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Life Cycle Cost Analysis for Road Maintenance Interventions

(A case Study for Alemgena District)

A Thesis in Road and Transport Engineering

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A Thesis

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The undersigned have examined the thesis entitled **Life Cycle Cost Analysis for Road Maintenance Intervention the case study of Alemgena Road Maintenance District** presented by Workie Tegen, a candidate for the degree of Master of Science and hereby certify that it is worthy of acceptance.

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DECLARATION

I, the undersigned, declare that this thesis is my original work, and has not been presented for a degree in any other university; and that all sources of materials used for the thesis have been duly acknowledged/referred.

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Workie Tegen

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LIST OF ACRONYMS

AADT:	Annual Average Daily Traffic
ERA:	Ethiopian Road Authority
ERCC:	Ethiopian Road Construction Corporation
ERFO:	Ethiopian Road Fund Office
ESAL:	Equivalent Standard Axel Load
ETB:	Ethiopian Birr
ETCA:	Ethiopian Transport Construction Authority
FDRE:	Federal Democratic Republic of Ethiopian
FHWA:	Federal Highway Administration
GDP:	Gross Domestic Product
HDM 4:	Highway Development and Management Tool
LCCA:	Life-Cycle Cost Analysis
NPV:	Net Present Value
RSDP:	Road Sector Development Program
RUC:	Road User Cost
TV:	Traffic Volume
WB:	World Bank

ABSTRACT

The main purpose of this study was to conduct the life-cycle cost analysis of road maintenance interventions undertaken by the Ethiopian Roads Authority (ERA), considering the Alemgena Road Maintenance District as a case study. In order to meet the objectives of the study, a case study was considered accounting for both quantitative and qualitative data. The road condition survey data were collected from ERA's Alemgena Road Maintenance District/(ARMD). From the five (5) road maintenance sections ten, (10) paved roads were selected for investigation and analysis. The collected data were entered into the Highway Development and Management Model (HDM-4) and life-cycle cost analysis (LCCA) was carried out to determine the economic viability of different road maintenance interventions. The roads conditions considered in the study ranges from poor to fair. The existing conditions of the roads help to determine the kinds of maintenance / improvements requirements. All possible input data were collected and entered into HDM-4. The LCCA was conducted for 20 years with additional one year of intervention period. The analyses were carried out with consideration of with and without improvement cases. The results indicated that the proposed interventions were economically viable fulfilling the requirements, with the net present values (NPVs) of well over zero, economic internal rates of return (EIRRs) of greater than the opportunity cost of capital, which was (10%), and benefit-cost ratios (B-CRs) of greater than one. This tells us that consideration of all costs and benefits during the lifetime of the projects give better decision for proposed interventions alternatives. In terms of budget, the 20 years' analysis period was considered in this investigation. The total lifetime cost of maintenance activities currently applied by ERA is much higher than the proposed maintenance interventions and it is not economically optimum therefore, based on the findings, workable recommendations and the need for further research were forwarded.

Key Words: Life-Cycle Cost Analysis, Road Maintenance Interventions, Evaluation Parameters

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

It has been a long-established fact that national and regional physical cohesion and market integration is dependent on a smooth and speedy flow of goods, services and people; which is in turn reliant on adequate and efficient means of transportation and communication (Mwase, 1995). In the context of Ethiopia, road network is the major means of transportation in the country and it is considered as critical to the development of other key economic and social sectors such as agriculture, industry, mining, tourism, education and health (ERA, 2015; MOFED, 2010).

Historically, the commitment of the Ethiopian government for the expansion of road network throughout the country goes back to 1951 with the establishment of the Imperial Highway Authority (IHA). By then, the road network in the whole country was only 6,400 km of which 3,400 km (53.1%) was asphalt and the remaining 3,000 km (46.9%) was gravel road. In the same manner, the current government has been working for the development of road transportation; particularly, by preparing the Road Sector Development Program (RSDP) and establishing separate Road Fund Administration in 1997 (ERA, 2015; FDRE, 1997). Since then, the road network in the country has increased from 26,550 km in 1997/8 to 60,466 km in 2013/14 (ERA, 2015; National Planning Commission, 2015). The above data shows that a dramatic increase in road network (annual average increase of 5.3%) had been witnessed in Ethiopia in during the sixteen years. Apart from expanding the road network, proper maintenance of the system should have been taken as vital to preserve its serviceability and structural integrity; which are important for the effectiveness of transportation services, safety of road users and economic development (Rouse & Chiu, 2009; Wilde et al., 2014).

Currently, the maintenance of the Federal roads is administered by the Ethiopian Roads Authority (ERA). ERA is undertaking the maintenance of the entire main road network of the country under ten maintenance districts, which are the subdivisions of five regional areas organized based on geographical proximity and convenience.

