parts, vehicle depreciation, utilization, etc.);
- Costs of travel time - for both passengers and cargo, due to road condition and traffic congestion (Hoban 1987); and
- Costs to the economy of road accidents (i.e., loss of life, injury to road users, damage to vehicles and other roadside objects).

Under strategic analysis, it is assumed that the environment throughout the study area is similar and that the road administration is responsible for one road class. The resulting road network matrix comprises (3 x2 x 3 =) 18 representative pavement sections. i.e.

- Three traffic categories (high, medium, low);
- Two pavement types (asphalt concrete, surface treatments); and

- Three pavement condition levels (good, fair and poor).

Typical applications of strategy analysis by road administrations would include:

- Medium to long term forecasts of funding requirements for specified target road maintenance standards
- Forecasts of long term road network performance under varying levels of funding
- Optimal allocation of funds according to defined budget heads; for example routine maintenance, periodic maintenance and development (capital) budgets
- Optimal allocations of funds to sub-networks; for example by functional road class (main, feeder and urban roads, etc.) or by administrative region
- Policy studies such as impact of changes to the axle load limit, pavement maintenance standards, energy balance analysis, provision of NMT facilities, sustainable road network size, evaluation of pavement design standards, etc.

(ii) Program Analysis

This deals primarily with the prioritization of a defined long list of candidate road projects into a one-year or multi-year work program under defined budget constraints. It is essential to note that here; we are dealing with a long list of candidate road projects selected as discrete segments of a road network. The selection criteria will normally depend on the maintenance, improvement or development standards that a road administration may have defined (for example from the output produced by the strategy analysis application).

It should be noted that the main difference between strategy analysis and program analysis is the way in which road links and sections are physically identified. Program analysis deals with individual links and sections that are unique physical units identifiable from the road network throughout the analysis. In strategy analysis, the road system essentially loses its individual link and section characteristics by grouping all road segments with similar characteristics into the road network matrix categories.

(iii) Project Analysis

A project is defined as the set of road works to be carried out on one or more road sections that can be grouped together conveniently to be undertaken as one contract or work instruction.

Evaluation of these road projects or investment options is, thus, carried out under project analysis.

Project analysis is concerned with evaluation of one or more road projects or investment options. The application analyses a road by link or by 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. Moreover, it allows users to assess the physical, functional and economic feasibility of specified project alternatives by comparison against a base case, or without project alternative.

Project analysis estimates the economic or engineering viability of road investment projects by considering the following issues:

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

Project analysis is concerned with the following types of road projects.

- Maintenance of existing roads
- Improvement of existing roads
- New construction
- Stage construction
- Evaluation of past projects

Among the above listed road projects, this paper focuses on maintenance of existing road section, particularly on the arterial road that starts from Megenagna and ends at Torhayloch. The necessary input data for carrying out the analysis will be presented in the next section.

Table 2-2 summarizes general framework within which HDM-4 needs to be considered. This study, however, selects the project analysis tool for carrying out the maintenance evaluation (H. R. Kerali 2000).

Table 2-2: The Role of HDM-4

Management Function	Description	HDM-4 Application
Planning	♦ Strategic analysis system ♦ Network planning system ♦ Pavement Management system	Strategic Analysis
Programming	♦ Program analysis system ♦ Pavement management system ♦ Budgeting system	Program Analysis
Preparation	♦ Project analysis system ♦ Pavement management system ♦ Bridge management system ♦ Pavement/ overlay design system ♦ Contract procurement system	Project Analysis

Source: (H. R. Kerali 2000)

2.6.3 Adaptation of HDM-4 to local condition

It is important to note that prior to using HDM-4 for the first time in any country, the system should be configured and calibrated for local use. Since HDM-4 is designed to be used in a wide range of environments, configuration of HDM-4 provides the facility to customize system operation to reflect the norms that are customary in the environment under study.

Default data and calibration coefficients can be defined in a flexible manner to minimize the amount of data that must be changed for each application of HDM-4. Default values are supplied with HDM-4, but these are all user-definable and facilities are provided to enable this data to be modified. For example, default data can be specified to define traffic ranges such as high, medium and low traffic that may vary according to the system of road classification that is used in the country. Reliability of the software depends on how well the prediction of the model fits the real behavior and the intersection between the various factors and condition to which it applies. Model parameters need to be adjusted to enhance accuracy of its representation of local conditions. This procedure is called Calibration.

Calibration of HDM-4 is intended to improve the accuracy of predicted pavement performance and vehicle resource consumption. The pavement deterioration models incorporated in HDM-4 were developed from results of large field experiments conducted in several countries. Consequently, the default equations in HDM-4 if used without calibration, would predict pavement performance that may not accurately match that observed on specific road sections. A fundamental assumption made prior to using HDM is that the pavement performance models will be calibrated to reflect the observed rates of pavement deterioration on the roads where the models are applied.

Calibration focuses on road user effect and on pavement deterioration and maintenance effect. Under road user effect, model predicts correct magnitude of costs and relativity between components. However under pavement deterioration and maintenance effect, model reflects local pavement deterioration trends and practices. The extent of HDM calibration may be defined as follows (Bennett and Paterson, 2000):

Level - 1: Basic Application - This level is applicable to all HDM analysis. It addresses most critical parameters and mostly depends on secondary data sources; that is, it is desk study. Moreover, it assumes that most of the calibration defaults values are appropriate for local conditions so only the most critical ones need to be addressed.

In order to run HDM-4 it is always necessary to undertake at least a Level 1 calibration; this can be viewed as a set-up investment for the model. Once this has been done, it generally does not need to be repeated for most of the input data files during future applications in the same country since many data items and most model parameters are relatively stable over time.

Level – 2: Calibration – Here, use of direct measurements of local conditions to verify and adjust prediction is very much critical. It requires measurement of additional input parameters and moderate field surveys to adjust key predictive relationships to local conditions. It requires a higher degree of data collection and precision than in a level 1 calibration and extends the scope.

Level – 3: Adaptation – Major Field survey to re-quantify fundamental principles and controlled experiments to enhance the existing predictive relationships is applied in this level. There is a need to do observation over a long term period.

In terms of effort, these three levels can be viewed as weeks, months and years. Figure 2-7 generalizes the time and resource needed in each of the calibration level. Every HDM analysis requires at least a Level 1 calibration.

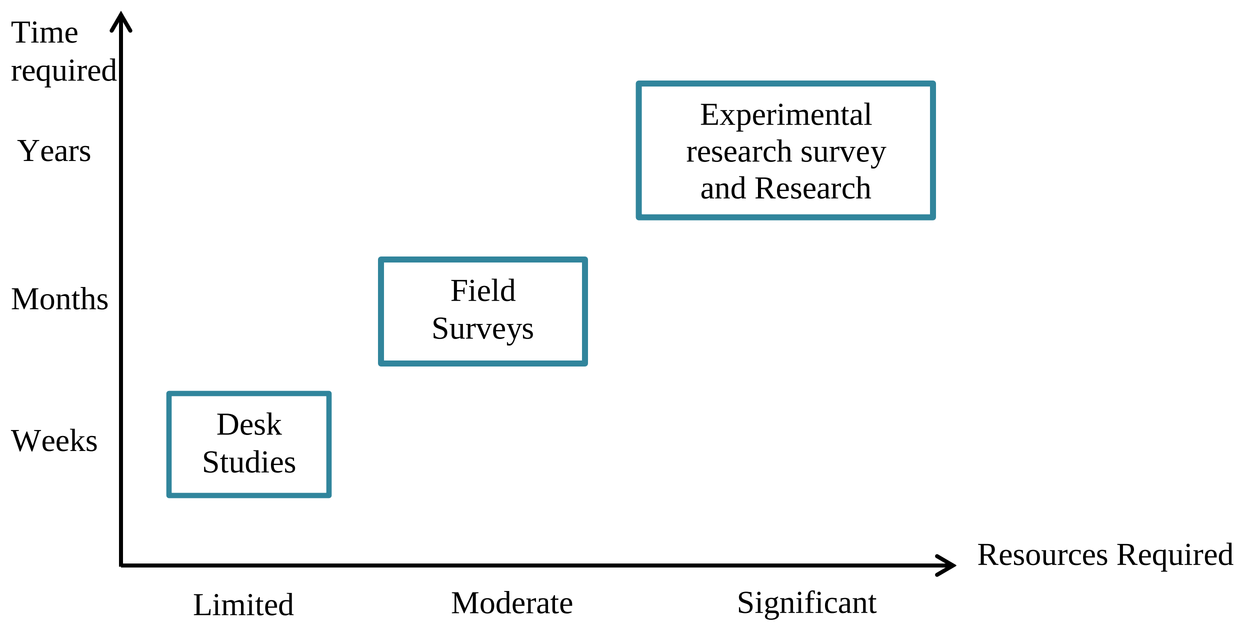

Figure 2-7: Hierarchy of Effect

Source: (Kerali, McMullen and Odoki 2000)

2.6.4 HDM-4 Input Data

Input data are the basic data items required to run HDM-4. The software is applicable to many countries due to the fact the default data are user definable. Every potential user can choose values that suit the local conditions. This enables the software to work with wide ranges of data type and quality. Some of the main input data required are divided into four groups and are discussed below.

(i) Road Network Data

This section provides the basic facilities for network referencing within HDM-4. It allows users to define different networks and sub-networks, and to define sections of road, which are the fundamental unit of analysis within HDM-4.

All network data are entered to the road network folder, and facilities are also available for modifying, deleting and maintaining this data. Sections are length of road over which physical characteristics are reasonably constant, the network referencing system also supports the concept of nodes that connect sections.

When a section is added to a specific road network, this can be based either on aggregate data or on an existing section. Under aggregate data, user selects for various section attributes and some of the data inputs are listed below.

a. Road Class: Classification of road section based on functional hierarchy. Road is defined by its name and the number of road classes to be defined is at the discretion of the user.
b. Speed-Flow Type: This is provided to enable the economic consequences of road capacity improvements to be determined. Factors mentioned for speed-flow relationships are: Capacity, Free Speed, and Speed at Capacity.
c. Traffic-Flow Pattern: Different levels of traffic at different hours of the day and on different days of the week and year need to be taken in order to do congestion analysis of the year.
d. Climate Zone: Climate brings a considerable impact on the rate at which the road deteriorates and at some points on the road user costs. The impact of Temperature, precipitation and winter condition on road deterioration and user cost will be analyzed.
e. Traffic Volume: Traffic volume is specified in terms of AADT flow. Detailed data values are associated in terms of the mean AADT.
f. Geometry Class: Road geometry is defined in terms of various parameters reflecting horizontal and vertical curvature. Data describing geometric class includes: Description, Average rise plus fall, Number of rises and falls per kilometer, Average horizontal curvature, super elevation, speed limit, and speed reduction.
g. Pavement Characteristics: Pavement characteristics vary with respect to road surface. i.e. Bituminous pavement and Concrete Pavement.
h. Road Condition: data under this section is given as Ride quality, surface distress and surface texture.
i. Pavement History: This includes construction quality, age, and previous condition.
j. Miscellaneous:

(ii) Vehicle Fleet

Vehicle fleet is a category where it describes diverse characteristics of vehicles operating on the road network being analyzed. It comprises a mix of representative vehicle types that use a road network. Parameters specified for the representative vehicles should reflect the overall physical and performance characteristics of the range of vehicles that use a road network (Gedafa 2006).

Figure 2-8 below shows level of classification to which the vehicles are grouped (Kerali, McMullen and Odoki 2000). Category section includes motorized and non-motorized vehicles. In Classes section, motorized vehicles are divided to several classes including motorcycles, cars, utilities, trucks, buses and non-motorized vehicles are divided into 4 classes including animal carts, bicycles, pedestrians, and rickshaw. Type section represents a set of vehicles within a class, which has different characteristics. Totally, there are 16 motorized vehicle types and 4 non-motorized vehicle types provided as standard default representative vehicles within HDM-4.

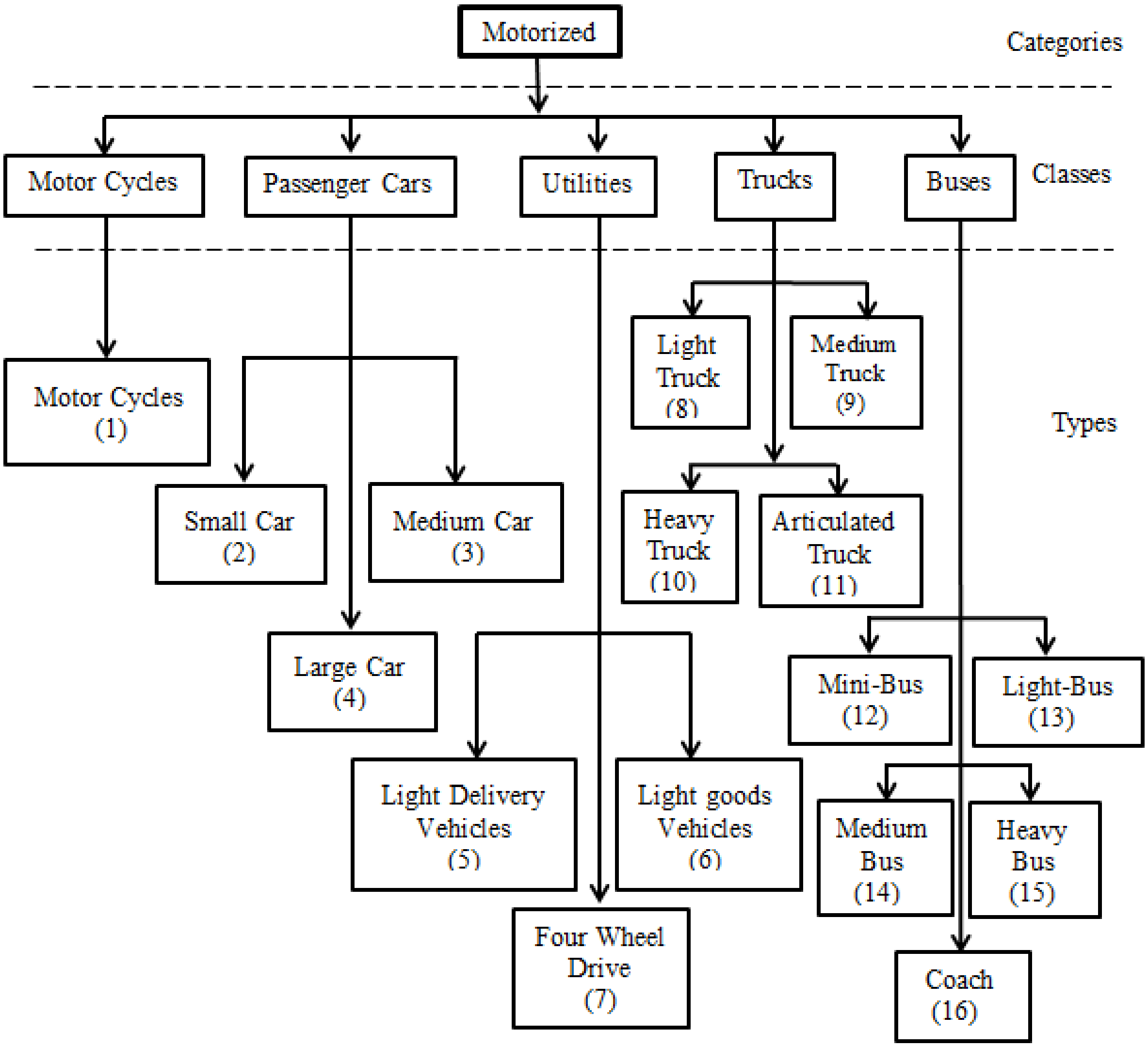

Figure 2-8: Hierarchical structure of the relationships between the levels of classification in HDM-4

(Source: The Highway Development and Management Series, Volume-2)

(iii) Traffic Data

Accurate traffic data is the most crucial information for getting reliable results from the economic analysis. It starts with describing traffic characteristics of road and must be presented with appropriate level of detail.

For the purpose of representing traffic characteristics for project level analysis, road links within a network must be categorized based on the following (Kerali, McMullen and Odoki 2000):

- Speed flow type: This defines parameters for capacity, speed-flow relationship shape, width effects and passenger car space equivalents for different road widths.
- Traffic flow pattern: This describes patterns of traffic flow along each road category, commuter routes (i.e. Weekday traffic - Weekend traffic - Recreational traffic).
- Non-motorized transport factor: Effect of non-motorized transport on motorized traffic speeds is measures in this section.
- Motorized transport factor: Here the effect of motorized transport on motorized traffic speed is assessed.
- Roadside friction: It measures the effect of roadside activity on traffic speeds and includes the effects of land use, roadside stalls, bus stops, parking, etc.

Traffic data are incorporated in several applications rather than being specified in one place. Traffic data types consider the following (Gedafa 2006):

- Traffic Categories including normal, diverted, and generated,
- Traffic Composition including volume and growth rates,
- Axle Loading,
- Road Capacity and Speed-Flow relationships, and
- Traffic-Flow pattern.

(iv) Road Works Standard

This section describes the specification of road work standard used within HDM-4. By definition, standard refers to the target or level of conditions and responses that a road administration aims to achieve. Road agencies set up different standards that can be applied in practical situations in order to meet specific objectives which are related to functional characteristics of the road network system.

In HDM-4, standard is stated as a set of operations or activities with definite intervention criteria to determine when to carry them out (Kerali, McMullen and Odoki 2000). Intervention levels define the minimum level of service that is allowed. The standards include the road maintenance and improvement standards are followed by the road administrations in their network management and development activities.

2.6.5 HDM-4 Reports

After inserting all the necessary data and performing the analysis, the last stage will be retrieving the results. Depending on the degree of accuracy of input data, HDM generate dependable reports in which users have direct access to the results database files. HDM-4 can produce the following outputs, which are helpful for road managers to make informed decision (Kerali, McMullen and Odoki 2000).

- Pavement deterioration and road works
    - Summary of annual pavement condition;
    - Quantities of road works;
    - Details of annual road work costs; and
    - Schedule of road works.
- Road user effects
    - Summary of road user costs (Vehicle operation, travel time and accident);
    - Traffic flow details;
    - Average travel speeds; and
    - Traffic volume to capacity ratios.
- Environmental effects
    - Vehicle emission; and
    - Energy consumption.
- Economic analysis results
    - Annual Cost Streams;
    - Discounted cash flow;
    - Net Present values (NPV);
    - Economic internal rate of return (EIRR);
    - Benefit Cost Ratio (BCR); and
    - First Year Benefits (FYB).

2.6.6 Limitation of HDM-4

HDM-4 has some improved features than HDM-III. Factors that were not considered in HDM-III have been considered in HDM-4. However, still HDM-4 lack some points. Some of them are (World Bank 2008),

- The model accepts but does not perform network traffic assignment;
- Limited estimation of environmental impacts, such as air pollution, and not costed internally;
- Only partially applicable to urban traffic conditions – through acceleration variance; and
- Option for evaluating cement blocks and cobblestone pavements not yet implemented.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

As described in chapter one, the main objective of this thesis is to measure the economic impact that comes as a result of poor maintenance; which is characterized in terms of delayed maintenance and inappropriate forecasting of the traffic demand. And the aim of the research is to suggest a better approach on the current practices of maintenance activities in order to maximize the road user's economic benefit, which helps greatly to move forward the realization of road maintenance program in Addis Ababa city in particular.

3.2 Research Design

To work on the objectives listed under chapter one, section 1.3, both descriptive and exploratory type of research methods have been employed. A qualitative type which identifies a situation, evaluate options and propose suggestions, is included as a research strategy together with descriptive type which focuses on analyzing current conditions. The research passes through three major processes of data collection, analysis and finally formulating conclusions and forwarding recommendations based on the findings.

3.3 Data Collection

Multiple data sources were used for the purpose of collecting all useful and supporting documents. Both primary and secondary data were incorporated for carrying out the research objectives.

3.3.1 Addis Ababa City Roads Authority (AACRA)

For the city of Addis Ababa, AACRA is duly responsible for managing the road network and overall road assets. The authority distinguishes roads of the city based upon their traffic volume priority and geometric characteristics. Table 3-1 below presents the standard width given to each road class. Each road class will serve the traffic flow according to their carriage way width.

Table 3-1: Geometric characteristics of the road class in Addis Ababa

Road Class		Standard Width (m)
Principal Arterial Streets	PAS-1	60
	PAS-2	50
	PAS-3	40
	PAS-4	30
Sub-Arterial Streets	SAS-1	25
	SAS-2	20
Collector Streets	C	15
Local Streets	L	10

The city has a total of 22% of paved road coverage. From the total length of paved roads, Table 3-2 below presents the lengths of respective road classes.

Table 3-2: Lengths of the Addis Ababa road classes

Road Class		Length (meter)
Ring Road	RR	47,082
Principal Arterial Streets	PAS-0	14,166
	PAS-1	22,875.69
	PAS-2	36,137.93
	PAS-3	87,820.65
	PAS-4	124,217.44
Sub-Arterial Streets	SAS-1	53,137.89
	SAS-2	86,543.37
Collector Streets	C	323,310
Local Streets	L	91,060.39

There are certain road sections which are regarded as strategic roads. These types of road are considered to have higher level of market activity and more importantly they have huge political image. Ministers, diplomats and higher government officials frequently use these types of roads. According to AACRA, 73.6% of the principal arterial street and 89.9% of the sub-arterial street are found within these strategic roads. Priority in road construction, maintenance and related activities are given to these types of road than others.

From the road classes, it can be understood that AACRA clearly classifies its road network. This paper particularly focuses on principal arterial road streets. As shown in the Table 3-2 above, there are five classifications under principal arterial streets. The road segments are categorized according to their carriageway widths and traffic flows. The details are depicted in Appendix.

3.3.2 Study Area

Addis Ababa city has four major corridors of road network and these are the East-West, North-South, Ring Roads and the Central Business Districts. This study considers the East-West corridor in carrying out the research work.

The East-West corridor starts at Ayat roundabout which is located at the Eastern side of the city, passes the Adwa Square, cross the Meskel square, continues towards Mexico Square and terminates at the Ring Road square around Torhayloch Hospital which is located at western side of the city. Therefore, this study, considered the road from Megenagna – Meskel Square – Torhayloch RA. It is estimated to cover a length of about 8.2km.

According to AACRA road classification, the study road network is classified as Principal Arterial Street-3 (PAS-3). It has a cross-sectional width of 40m. The recent nature of the infrastructure and availability of road design documents and fresh construction cost, the sample areas including different types of topography, climate and geometry; helps the research work to archive its objective in a rational manner.

The road network is regarded as an important business corridor. Large scale business, commercial and residential building complexes are being developed and will continue to be developed along the corridor. Hence, the corridor itself is source of origin and destination of large volume of trips. This is a concern for expected demand for the two ends, also for the demand along the corridor.

It exhibits high capacity public transport service providing adequate service for through traffic. In addition, it’s a business corridor; access to the various services with limited conflict with traffic.

For the purpose of analysis, the study road network is divided to thirteen sections as depicted in Table 3-3 below.