In Ethiopia, road maintenance is financed by the Government and administered by the Road Fund Office, established in 1997. The financing of road maintenance was stipulated in the Road Sector

Development Program (RSDP) that about 26% will be contributed by road users, another 26% will be coming from regular government budget and the remaining 48% coming from the Development Partners (Office of Road Fund Administration, 2001). Nevertheless, ERA's report indicates that inadequate fund, absence of integrated maintenance intervention measure and lack of comprehensive approach are noticed as the major problems in road maintenance activities in Ethiopia (ERA, 2015; MOFED, 2010).

More specifically, with ever-increasing costs of road maintenance and limited budgetary allocation, it is essential for road agencies to utilize different economic and operations research tools in order to facilitate proper decision-making for economically reasonable long-term investments. Nowadays, Life-Cycle Cost Analysis (LCCA) is one of such economic analysis tools with significant application in road pavement construction and maintenance intervention projects (FHWA, 2002; Rouse & Chiu, 2009).

Based on principles of economic analysis, the LCCA is widely applied in the estimation of the total long-term economic viability of different road maintenance intervention options (Babashamsi et al., 2016). It is a model that helps road agencies in decision-making to optimize the total benefit-cost relationships of a road over its lifetime in relation to the available financial capacity and different road maintenance alternatives, thereby improving the economic viability of the road asset (Rouse & Chiu, 2009). Being induced with this, this study is targeted to assess the life-cycle cost analysis of road maintenance interventions in the case of Alemgena Road Maintenance District in Ethiopia.

1.2 Statement of the Problem

The escalating costs, absence of integrated intervention measure and lack of comprehensive approach in road maintenance in Ethiopia, apparently calls for the use of LCCA for appropriate economic decision making by ERA in road maintenance interventions. More specifically, identifying the long-term economic viability of different road maintenance interventions (i.e., LCCA) through scientific research, in Ethiopia, appears to be an urgent priority for effective and efficient management of road asset.

Nevertheless, in the present Ethiopian context, the LCCA of the currently implemented road maintenance interventions is neither addressed by research nor applied by ERA. With the intention of filling this gap, the main purpose of this study is to evaluate the LCCA of road maintenance interventions taking sample roads from the Alemgena Road Maintenance District in Ethiopia.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of the study is to propose the appropriate type of maintenance activities at the right time so as to optimize the total lifetime costs of roads by using LCCA and HDM4 tool.

1.3.2 Specific Objectives

The specific objectives of the study were to:

- Identify different maintenance intervention activities based on road defects;
- Comparing of costs and benefits of different maintenance intervention over 20 years;
- Determine an appropriate preventive method for road sections based on LCCA; and
- Evaluate current and proposed road maintenance option based on current allocated budget.

1.4 Hypothesis

Currently existed inappropriate maintenance interventions of roads result in a higher lifetime costs.

1.5 Significance of the Study

Determining the LCCA of different road maintenance interventions is a precondition for implementing economically viable maintenance alternatives and keeping the road asset in good condition during its lifetime. Currently, however, the LCCA of road maintenance interventions in Ethiopia has not been examined through research. Therefore, the findings of this study are envisaged to have the following significance.

- Identify and provide base information for road agencies on the lifetime costs and benefits of road maintenance interventions in Ethiopia; thereby, indicating on how to integrate economic variables to the road maintenance planning.

- The findings could also help the ERA and policy makers in making decisions about the appropriate road maintenance types with lower lifetime costs and higher net present value for the economy.
- Finally, it is hoped that the findings of this study and their implications could serve as stepping stones for conducting further studies in the area of road maintenance activities with consideration of lifetime costs and benefits.

1.6 Scope of the Study

ERA performs road maintenance activities in five established regional areas and ten maintenance districts. Out of these, the current study has taken only sample roads from the Alemgena Road Maintenance District (ARMD), which is the central ERA's regional areas of road maintenance activities.

1.7 Limitation of the Study

The data collected in this study were from one road maintenance district (RMD), which is restricted to the central geographical areas of road network in Ethiopia. The topographic nature, climate zone, and traffic volume would have significant influence on the cost of maintenance prevalently as well as over the lifetime of the road. Thus, the findings of this study may not be generalized, but replicated to other ERA's regional areas.

1.8 Organization of the Study

This thesis is organized under five chapters. Chapter One presents background of the study, statement of the problem, objectives of the study, significance of the study, scope of the study and limitation of the study.

Chapter Two treats reviews of related literatures; Chapter Three deals with the methodology of the study, which includes; design of the study, description of the study area, sample size and sampling technique, data type and procedures of data collection, and methods of data analysis.