Table 3-3: Sections of the study road network

Section	Route Name	Chainage	Length (meter)
Section 1	Megenagna - Lem Hotel	0+000 - 0+320	320
Section 2	Lem Hotel - 22 Mazoria	0+400 - 0+940	540
Section 3	22 Mozoria - Getahun Besha Bldg	0+940 - 1+660	720
Section 4	Getahun Besha Bldg. - Wuhalimat	1+660 - 1+820	120
Section 5	Wuhalimat - Urael	1+920 - 2+400	480
Section 6	Ureal - Bambis	2+400 - 3+100	700
Section 7	Bambis - Estifanos	3+100 - 3+980	880
Section 8	Stadium - Legehar	4+540 - 5+100	560
Section 9	Legehar - Kera Junction	5+200 - 5+400	200
Section 10	Kera Junction - Mexico Square	5+400 - 5+720	320
Section 11	Mexico Square - Lideta	5+720 - 6+500	780
Section 12	Lideta - Coca Cola Factory	6+620 - 7+720	1,100
Section 13	Coca Factory -Torhayloch	7+300 - 8+200	900
Overall	Megenagna - Torhayloch	0+000 - 8+200	8200

Note: (0+320-0+400)- - - - Lem hotel Junction
(3+980-4+540)- - - - Meskel Square
(5+100-5+200)- - - - Leg Junction
(6+500-6+620)- - - - Mexico Transition
(7+720-7+300)- - - - Firdebet Junction

3.3.3 Traffic Data

Traffic is the most important factor in pavement design and analysis. Detail information should be carefully taken in order to make a credible study. The information starts from collecting a daily traffic on the road way section where the pavement is going to be constructed, upgraded, maintained or etc. The traffic counts must be adjusted for daily (weekday versus weekend) and seasonal variations to obtain the annual average daily traffic (AADT).

Here in this project, traffic count is done manually by Core Consulting Engineers supervision for seven consecutive days, including two days of 24 hours and three days of 12 hours.

In carrying out the traffic surveys in this study, the vehicle classifications of ERA were used with slight modifications as shown in Table 3-4 below.

Table 3-4: Vehicle Classification

Vehicle Classification	**Description**
1. Passenger vehicles	
➬ Cars	Small automobiles
➬ Land Rovers	4WD and utility vehicles
➬ Small Bus	Buses up to 25 passenger seats
➬ Medium Bus	Buses with 25 up to 45 passenger seats
➬ Large Bus	Buses with over 45 passenger seats.
2. Freight vehicles	
➬ Small Truck	Trucks of capacity up to 3.5 tons load.
➬ Medium Truck	Trucks of capacity 3.5 up to 7.5 tons load.
➬ Heavy Truck	Trucks of capacity over 7.5 tons load.
➬ Truck and Trailer	Articulated Trucks and tanker trailers of capacity over 12 tons load.
3. Miscellaneous	Two wheel locomotives like bicycles and motor cycles.

Average Daily Traffic (ADT) is converted to Annual Average Daily Traffic using seasonal factor, (equal to 1 assuming there is no seasonal change in traffic operation in Addis Ababa). Table 3-5 below shows AADT data along each street segment. It is calculated for each station using the seasonal factor together with the collected daily traffic count. Similarly, Table 3-6: shows the total AADT on Torhayloch to Megenagna lane (West - East) and Table 3-7 shows the total AADT on Megenagna to Torhayloch lane (East - West).

Table 3-5: AADT along the street segment

Station	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck Trailer	Total
Lem Hotel							
Lem Hotel to Megenagna	3438	613	267	130	25	14	**4487**
Megenagna to Lem Hotel	3434	448	227	43	6	2	**4161**
22 to Lem Hotel	4961	456	310	97	53	5	**5881**
Lem Hotel to 22	5173	434	368	65	32	9	**6081**
22 Mazoria							
22 to Lem Hotel	6733	667	495	69	24	6	**7994**
Lem Hotel to 22	5468	1209	708	80	41	12	**7517**
22 to G. Besha	3121	315	393	141	43	17	**4030**
G.Besha to 22	3662	533	391	173	71	8	**4838**
Getahun Besha							
G.Besha to 22	5459	488	437	171	87	9	**6651**
22 to G. Besha	5044	367	391	109	76	2	**5989**
G.Besha to Wuhalimat	4293	306	353	113	48	3	**5116**
Wuhalimat to G.Besha	2958	439	273	136	14	4	**3823**
Wuhalimat							
Wuhalimat to G.Besha	3572	540	357	131	64	5	**4670**
G.Besha to Wuhalimat	4855	362	319	132	52	13	**5732**
Wuhalimat to Ureal	4649	441	385	131	41	9	**5657**
Ureal to Wuhalimat	5053	511	415	147	51	13	**6190**
Ureal							
Ureal to Bambis	4055	392	296	58	210	51	**5061**
Bambis to Ureal	3410	777	344	57	207	84	**4878**

Station	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck Trailer	Total
Estifanos							
Estifanos to Bambis	2860	486	397	277	48	6	**4074**
Bambis to Estifanos	3020	377	308	181	71	4	**3961**
Leghar							
Leghar to Stadium	8837	1335	694	351	68	31	**11316**
Stadium to Legar	7064	871	546	214	76	24	**8794**
Leghar to Kera Junction	6937	849	232	274	76	28	**8396**
Kera Junction to Leghar	5793	682	179	239	78	18	**6989**
Kera Junction							
Kera Junction to Leghar	3473	535	129	69	19	3	**4228**
Leghar to Kera Junction	3619	419	144	88	20	9	**4298**
Kera Junction to Mexico	5116	442	181	66	24	8	**5837**
Mexico to Kera Junction	4296	647	172	42	15	7	**5180**
Lideta							
Lideta to Mexico	3444	298	283	130	155	8	**4317**
Mexico to Lideta	3947	754	429	172	172	9	**5482**
Lideta to Coca	2482	523	331	243	220	16	**3815**
Coca to Lideta	2745	453	372	387	296	86	**4339**
Coca							
Coca to Lideta	2688	382	311	422	250	35	**4088**
Lideta to Coca	2086	387	247	168	142	19	**3048**
Coca to Torhayloch	3969	781	365	472	315	28	**5930**
Torhayloch to Coca	5506	1123	542	719	560	37	**8487**

Table 3-6: Total AADT on Torhayloch to Megenagna lane (West to East)

Direction One: Torhayloch to Megenagna (West to East)							
Location	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck Trailer**	**Total**
Lem Hotel to Megenagna	3438	613	267	130	25	14	**4487**
22 to Lem Hotel	5847	561	402	83	38	6	**6938**
G.Besha to 22	4560	511	414	172	79	8	**5744**
Wuhalimat to G.Besha	3265	489	315	133	39	5	**4247**
Ureal to Wuhalimat	5053	511	415	147	51	13	**6190**
Bambis to Ureal	3410	777	344	57	207	84	**4878**
Estifanos to Bambis	2860	486	397	277	48	6	**4074**
Leghar to Stadium	8837	1335	694	351	68	31	**11316**
Kera Junction to Leghar	4633	608	154	154	49	11	**5608**
Mexico to Kera Junction	4296	647	172	42	15	7	**5180**
Lideta to Mexico	3444	298	283	130	155	8	**4317**
Coca to Lideta	2717	418	341	405	273	60	**4213**
Torhayloch to Coca	5506	1123	542	719	560	37	**8487**

Table 3-7: Total AADT on Megenagna to Torhayloch lane (East to West)

Direction Two: Megenagna to Torhayloch (East to West)							
Location	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck Trailer**	**Total**
Megenagna to Lem Hotel	3434	448	227	43	6	2	**4161**
Lem Hotel to 22	5320	822	538	73	36	10	**6799**
22 to G. Besha	4082	341	392	125	59	10	**5010**
G.Besha to Wuhalimat	4574	334	336	122	50	8	**5424**
Wuhalimat to Ureal	4649	441	385	131	41	9	**5657**
Ureal to Bambis	4055	392	296	58	210	51	**5061**
Bambis to Estifanos	3020	377	308	181	71	4	**3961**
Stadium to Leghar	7064	871	546	214	76	24	**8794**
Leghar to Kera Junction	5278	634	188	181	48	18	**6347**

Direction Two: Megenagna to Torhayloch (East to West)							
Location	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck Trailer**	**Total**
Kera Junction to Mexico	5116	442	181	66	24	8	**5837**
Mexico to Lideta	3947	754	429	172	172	9	**5482**
Lideta to Coca	2284	455	289	205	181	18	**3431**
Coca to Torhayloch	3969	781	365	472	315	28	**5930**

3.3.4 Maintenance Expenditure

Transportation costs in general include all costs associated with road construction, maintenance, rehabilitation, and other environmental and societal costs.

Road maintenance cost, in particular, is a major factor for the up keeping of road asset value of a country (Office of the Road Fund Administration 2001). For a healthy and dependable road environment, it's a must to secure finances with regard to maintenance works.

The Addis Ababa City Roads Authority plans and performs its activities based on the budget allocated to the authority. The authority's road program is financed both by Road Fund and by Addis Ababa City Administration. The budget given will be distributed to every department and tasks are executed as required. Because of the fact that the budget is very much limited, the maintenance department is forced to focus on highly deteriorated road sections and on strategic roads.

The budget that comes from City Road Administration is used for capital projects (new projects) and salaries for permanent employee of the Authority. On the other hand, Road Fund Administration releases budgets for addressing the city road maintenance problems. Chart 3-1 and Chart 3-2 below show the amount of budgets allocated and utilized since 2011 G.C. as provided by AACRA.

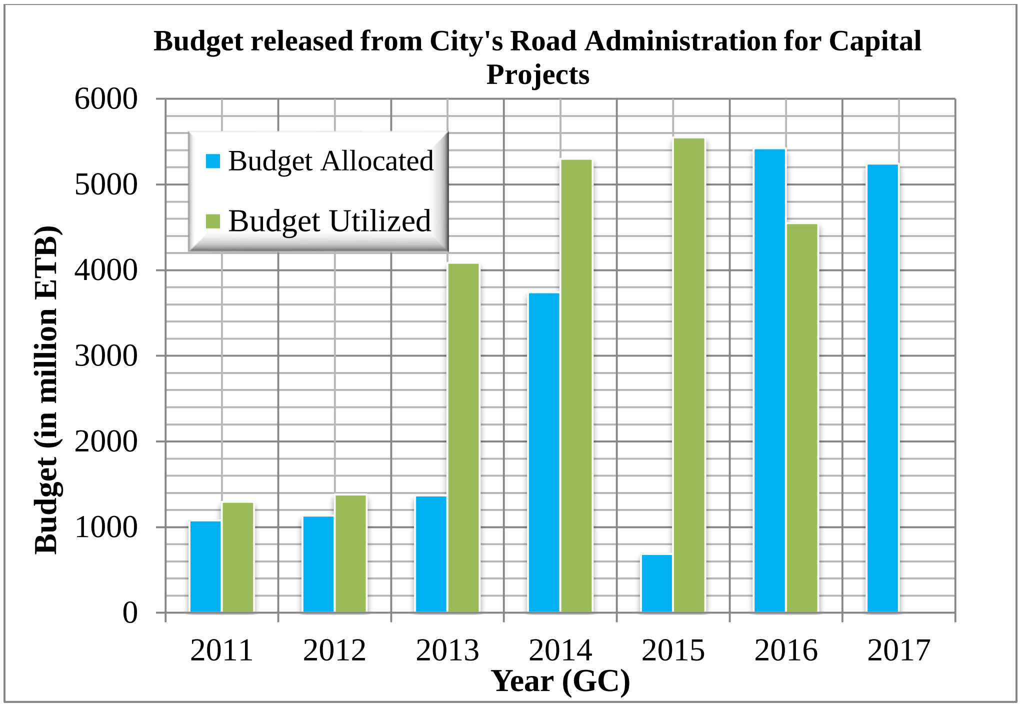

Chart 3-1: Budget released from City's Road Administration

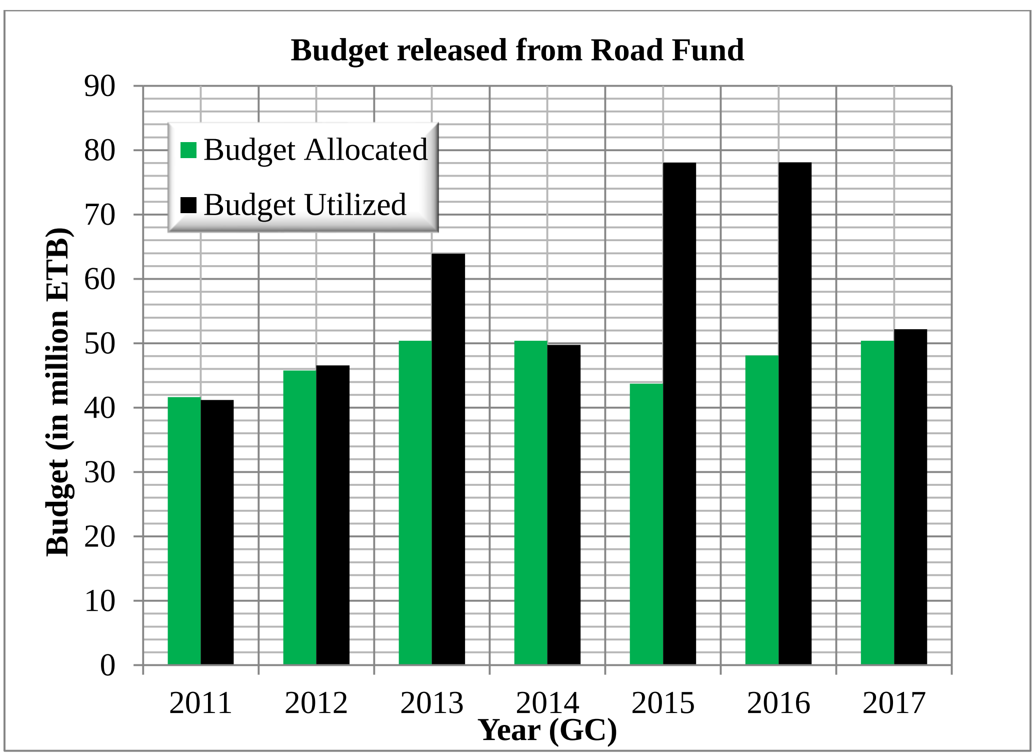

Chart 3-2: Budget released from Road Fund

3.3.5 Maintenance Strategy of AACRA

The Road Asset Management Team of AACRA is responsible for defining maintenance activities and setting out schedules for the tasks to be done. The procedure starts from road condition survey. Road condition survey includes categorizing roads according to their severity levels and road classes. Most of the time, roads with higher severity level of deterioration and roads that bear higher political pressure get priority during the work. Table 3-8 below shows the matrix method of road condition and traffic priority method used by AACRA for prioritizing their maintenance schedules. The Road Construction and Maintenance Team acquire this information before applying their measures.

Table 3-8: Matrix Method of AACRA for Maintenance Work

Priority Matrix	Strategic	PAS	SAS	L
	Traffic Priority			
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

In general terms, road construction and maintenance department performs two types of maintenance as follows.

(i) Emergency Maintenance – This type of maintenance is done immediately after the rainy season. Due to the fact that the city has very poor drainage facilities, many of the roads deteriorate as the result of the water running on the pavement surface. Repair action will, then, take place in order to address these defects. This maintenance type is temporary in its nature that it only addresses defects noticed on the mentioned time interval.

(ii) Annual Maintenance – This type of maintenance is done based on the report that comes from road asset management team. The team finalizes their condition survey documents and informs the road construction and maintenance team about defects and measure to be taken to address the problem on the road segments. As the name implies, this procedure applies every year after the completion of road condition survey.

Even though the treatments they apply gives short term benefit, they strongly believe as it improve the functional performance of the roadway.

3.4 Data Analysis

3.4.1 Traffic Analysis

Traffic Composition

Table 3-9 below presents average traffic compositions of each vehicle types on the study road sections. The result is calculated by taking the average value of both directions total count (referring to Table 3-6 and 3-7 from section 3.3.3) with respect to each vehicle type. For example, for small bus:

West-East (Direction one): Total count from each road segment = 5821.462

Average $value_1$ = 4451.231

Percentage $value_1$ = 100* (4451.231/5721.462) = 76.46%

East-West (Direction two): Total count from each road segment = 5530.308

Average $value_2$ = 4368.615

Percentage $value_2$= 100*(4368.615/5530.308) = 78.99%

Now, Average value of Percentage $value_1$ and Percentage $value_2$ = 77.7%

Table 3-9: Average traffic composition on the project road

Vehicle Type	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck & Trailer	Total
% Composition	77.7	10.5	6.2	3.3	2.0	0.3	100.0

Traffic Forecasting

Design traffic volume is very uncertain process. It requires analysis and forecast of past and future traffic growth trends, social and economic development trends.

The traffic count was done in 2012 GC. It was anticipated that the road will be open for traffic in 2016. For the purpose of maintaining the road in current year, the traffic shall be forecasted to this year based upon the GDP growth rate and demand elasticity.

Table 3-10 below presents the traffic growth rate for 24 consecutive years. GDP growth rate at each interval of the years is calculated and then multiplied by the demand elasticity that gives the expected traffic in respective years.

Table 3-10: Traffic Growth Rate

Variables	Demand Elasticity (e)		Growth Rates (%)		
	2011-2020	2020-2035	2011-2015	2016-2020	2021-2035
GDP Growth Rate (%)			**7**	**6.5**	**6**
Passenger Traffic			**$\Delta t = e^*(\Delta GDP)$**		
Small Bus	1.1	1.1	7.7	7.2	6.6
Cars/4wheel Drive	1.2	1.2	8.4	7.8	7.2
Medium & Large Bus	1.0	1.0	7.0	6.5	6.0
Freight Traffic					
Small Truck	1.1	1.0	7.7	7.2	6.0
Medium & Heavy Truck	1.2	1.1	8.4	7.8	6.6
Truck & Trailer	1.4	1.3	9.8	9.1	7.8

- **Base year AADT Determination**

The base year AADT is computed by converting the current normal traffic count from 2012 to 2016 by using the appropriate traffic growth factors. Table 3-11 below presents the calculated value of five year AADT with respect to each vehicle type.

$$\mathbf{AADT_b = AADT_{2012}\,(1+r)^{n}} \qquad \text{… .. (3.1)}$$

Where: $AADT_b$ = Base year AADT

$AADT_{2012}$ = AADT at the time of traffic count is conducted

r = growth rate (in decimal)

n = time period in years between the 2012 and opening year, 2016.

Table 3-11: Base year AADT

AADT	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck & Trailer	Total
$AADT_{2012}$	8473	1208	703	338	190	31	10943
$AADT_{2013}$	9126	1293	753	367	206	34	11779
$AADT_{2014}$	9829	1383	805	398	224	38	12677
$AADT_{2015}$	10585	1480	862	431	252	41	13651
$AADT_{2016}$	11347	1576	918	465	272	45	14623

Next, the traffic can be projected to the required year using the base year AADT (2016 GC) and the respected time period. Table 3-12 below presents the forecasted AADT values starting from year 2017 GC to 2036 GC.

$$\mathbf{AADT_n = AADT_b\ (1+r)^{n}} \quad \ldots\ ..\ (3.2)$$

Where: $AADT_n$ = Projected AADT on the n^{th} year

$AADT_b$ = Base year AADT ($AADT_{2014}$)

r = Growth rate (in decimal)

n = Time period (in years) between the base year, 2016, and the n^{th} year

Table 3-12: Projected AADT

AADT	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck & Trailer	Total
$AADT_{2016}$	11347	1576	918	465	272	45	14623
$AADT_{2017}$	12164	1679	978	502	294	50	15667
$AADT_{2018}$	13040	1788	1042	541	317	54	16782
$AADT_{2019}$	13979	1904	1109	583	341	59	17975
$AADT_{2020}$	14986	2028	1181	628	368	64	19255

AADT	Small Bus	Medium Bus	Large Bus	Medium Truck	Heavy Truck	Truck & Trailer	Total
$AADT_{2021}$	15975	2150	1252	670	392	69	20508
$AADT_{2022}$	17029	2279	1327	714	418	75	21842
$AADT_{2023}$	18153	2415	1407	761	445	80	23261
$AADT_{2024}$	19351	2560	1491	811	475	87	24775
$AADT_{2025}$	20628	2714	1581	865	506	93	26387
$AADT_{2026}$	21989	2876	1676	922	539	101	28103
$AADT_{2027}$	23441	3049	1776	983	575	108	29932
$AADT_{2028}$	24988	3232	1883	1048	613	117	31881
$AADT_{2029}$	26637	3426	1996	1117	653	126	33955
$AADT_{2030}$	28395	3631	2115	1190	696	136	36163
$AADT_{2031}$	30269	3849	2242	1269	742	146	38517
$AADT_{2032}$	32267	4080	2377	1353	791	157	41025
$AADT_{2033}$	34396	4325	2519	1442	844	170	43696
$AADT_{2034}$	36666	4584	2671	1537	899	183	46540
$AADT_{2035}$	39086	4859	2831	1638	959	197	49570
$AADT_{2036}$	41666	5151	3001	1746	1022	212	52798

3.4.2 Axle Load and OD Survey

Axle Load Survey

Axle load survey is carried out together with the traffic count. Each axle of the vehicle has weight and EALF is calculated for each axle. In this study, a twelve hour axle load survey was conducted on two survey stations (at Torhayloch and Megenagna) using appropriate equipment, INTERCOMP LP600 portable weighbridge.

As many as 436 vehicles on the first station and 247 vehicles on the second survey station were weighted covering all categories of buses (small, medium and large) and trucks (small, heavy and truck-trailer) on both lanes.

3.4.3 Truck Factors

Truck factor of each vehicle class is determined by summing the load equivalence factor of each axle of the vehicle. The equivalence factor of the axle is determined using the following relations,

$$\mathbf{EF} = \left(\frac{\mathbf{Axle\ Load\ (Kg)}}{\mathbf{8160\ Kg}}\right)^{\mathbf{4.5}} \qquad \text{….. (3.3)}$$

$$\mathbf{TF} = \sum_{i=1}^{n} \mathbf{EF} \qquad \text{… .. (3.4)}$$

Where: EF = Equivalence Factor

TF = Truck Factor

n = the number of axles of the vehicle

For the study road, axle load analysis was made on directional basis, i.e. the truck factor of each commercial vehicle class was determined on each direction and the maximum value for each vehicle type was taken. Table 3-13 below presents truck factors determined from the axle load survey data of the study road.

Table 3-13: Calculated TF values

Vehicle Type	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck and Trailer**
TF based on measured data	0.008	0.121	4.439	0.512	5.062	5.759
Recommended TF	0.008	0.121	4.439	0.512	5.062	7.000

The truck factor of the truck and trailer is very small to represent the damaging effect of articulated truck. Hence referring to the survey data of other projects, truck factor of 7 was adopted to truck and trailer.

As it can be seen in each analysis, the consultant did not perform traffic analysis and axle load survey for cars, 4WD and small trucks. This is due to the fact that they do not contribute significantly to the structural damage, particularly for paved roads. Even though cars, land rovers, and small buses (generally vehicles up to 24-passenger seats) are counted in any regular traffic count survey, their number does not influence the pavement design of paved roads. It is also worth noting that the "heavy" vehicles used in the development of the pavement structures essentially correspond.

- **Design lane and Distribution Factor**

The design lane and lane distribution factor for each of the homogeneous section were determined by the consultant, Core Consulting Engineers plc., depending on the actual traffic condition and AASHTO design guide recommendation.

The consultant found directional split factor and lane distribution factor to be 0.5 and 0.6 respectively.

- **Design Traffic**

With the truck factors and the forecasted year by year AADT known, the cumulative number of equivalent standard axles expected over the design life of the road on the design lane is computed using the following formula:

$$\mathbf{CESA = 365 * \sum_{i=2016}^{2036} AADT_i * TF_j * D * L} \qquad \ldots .. (3.5)$$

Where: CESA = Cumulative Equivalent Standard Axles

TF_j = Truck Factor for each vehicle type

$AADT_i$ = Annual average daily traffic on the i^{th} year

D = Directional Split Factor

L = Lane Distribution Factor

Table 3-14 below shows the detail results of cumulative equivalent standard axles on the design lane for consecutive 21 years. According to the cumulative value the traffic class will be T8 based to ERA traffic class category.

Table 3-14: Cumulative Equivalent Standard axles on the Design Lane

AADT	Small Bus	ESA	Medium Bus	ESA	Large Bus	ESA	Medium Truck	ESA	Heavy Truck	ESA	Truck & Trailer	ESA	Total	CESA
2016	11,347	**9,940**	1,576	**20,881**	917	**445,727**	465	**26,070**	272	**150,767**	43	**32,960**	14,620	**686,344**
2017	12,164	**10,656**	1,678	**22,233**	977	**474,891**	501	**28,088**	293	**162,407**	47	**36,026**	15,660	**734,299**
2018	13,040	**11,423**	1,787	**23,677**	1,041	**505,999**	540	**30,275**	316	**175,155**	51	**39,092**	16,775	**785,621**
2019	13,979	**12,246**	1,903	**25,214**	1,109	**539,052**	582	**32,629**	341	**189,013**	56	**42,924**	17,970	**841,077**
2020	14,985	**13,127**	2,027	**26,857**	1,181	**574,049**	627	**35,152**	368	**203,978**	61	**46,757**	19,249	**899,920**
2021	15,974	**13,993**	2,149	**28,473**	1,252	**608,560**	668	**37,451**	392	**217,281**	66	**50,589**	20,501	**956,348**
2022	17,028	**14,917**	2,278	**30,182**	1,327	**645,016**	712	**39,918**	418	**231,693**	71	**54,422**	21,834	**1,016,146**
2023	18,152	**15,901**	2,415	**31,998**	1,407	**683,901**	759	**42,553**	446	**247,213**	77	**59,021**	23,256	**1,080,586**
2024	19,350	**16,951**	2,560	**33,919**	1,491	**724,731**	809	**45,356**	475	**263,287**	83	**63,620**	24,768	**1,147,863**
2025	20,627	**18,069**	2,714	**35,959**	1,580	**767,991**	862	**48,327**	506	**280,470**	89	**68,219**	26,378	**1,219,036**
2026	21,988	**19,261**	2,877	**38,119**	1,675	**814,168**	919	**51,523**	539	**298,762**	96	**73,584**	28,094	**1,295,417**
2027	23,439	**20,533**	3,050	**40,411**	1,776	**863,261**	980	**54,943**	575	**318,716**	103	**78,950**	29,923	**1,376,813**
2028	24,986	**21,888**	3,233	**42,836**	1,883	**915,271**	1,045	**58,587**	613	**339,779**	111	**85,082**	31,871	**1,463,442**
2029	26,635	**23,332**	3,427	**45,406**	1,996	**970,197**	1,114	**62,455**	653	**361,951**	120	**91,980**	33,945	**1,555,321**
2030	28,393	**24,872**	3,633	**48,135**	2,116	**1,028,525**	1,188	**66,604**	696	**385,785**	129	**98,879**	36,155	**1,652,801**
2031	30,267	**26,514**	3,851	**51,024**	2,243	**1,090,256**	1,266	**70,977**	742	**411,282**	139	**106,544**	38,508	**1,756,597**
2032	32,265	**28,264**	4,082	**54,084**	2,378	**1,155,876**	1,350	**75,686**	791	**438,443**	150	**114,975**	41,016	**1,867,328**
2033	34,394	**30,129**	4,327	**57,331**	2,521	**1,225,384**	1,439	**80,676**	843	**467,266**	162	**124,173**	43,686	**1,984,958**
2034	36,664	**32,118**	4,587	**60,775**	2,672	**1,298,780**	1,534	**86,002**	899	**498,306**	175	**134,138**	46,531	**2,110,119**
2035	39,084	**34,238**	4,862	**64,419**	2,832	**1,376,552**	1,635	**91,665**	958	**531,009**	189	**144,869**	49,560	**2,242,750**
2036	41,664	**36,498**	5,154	**68,288**	3,002	**1,459,184**	1,743	**97,720**	1,021	**565,929**	204	**156,366**	52,788	**2,383,984**
∑	**496,425**	**434,868**	**64,170**	**850,220**	**37,376**	**18,167,371**	**20,738**	**1,162,655**	**12,157**	**6,738,491**	**2,222**	**1,703,163**	**633,088**	**29,056,769**

3.4.4 Subgrade Soil Strength (Design CBR)

Subgrade soil is an important input for HDM-4 project analysis. In pavement design, it is the upmost importance as they carry the entire pavement structure and hence the total load. Stability of pavement structure greatly relies on the engineering properties of subgrade soils, most notable shear engineering and expansiveness properties. Therefore, to know the strength of the subgrade, representative samples were collected by soil and material testing division team of core consulting engineers and CBR test is conducted.

The CBR value is a percentage of a standard value which is intended to represent the value that would be obtained with compacted crushed stone. The subgrade soils were first collected from the project site at 300m interval by digging test pits of 1m depth. The samples were then logged, tagged, sampled and transported for the test to be performed.

The strength of subgrade soils is dependent on the type of soil, density, and moisture content. The design CBR of the subgrade soil, therefore, should be evaluated at the moisture content and density representative to the subgrade condition during the service time of the pavement structure.

In order to determine the homogenous sections of the road soil (Megenagna to Torhayloch), extensive survey was conducted. Almost all of the project area is underlain by expansive soils that it shall be removed and replaced by improved subgrade material, rock fill material, having a minimum CBR value of and swell index.

The design CBR value was determined for each of the homogeneous sections from Megenagna to Torhayloch taking the 90th percentile of the subgrade CBR values. The values of design CBR in accordance with ERA's pavement Design manual, 2002 was determined. Majority of the soils along the section have distinct features of low CBR values and high Swell Indices. As a result, the design CBR value was taken to be 8% with swell index less than 2%. This refers to S4 category of ERA subgrade classification.

3.4.5 Pavement Structure

Pavement structure is one of the most important inputs in HDM-4 data inputs. The pavement structure is designed using the ERA Pavement Design Manual 2002. The pavement designed based on the ERA design manual was found to be economically feasible.

The design approach requires choosing alternatives from ERA structural catalogue. The catalogue offers, in eight different charts, alternative pavement structures for combinations of traffic and subgrade classes.

For S4 subgrade class and T8 traffic class, there are the following two alternative structures. Chart 3-3 and Chart 3-4, in ERA structural design catalogue, Chart 5 and Chart 7 respectively.

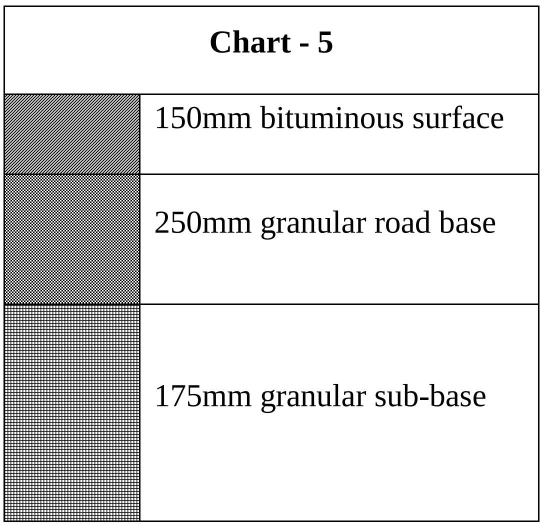

Chart 3-4: Chart 5 of ERA Structural Design Catalogue

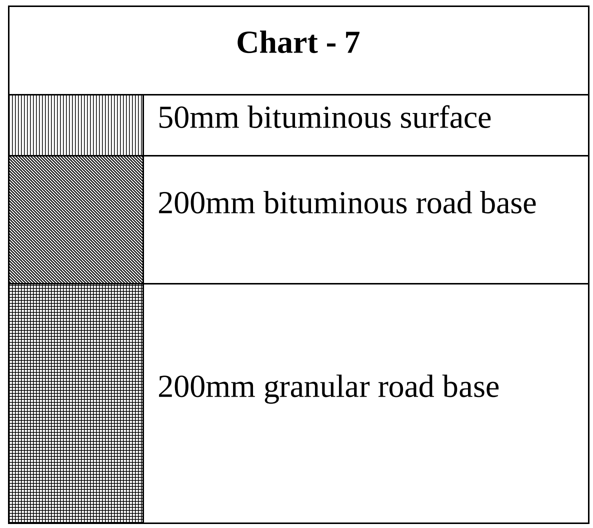

Chart 3-3: Chart 7 of ERA Structural Design Catalogue

To choose the more economical structure from the above two alternatives, cost comparison is a must to conduct. Taking the latest unit rate prices with respect to each quantity of materials ascertains Chart 5 to bring the more economical pavement structure than Chart 7.

3.4.6 HDM-4 Analysis

i. Defining the research Road Network and Section data

In this research maximum effort was made to use precise data and information along each and every road segment. The road network from Megenagna to Torhayloch totally covers a length of about 8.2 km. This network is further divided into thirteen sections with similar homogeneous characteristics. Basic data needed for the road network is summarized in Table 3-15 below.

Table 3-15: Road Network data

Road Name	Section Name From	Section Name To	Length (Km)	No. Lane	Lane width (m)	Walkway width (m)	Super-elevation (%)	AADT (2017)
Megenagna to Torhayloch (East to West)	**Megenagna** *(0+000)*	**Lem Hotel** *(0+320)*	0.32	6	3.5	4	4	12,181
	Lem Hotel *(0+400)*	**22** *(0+940)*	0.54	6	3.5	4	4	19,351
	22 *(0+940)*	**G.Besha** *(1+660)*	0.72	8	3	4	4	15,167
	G.Besha *(1+660)*	**Wuhalimat** *(1+820)*	0.16	6	3.5	4	4	13,638
	Wuhalimat *(1+920)*	**Urael** *(2+400)*	0.48	6	3.5	4	4	16,708
	Urael *(2+400)*	**Bambis** *(3+100)*	0.7	8	3.5	4	4	14,030
	Bambis *(3+100)*	**Estifanos** *(3+980)*	0.88	6	3.5	4	4	11,328
	Stadium *(4+540)*	**Leghar** *(5+100)*	0.56	6	3.5	4	4	28,350
	Leghar *(5+200)*	**Kera Junction** *(5+400)*	0.2	6	3	4	4	16,875
	Kera Junction *(5+400)*	**Mexico** *(5+720)*	0.32	6	3.5	4	4	15,537
	Mexico *(5+720)*	**Lideta** *(6+500)*	0.78	8	3.5	4	4	13,822
	Lideta *(6+620)*	**Coca** *(7+720)*	1.1	6	3.5	4	4	10,808
	Coca *(7+300)*	**Torhayloch** *(8+200)*	0.9	6	3.5	4	4	20,373

ii. Establishing Vehicle Fleet Characteristics

Table 3-16: Basic characteristics of each vehicle type

Vehicle Fleet Characteristics							
Vehicle type	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck & Trailer**	**Source**
Base Type	Bus Light	Bus Medium	Bus Heavy	Truck Medium	Truck Heavy	Truck Articulated	(ERA 2002) Pavement Design Manual with slight modification
Class	Buses	Buses	Buses	Truck	Truck	Truck	
Description	Buses up to 25 passenger seat	Buses with 25 to 45 passenger seat	Buses with over 45 passenger seat	Trucks of capacity 3.5 to 7.5 tons load	Trucks of capacity > 7.5 tons load	Articulated truck of capacity > 12 tons load	
Basic Characteristics							
Passenger car space Equivalent	1.6	1.8	2	1.8	2	2.2	W.T Consulting PLC
No. Wheels	4	4	6	6	10	18	Feasibility Report
No. axles	2	2	2	2	3	6	
Tyre Type	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Bias Ply	Interview
Base No. of recaps	1.3	1.3	2.4	2.4	2.4	3.6	
Retreated Cost	15%	15%	15%	15%	15%	15%	
Annual Km	34,000	34,000	34,000	10800	10800	5400	
Working hours	2880	2880	2880	1500	1500	1500	
Average Service life	15	15	16	20	20	20	
Private use	0%	0%	0%	0%	0%	0%	
Passengers	25	45	60	1	1	1	
Work related trips	100%	100%	100%	100%	100%	100%	

Vehicle Fleet Characteristics							
Vehicle type	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck & Trailer**	**Source**
Base Type	Bus Light	Bus Medium	Bus Heavy	Truck Medium	Truck Heavy	Truck Articulated	(ERA 2002) Pavement Design Manual with slight modification
Class	Buses	Buses	Buses	Truck	Truck	Truck	
Description	Buses up to 25 passenger seat	Buses with 25 – 45 passenger seat	Buses with over 45 passenger seat	Trucks of capacity 3.5 to 7.5 tons load	Trucks of capacity > 7.5 tons load	Articulated truck of capacity > 12 tons load	
Economic Unit Cost							
New Vehicle	1,650,000	1,850,000	2,650,000	3,150,000	3,581,727	4,300,000	W.T Consulting PLC
Replacement Tyre	8,450	7,600	15,200	14,800	15,000	15,700	
Maintenance Labor	41.44	40.01	53.96	45.80	45.80	50.97	
Crew Wage	65	40.28	62.21	43.67	84.19	88.75	
Annual Overhead	6,000	5,800	7,000	6,000	7,500	8,000	
Annual Interest (%)	12	12	12	12	12	12	
Fuel (liter)	17.34	17.34	17.34	17.34	17.34	17.34	NOC Corporation
Lubricant Oil (liter)	73.21	73.21	73.21	73.21	73.21	73.21	
Passenger Working Time Value	12	8.5	12	13	14	16	W.T Consulting PLC
Passenger Non-Working Time Value	6	6	6	8.5	8.5	8.5	
Cargo time value	0	0	0.6	0.42	1	1.3	
ESALF	0.03	0.1	0.742	0.148	3.944	7.44	Core Consulting Engineers PLC
Operating Weight (Kg)	5200	5500	9000	13000	22000	28000	

Vehicle Fleet Characteristics							
Vehicle type	**Small Bus**	**Medium Bus**	**Large Bus**	**Medium Truck**	**Heavy Truck**	**Truck & Trailer**	**Source**
Base Type	Bus Light	Bus Medium	Bus Heavy	Truck Medium	Truck Heavy	Truck Articulated	(ERA 2002) Pavement Design Manual with slight modification
Class	Busses	Busses	Busses	Truck	Truck	Truck	
Description	Buses up to 25 passenger seat	Buses with 25 – 45 passenger seat	Buses with over 45 passenger seat	Trucks of capacity 3.5 to 7.5 tons load	Trucks of capacity > 7.5 tons load	Articulated truck of capacity > 12 tons load	
Financial Unit Cost							
New Vehicle	2,062,500	2,312,500	3,312,500	3,937,500	4,477,158.75	5,375,000	W.T Consultant PLC
Replacement Tyre	10,562.5	9500	19,000	18,500	18,750	19,625	
Maintenance Labor	49.728	48.012	64.752	54.96	54.96	61.164	
Crew Wage	78	48.336	74.652	52.404	101.028	106.5	
Annual Overhead	7200	6960	8400	7200	9000	9600	
Annual Interest	14	14	14	14	14	14	
Fuel	21.675	21.675	21.675	21.675	21.675	21.675	NOC Corporation
Lubricant Oil	91.51	91.51	91.51	91.51	91.51	91.51	

iii. Submission of Work Standard

The HDM-4 software evaluates maintenance work standard alternatives defined by the user. Maintenance options are specified as either Scheduled (Time bound) or Pavement condition responsiveness maintenance. The policy of scheduled (Time bound) type of maintenance of pavements is based on providing routine maintenance whenever required and renewal/strengthening after every specified years without analyzing its economic implications. Whereas; Condition-responsive ones are specified by the threshold values of pavement condition indices such as roughness (mm/Km), Potholes (Maximum number), Cracking and Patching area (%), Skid resistance (Minimum number) at which maintenance works are applied in the simulation of pavement deterioration, and their intensities w1, w2, ..., wk. Since each threshold value of a condition-responsive work corresponds to specific application timing.

The definition of maintenance work standard shall, to a great extent, be governed by the difference in road condition and agency's resource availability. In each year of the analysis, the agency will experience a real outlay of funds (construction, labor and materials costs) and the system users will accrue real user costs (increased travel time, vehicle wear and tear, etc.)

Maintenance of asphalt road on a separate basis is submitted to address the base case and project case. Alternative one is labeled as base case and alternative two as project case. The difference between the baseline scenario and project case maintenance scenario (recorded as net present value) is the cost of delayed maintenance, in case-one, and the cost of increased traffic demand, in case-two.

This research adopts condition responsiveness maintenance scenario that will bring good performance of pavement and intervention periods are established for the dominant distress types. Total patching area, total carriageway cracked and potholing are used to form the maintenance treatments. From pavement condition survey report, a standard critical threshold level is recorded below which the pavement is considered unacceptable and in need of major rehabilitation.

Effective year for the application of maintenance starts at 2017 for base case1 and at 2022 for the project case1. Unit prices for the type of maintenance treatments are used according to the

AACRA unit rates. Table 3-17 shows the established unit rates of AACRA for different maintenance work items and severity level.

Table 3-17: Unit Costs for different maintenance work items

Work Item	Distress Type	Extent	Economic Unit Cost (ETB)	
Patching	Bleeding	1	206.47	Per m^2
	Delimination			Per m^2
	Crocodile Cracking			Per m^2
	Corrugation	2	212.41	Per m^2
	Raveling			Per m^2
	Rutting	3	218.35	Per m^2
	Lacy Edge			Per m^2
	Potholes			Per m^2
Rehabilitaion-1	Shoving asphalt		298.20	Per m^2
Rehabilitaion-2	Low Shoulder		145.92	Per m^2
Sealing	Transversal Cracking		13.56	Per m^2
	Longitudinal Crackin			Per m^2
Overlay				
Asphalt Concrete Overlay (5cm)			273.88	Per m^2
Asphalt Concrete Overlay (3cm)			84.58	Per m^2

For studying the effect of increased traffic flow an increase in 0.05 percentage of the normal traffic for each vehicle types is used. Base case2 and Project case2 alternatives are used and project analysis is compared with the previous one so that changes will be examined.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The effect of time and load on maintenance scenario is discussed hereunder. Generated reports from HDM-4 under cost steam section are presented and discussed briefly using economic indicators. As explained in the previous chapter, economic indicators evaluate the impact of a project on economic welfare which means if the benefits accrued from the project exceed the costs incurred on it or not.

The report shows economic analysis of two alternative project cases at 10% discount rate which is the opportunity cost of capital in Ethiopia. The analysis is made by comparing the projects case, where the effect of time is applied, in relation to the base case, where proper time is considered. Table 4-1 summarizes the values retrieved from HDM-4 project analysis (Project case versus base case).

Table 4-1: Economic analysis of Project Case relative to Base Case

Case - I: Considering the Effect of Delayed Maintenance		
NPV (in millions ETB)	Undiscounted	-186.11
	Discounted	-194.79
NPV/CAP	Base Case1	0
	Project case1	-0.057
EIRR		-1.3%
Case - II: Considering the Effect of Increase Traffic Demand		
NPV (in millions ETB)	Undiscounted	-180.68
	Discounted	-193.7
NPV/CAP	Base Case2	0
	Project case2	-0.056
EIRR		-1.3%

NPV/CAP refers to net present value ratio to capital costs.

NPV focuses on the total welfare gain over the whole life of an investment. For the above case (case-I) shown in Table 4-1, the project case which considers maintenance to be delayed for five years results a negative NPV in relation to the base case, proper time consideration. In principle, for a project or any investment to be feasible, NPV should give a positive value (i.e. NPV≥0) as it is considered to show an absolute welfare gain over the whole life of the project.

However, the NPV parameter is showing as the investment in the base case is more profitable than the project case. Discounting all future expenses and benefits to present value is no worth for the project case alternative. This means treatments that were expected to be applied for that particular time duration, five years, is never applied. Pavement structures damages from time to time that the cost of repairing facilities will also rise accordingly.

The other parameters which HDM-4 retrieves are the BCR and EIRR values. Even though these parameters are not mostly recommended for use in decision making process of road projects, they hold their own interpretations.

Based on the explanation given by (Sartori, Catalano and Genco 2014), Benefit to Cost ratio (BCR) is a quantitative tool for judging the economic advantages or disadvantages of an investment decision by evaluating its costs and benefits.

BCR attempts to identify and then quantify the costs and benefits of an activity and converts available data into manageable information. It can be estimated as ratio of the present value of net recurrent benefits to the present value of capital costs (Massimo Florio, et al. 2008).

$$\mathbf{BCR = \frac{Net\ Present\ Value\ of\ Benefits}{Net\ Present\ Value\ of\ Costs}} \qquad \text{… .. (4.1)}$$

However, HDM-4 calculates this parameter as the ratio of net present value to capital costs.

$$\mathbf{BCR = \frac{NPV}{CAP} + 1} \qquad \text{….. (4.2)}$$

Like the previous indicator, this method provides information that will assist decision-makers in the efficient allocation of resources. And it considers the time period of analysis to be the projected life of the project.

As it can be seen in Table 4-1, NPV/CAP value of the project cases (both scenario) shows a reduced value than the base cases. Using equation 4.2, BCR shows as the costs of the project exceed the benefits. This violates the major target in economic evaluation of maintenance, which is either maximizing benefit or minimizing cost. For any project to be acceptable, the minimum requirement is to get equal present value of benefits and cost.

From the results in Case-I, we can clearly see the variation in benefits both in discounted and undiscounted basis. The timing of a project is, thus, an important decision that needs to be analyzed in every case. Postponing a project changes the time profile of benefits and costs and hence the projects NPV. Postponing a project for example; one year merely shifts all costs and benefits by one year, the present value of both benefits and costs will be reduced by some percentage, as will the NPV of the project itself. In these cases, the sooner the project starts, the higher the NPV.

On the other hand, considering the effect of increased traffic by 0.05%, results in a decrease in NPV and VOC savings. This has a direct relation with the damage the cumulative axle poses on the pavement structure. If pavements are not maintained for the expected traffic demand, structural adequacy cannot be sustained.

EIRR, by definition, is the discount rate that brings the net present value (NPV) of a series of cash flows to zero (Spears 2017). It measures profitability of a project in a relative manner. In addition, it assumes that cash inflows are reinvested at computed internal rate of return. It evaluates which investment is providing comparatively better rate of return. EIRR is sometimes preferred due to the general disposition of business people towards rate of return rather than actual money return (Bruce J. Feibel 2003).

Given the (period, cash flow) pairs (n, C_n) where n is a positive integer, the total number of periods N, and the net present value NPV, the internal rate of return r is illustrated in Figure 4-1 below:

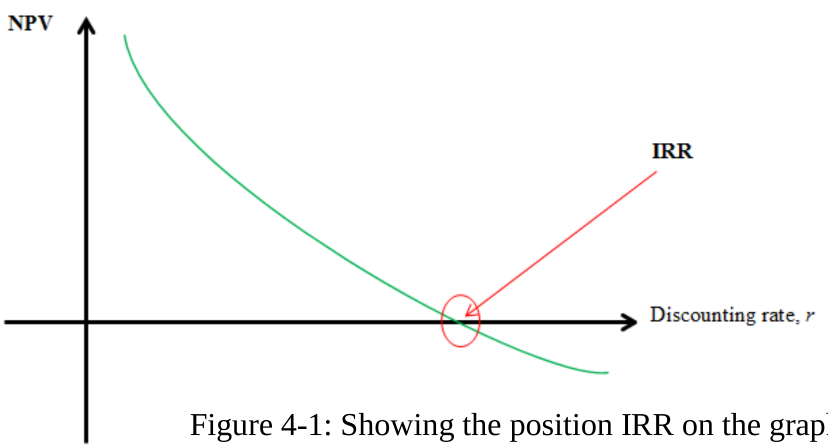

Figure 4-1: Showing the position IRR on the graph

$$\mathbf{NPV} = \sum_{n=0}^{N} \frac{\mathbf{C_n}}{\mathbf{(1+r)^n}} \quad \dots .. (4.3)$$

EIRR on both cases holds the same value. Basically, from the stand point of IRR, a project is accepted if and only if the rate of return of the project is greater than the opportunity cost of capital (discounting rate). The higher the percentage compared to OCC, the better the viability of the project would be.

Negative EIRR, on the other hand, indicates the sums of post-investment that is benefits are lesser than costs after maintenance application. This is the case for the current evaluation between the base case and the project case. As seen in Table 4-1 above, the project case does not bear enough return to the capital investment. Conversely stating, the base case is generating enough return to the project.

Keeping in mind the target in economic consideration which is maximizing benefits, infrastructure should provide the maximum benefit, with considerable cost, to the users of the facility. With reference to road infrastructures, activities applied to preserve the road asset should carefully consider all governing parameters. HDM-4 report assures the effect of taking time to apply maintenance and in accurate measurement of the traffic flow will have a reduced economic gain. As time goes on, the benefit the road users get from the road infrastructures starts to decline and accordingly the cost of using the road increases. The road agencies are also wasting their resources due to inappropriate considerations of the road condition variables.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study points out the general approach of AACRA towards the practice of maintenance activities. According to the research, AACRA do not have a defined and restricted protocol in this area. The present policy of AACRA in maintenance of pavements is based on providing routine maintenance whenever required and randomly strengthening the road network each year without analyzing its economic implications.

From the condition survey reports, the major distresses that exist in the city are potholes, cracks and rutting. Severity of each distress and percentages of their damages are given in manual inspection and correspondingly the type of treatments and extent of the work needed to recover the road section from the distresses are given by the road asset department team. However, the team has no ways of measuring the quality of work performed or a way of considering future demands that have the capability to affect pavement performances. Lack of advanced technologies (equipment) and budget constraints are mentioned as a factor for not doing quality assessment. This will let them not to be able to evaluate economic benefits and costs as a result of declined performance and serviceability of pavements.

With special attention to the value of time and traffic demand, this study clearly shows the economic loss to the road users as a whole. Economic indicators for consecutive 20 years show a decrease in economic benefits for not considering these two essential parameters.

Apart from these quantitative descriptions, a delay in maintenance will incur additional cost due to high rate of inflation. The cost of doing now and doing some time later will result in additional costs in respect of: material, equipment and man-power. Thus, when repair works are delayed it will often involve extensive rehabilitation and even re-construction, costing the country in general and the city administration in particular unnecessary huge capital and many more times less costly maintenance carried out earlier.

Furthermore; considering traffic demand, its fulfillment would be the maintenance of safe and acceptable road driving condition. Road users experience reductions in route security and journey time reliability as a result of lower road maintenance standards. This leads to a loss in productivity because of more time in travelling and reduced working time.

The most cost-effective form of maintenance is achieved when an organization is capable and prepared to carry out appropriate interventions at an early stage of deterioration and thus limit the extent of damages.

As NPV results indicate, the cost of recovery from deteriorated pavement conditions is much higher than the costs of retaining existing quality levels. What should be done normally are: reasonable level of effort that should be applied; standardized quality of work; the extent of the work; the condition of the work; the condition of the pavement at the time maintenance is applied; and the rate of change of road condition at the right time are all very relevant to effective application of the required maintenance activities. Considering the importance of a well-established and efficient road network to the country's economy, it's a must to put much care and emphasis to maintenance strategies/program of the road sections.

Efficient maintenance therefore requires an adequate balance between sustained performance on one hand, and increased maintenance costs on the other.

5.2 Recommendations

Based on the findings of the study, the following recommendations are forwarded for the improvement of the current road maintenance practice at AACRA.

- Randomness in time interval of maintenance interventions should be changed to specific and result-oriented condition responsiveness. Intervention based on the condition of the road will be very much helpful to bring the pavement to its original condition before it is too late. Predominant and critical distress types should be identified through condition surveys and triggering value should be established for applying maintenance work before they pose more damage. As a result, the desired pavement performance can be achieved.
- Preservation of existing road conditions should be given equal emphasis and considerations as capital projects. AACRA must focus particularly on preventive maintenance than maintaining roads with higher rate of deterioration.
- AACRA must establish defined work schedule and detailed method of assessing the quality of their work with regard to their practice in road maintenance.
- Quality assurance methodologies for post-maintenance application need to be established in order to evaluate whether the desired target is achieved or not. Result driven works absolutely bring the standards and quality of the existing city's road to the next level.
- AACRA together with the City Administration should give adequate consideration to road maintenance works and seek for various funding options to fill the maintenance backlog. Budget limitation shall not be put as a reason for poorer level of service of the city roads once they have been constructed in good condition.

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APPENDICES

Appendix A: Some of the road segments in Addis Ababa under each road class.

Table A-1: Road Segments under Principal Arterials Street

PAS-0	From National palace (Gebriel Junction) to Hilton hotel
	From Hilton Hotel to Economic Commission for Africa
	From Akaki Tulu-Dimtu to Lebu RA
PAS-1	From Junction of Road No. 132PAS to AA boarder
	From Ayat Sq. to Yerer Goro School
	From Yerer Goro School to IT Park
	From IT Park to Akaki Tulu-Dimtu RA
	From Lebu RA to Welete Suk
PAS-2	From Tewodros Sq. to Arada Building
	From Megenana Sq. through CMC to Ayat Sq.
	From Ayat RA to Ayat Condominium
	From CMC Sq. through Sumit to no 149 & 150 PAS2 Junction (Meri radio Beken)
	From Ayat Sq. to Keralo Road No 135PAS
	From Bole Brass Sq. to Civil Aviation Gumruk
	From Airport Gumruk to No 150 Road
	From Kaliti RA through Kaliti metal to Tulu Dimto Sq. (along Debrezeit road)
PAS-3	From Legahare to Tewodros Sq.
	From Ambasader theater to Zewditu Hospital
	From Zewditu Hospital to Sheraton Hotel
	From Sheraton Hotel to National Palace
	From Grand Palace (Gebi Gebriel jun.) to 6 Kilo
	From Giorgis Sq. to Afencho Ber
	From Afencho Ber to Yekatit 12 Hospital
	From Mexico Sq to Beherawi theater
	From Torhayloch to Saris Weintej
	From Saris Weintej through Mexico Sq. to Meskel Sq.
	From Mola Maru to Jhoshasen
	From Dese hotel through Abenet to Atobis Tera
	From Mirab Hotel to Sebatena Police Station
	From Minilik Sq. to Mesalemia Junction
	From Rufael through Semen Mazegaga to Kechene bridge
	From 4 Kilo to Shiro Meda (RR)
	From Megenana to Minilik hospital
	From Minilik Hospital to Janmeda Jun.
	From Yordanos hotel to Kazanchiz Meberat

	From Meskel Sq. to Gotera Interchange
	From Gotera Interchange to Kality RA
	From Meskel Sq. to Bole airport RA
	From Zerihun Building through Atlas hotel to WORBEC building
	From Meskel Sq. to Megenana RA
	From Akaki Road(Tirunesh Bejing) to Kality Technology University
	From Gofa Mazoria to Gofa Meberat
	From Gofa Meberat to Lafto Bridge
	From Gofa Mazoria to Telecomunication Building Kikos Junction
	From Telecomunication Building Kikos Junction
	From St. Michael RA through Jamo CGS overseas PLC to Alem Gena
	From Ayer Tena RA to Tatek Ambo
	From Ayer Tena road K/Mehiret church to yeshi Debele road
PAS-4	From Ministry of Health to National bank of Ethiopia
	From Ethiopia hotel to national palace
	From Kaznchis Super market to Kazanchiz Meberat
	From Meskel Sq. Mebrate to post office
	From Filwha hotel to Zewditu Hospital
	From Zeditu Hospital through Horma garage to Post Office
	From Post Office to Tikur anbesa hospital
	From Tewodros Sq. Mega Anfi teater to audit service Off. Building
	From Degol Sq. to Minilik Sq.
	From Arada Building to Municipality
	From Arada Building to Abune Petros
	From Anbesa Gibi to Total Gas station
	From Kideste Mariam Jun. to 4 kilo
	From Mexico Sq. to Di Afrique (No 41 PAS Jun.)
	From Diafrique to Berbere tera
	From Areke fabrica to Tekle-Haymanot Sq
	From Koka bridge through Abenet Hotel to Tekle-Haymanot Sq
	From Ministry of Health to Chefe Meda (Pepci)
	From Pepsi to Jhosansen
	From Berbere Tera to Hunenaw Mera (Adarashea)
	From T/Himanot Sq to sinima Ras junction
	From Kolfe RA through Feteno Derash to no 196 PAS0
	From Winget to Asko Bridge
	From Asko Bridge to Sansusi Bridge
	From Abune Petros Square - Paster
	From Paster to Winget
	From Mesalemia junction to Medhanialem high school
	From Autobes Tera to Paster
	From Giorgis through Semen Mazegaga Adisu gebeya (Total)

	From Total to Kela
	From Shiro meda to Entoto Mariam
	From Sidist Kilo to Minilik hospital
	From Arat Kilo to Kebena bridge
	From ECA to Meskel Sq.
	From Gibi Gebriel junction to Kazanchiz 6th Police Station
	From Kazanchiz Total to S/t Urael church
	From Shola market to Lem hotel
	From Lem hotelYenegew sew School to RR
	From Gotera inter change to Wolo Sefer
	From S/t Urael church to Bole brass clinic
	From Wereda 17 health center to Gergi RA
	From Gergi RA to no 124 SAS2 junction (no 46 bus terminal)
	From RR to meberat hail (E.L.P.O)
	From Mebrat hail to Yerer Goro
	From Ararat junction to Kotebe Karalo
	From Semen Terminal to Karalo
	From Gured Shola through Sumite to Yeka Bole
	From Debrezeit road to Gelan Condominium
	From Kaliti metal to no 167 PAS1
	From Pushikin Sq through Kera to Gotera
	From Bulgaria Mazoria to Kera
	From Mexico beside Federal Inland revenue to Orbis Jun.
	From Orbis Jun. to AU Hall
	From Mexico to Tinbajo Monopol Sq
	From Tinbaho Monopol sq. to Mekanisa RA
	From Tinbajo monopol through African union hall to Bulgaria Mazoria
	From AU to Ledeta Tebel
	From Tele ring road (Iran Embassy)
	From Pushkin to Tele
	From Wereda 23 health Center to Total RA
	From Dese hotel through Bisrate Gebriel no 189 PAS4 junction
	From Koshe RA City Tip RR to Bisrate Gebriel Junction
	From Lafto Meberat to Lebu Sq. through mekanisa addis sefer to no 192 PAS
	From Lebu RA to Left &Right Side
	From Ayertena RA through Repi Elementery School to Jima ber

Note: Road no. 132 PAS = From Ararat junction to Kotebe Karalo

Road no. 149 PAS = From Bole Brass Sq. to Civil aviation Gumruk

Road no. 135 PAS = From Semen Terminal to Karalo

Appendix B: Some Input Data for HDM-4 Analysis

1. Design Speed

Design speed is crucial control element in the road design process. It is the maximum safe speed that can be maintained over a specific section of the road when conditions are so favorable that the design features of the road governs. Design speed adopted for the road network from Torhayloch to Megenagna is based on geometric design manual of AACRA.

The assumed design speed should be a logical one with respect to topography, anticipated operating speed, adjacent land use, presence of bicycle and pedestrian accommodations and the functional classification of the highway. Once the design speed is selected, all of the pertinent features of the highway should be related to it to obtain a balanced design. Above minimum design values should be used, where practical. Some design features, such as curvature, super-elevation, and sight distance are directly related to and vary appreciably with design speed. Therefore, wider lanes, shoulders and clearances should be considered for higher design speeds. Thus; when a change is made in design speed, many elements of the highway design will change accordingly.

Table B-1: Minimum design speeds adopted from AACRA

Road type	Minimum design speed for CARS (Km/hr.)
Arterial Road Controlled Access	80
Arterial and sub-arterial road with frontage access	70

However, AASHTO generally recommends a design speed in the range from 50 to 100 Km/hr. for urban arterial roads on which a maximum design speed of 100Km/hr. is to be adopted. Drivers under normal conditions don’t have an operating speed higher than 80Km/hr. Design speeds are selected on the basis of 10Km/h incremental.

2. Climate

Climate has its own effect on road network in the way it accelerate the rate of deterioration. Temperature, rainfall and winter condition of an area the main conditions to be discussed in pavement design.

The project area is located on the higher part of the city, having altitude of 2350 – 2405m above the mean sea level, which is considered as Dega.

3. Temperature

For Addis Ababa area, the monthly temperature is high during the months of March through May, about 27.5^{o}C. And it is low in the months of November through January, 4.7^{o}C. The effective temperature is lower than 25^{0}c, which is good and time comfortable.

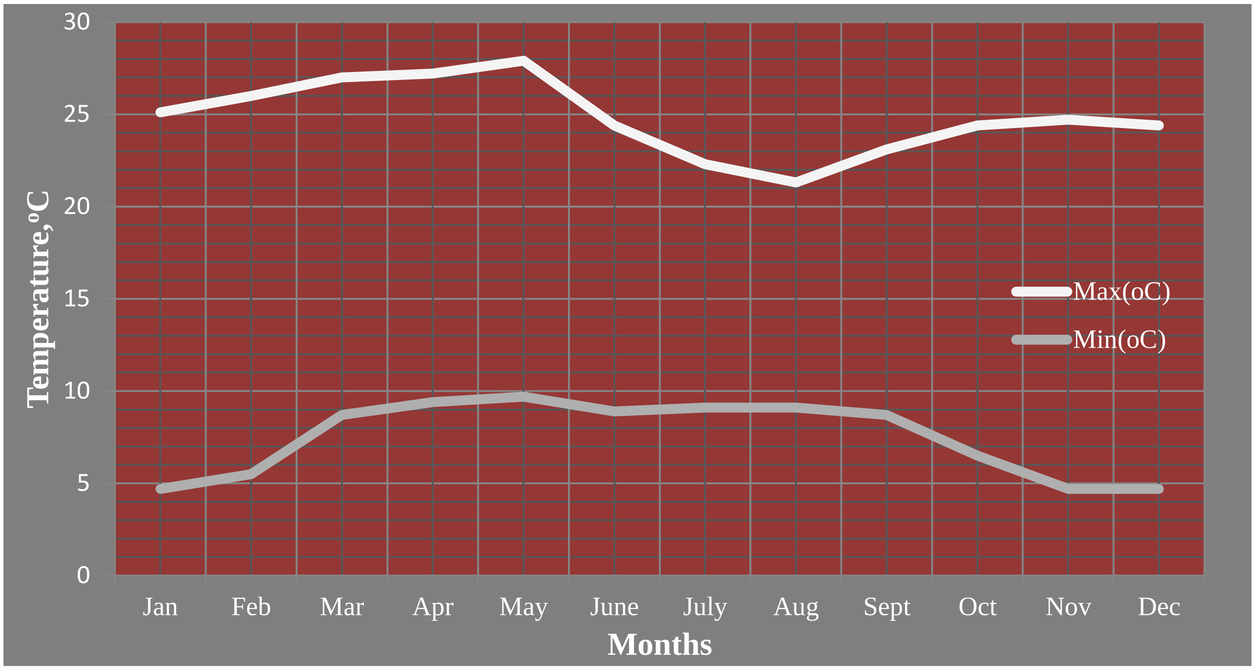

Figure B-1: Mean Annual Temperature of Addis Ababa

4. Rainfall

Since the project area is located in Addis Ababa, the rainfall of the city is considered for the project area. Accordingly the mean annual rainfall of the project area varies in the range of 918mm - 1567mm, and the rainy period is between June and September, although occasional shower is expected in the months of March, April, May, October and November.

The mean monthly rainfall is high during the months of July and August i.e. 250mm and 280mm and it is low during the months of November and December i.e. 8mm and 9mm respectively.

Table B-2: Mean Annual RF of Addis Ababa

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

In HDM-4, the environment is classified under five moisture and temperature classifications. The climatic zone of each section of the research areas was identified based on the mean monthly temperature; mean monthly rainfall which is currently available under the default configuration of HDM-4. Accordingly, the climate types of all the road sections were classified as semi-arid/Tropical.

5. Topography

The terrain of the land traversed by the road has a direct influence on the geometric design of the road. Although the type of the terrain has an effect on the geometric design parameters of the design process, it is more evident in its effect on vertical alignment.

The terrain of the project alignment is dominantly flat except the short stretch near Stadium, which is rolling.

Appendix C: Generated Reports of HDM-4 under Cost Streams

Case – I: The Effect of Delayed Maintenance

Setup Run

Conduct Economic Analysis

Base Alternative – Base Case1

Table C-1: Economic Analysis Summary for the Effect of Delayed Maintenance-Option 1

HDM - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Megenagna to Torhyloch**

Run Date: **10-06-2017**

This report shows total economic benefits using the following:
Currency: Ethiopian Birr (millions).
Discount rate: 10.00%.
Analysis Mode: Analysis-by-Project

Alternative: PROJECT CASE1 vs Alternative: BASE CASE1

	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	5,787.10	77.71	0.00	2,962.01	2,716.70	0.00	0.00	0.00	-186.11
Discounted	1,297.00	24.94	0.00	539.09	588.06	0.00	0.00	0.00	-194.79

Economic Internal Rate of Return (EIRR) = -1.3% (No. of solutions = 2)

Table C-2: Economic Indicators Summary for the Effect of Delayed Maintenance- Option 1

H D M - 4

HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: **Megenagna to Torhyloch**

Run Date: **10-06-2017**

Currency: **Ethiopian Birr (millions)**

Discount Rate: **10.00%.**

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	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/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
BASE CASE1	2,119.458	2,119.427	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PROJECT CASE1	3,441.402	3,416.431	1,321.943	1,127.150	0.000	-194.793	-0.057	-0.057	-1.3 (2)

Figure in brackets is number of IRR solutions in range -90 to +900

OR

Setup Run
Conduct Economic Analysis
Base Alternative – Project Case1

Table C-3: Economic Analysis Summary for the Effect of Delayed Maintenance - Option 2

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Megenagna to Torhyloch**
Run Date: **10-06-2017**

This report shows total economic benefits using the following:
Currency: Ethiopian Birr (millions).
Discount rate: 10.00%.
Analysis Mode: Analysis-by-Project

Alternative: BASE CASE1 vs Alternative: PROJECT CASE1

	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	-5,787.10	-77.71	0.00	-2,962.01	-2,716.70	0.00	0.00	0.00	186.11
Discounted	-1,297.00	-24.94	0.00	-539.09	-588.06	0.00	0.00	0.00	194.79

Economic Internal Rate of Return (EIRR) = 15.6% (No. of solutions = 2)

Table C-4: Economic Indicators Summary for the Effect of Delayed Maintenance - Option 2

H D M - 4

HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: **Megenagna to Torhyloch**

Run Date: **10-06-2017**

Currency: **Ethiopian Birr (millions)**

Discount Rate: **10.00%.**

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	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/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
PROJECT CASE1	3,441.402	3,416.431	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BASE CASE1	2,119.458	2,119.427	-1,321.943	-1,127.150	0.000	194.793	0.092	0.092	15.6 (2)

Figure in brackets is number of IRR solutions in range -90 to +900

Case – II: The Effect of 0.05 Percent Traffic Growth

Setup Run

Conduct Economic Analysis

Base Alternative – Base Case2

Table C-5: Economic Analysis Summary for the Effect 0.05 Percent Traffic Growth

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Megenagna to Torhyloch**
Run Date: **10-06-2017**

This report shows total economic benefits using the following:
Currency: Ethiopian Birr (millions).
Discount rate: 10.00%.
Analysis Mode: Analysis-by-Project

Alternative: PROJECT CASE2 vs Alternative: BASE CASE2

	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	5,787.10	77.71	0.00	2,969.86	2,714.28	0.00	0.00	0.00	-180.68
Discounted	1,297.00	24.94	0.00	540.19	588.05	0.00	0.00	0.00	-193.70

Economic Internal Rate of Return (EIRR) = -1.3% (No. of solutions = 2)

Table C-6: Economic Indicators Summary for the Effect 0.05 Percent Traffic Growth

HDM-4

HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Indicators Summary

Study Name: **Megenagna to Torhyloch**

Run Date: **10-06-2017**

Currency: **Ethiopian Birr (millions)**

Discount Rate: **10.00%.**

Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	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/RAC)	NPV/Cost Ratio (NPV/CAP)	Internal Rate of Return (IRR)
BASE CASE2	2,119.458	2,119.427	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PROJECT CASE2	3,441.402	3,416.431	1,321.944	1,128.244	0.000	-193.700	-0.056	-0.057	-1.3 (2)

Figure in brackets is number of IRR solutions in range -90 to +900