Chapter Four deals with the analysis of the data and interpretation of the results. Finally, Chapter Five presents the summary, conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the review of theoretical and empirical literatures related to the topic, objectives, and variables of the study. The chapter begins by discussing the concept of life-cycle cost analysis, its purposes as related to road maintenance interventions, and the steps involved in applying the approach. The components of economic analysis in life cycle costing, types of costs involved (initial construction costs, maintenance costs and rehabilitation costs), road fund administration, the types and purposes of road maintenance are also presented in this chapter. Finally, the chapter includes reviews on such topics like road condition survey, road maintenance interventions, and data types required for HDM-4 (Highway Development and Management tool).

2.2 The Life-Cycle Cost Analysis

2.2.1 Overview of LCCA

The development of road infrastructure, in any country, stands as one of the investment areas demanding huge initial capital and maintenance costs (Gwilliam & Shalizi, 1999). With ever-increasing costs of road construction, maintenance and rehabilitation, road agencies are applying different models or tools from the fields of economics and operations research in order to facilitate proper decision-making for economically reasonable long-term investments (Babashamsi et.al., 2016). Nowadays, Life-Cycle Cost Analysis (LCCA) is one of such an economic analysis tools with significant application in road pavement construction and maintenance intervention of projects (FHWA, 2002; Rouse & Chiu, 2009).

The concept of life-cycle cost-benefit analysis was first introduced in 1960 by the American Association of State Highway Officials (AASHO) for highway investment decisions; based on the economic evaluation of highway upgrades during the planning stage (Babashamsi et.al., 2016; Coe, 1981). The cost of road construction consists of design expenses, material extraction, construction equipment, maintenance and rehabilitation strategies, and operations over the entire service life

(Frangopol et.al., 1997). Investments in road infrastructure are made with the purpose of providing service for a relatively extended number of years.

The ability of a given road asset to provide service over its lifetime is not only dependent on initial investment but also contingent on periodic maintenance and rehabilitation activities (FHWA, 2002). However, in most road investment projects, it is not uncommon that road authorities commit the available resources more on initial construction costs with less or no emphasis to the future maintenance and rehabilitation costs. (Babashamsi et.al., 2016) asserts that the LCCA is an important economic tool that can help road authorities to calculate the lifetime costs and benefits of highways for making the most preferable investment decisions.

The life cycle costing as related to road asset focuses on the costs associated with all the phases of its lifetime: design, construction, operation, and maintenance (Baumann, 2006; Rouse & Chiu, 2009). Therefore, the conceptual essence behind the LCCA is that road infrastructure investment decisions should consider all of the costs incurred during the period over which the alternatives are being compared (Coe, 1981; FHWA, 2002). As asserted by the foregoing, that is what makes the LCCA peculiar and highly applicable to road investment decisions by comparing the alternative projects incorporating both the initial construction and subsequent future maintenance costs.

2.2.2 The Purpose of LCCA in Road Maintenance Interventions

(Frangopol et.al., 1997) noted that many repair maintenance strategies are based on experience and local practice rather than on sound theoretical investigations. They also argue that maintenance based solely on experience may be more expensive and less safe than those based on a more rational approach. This situation clearly calls for the application of the life-cycle cost approach for guiding decisions in investments of road maintenance. Because of limited capital resources and increasing demand for new road infrastructure, road authorities usually focus more on lower road maintenance expenses. In most developing countries, where there are budget constraints, governments and road authorities are regularly challenged with funding road projects due to limited financial capacity (Babashamsi et.al., 2016).

The main purpose of LCCA in road investment decisions is, therefore, to optimize the total benefit-cost relationships of a road over its lifetime (Rouse & Chiu, 2009). Based on principles of economic analysis, the LCCA is widely applied in the estimation of the total long-term economic viability of different road maintenance intervention options (Babashamsi et.al., 2016). As to (FHWA,2002), the major purposes of applying the LCCA in road maintenance includes the comprising of life cycle costs, considerations of the agency and user costs, a focus on preservation strategies, and stewardship.

The inclusion of life cycle costs: Including not only the initial costs of construction but also equally considering and including future maintenance as well as rehabilitation costs of the road asset is at the heart of LCCA (Coe, 1981; Frangopol et.al., 1997).

Considerations of both the agency and user costs: The LCCA, as an economic analysis tool for decision-making purposes, provides a framework for considering tradeoffs between user costs and additional agency expenses. In the analysis of life-cycle costs; travel time, vehicle costs, and safety impacts become more important to investment decisions (FHWA, 2002). Therefore, LCCA provides a means for transportation decision makers to extend consideration of the merits of alternative projects by accounting for both agency costs and road user costs (Choi.et al., 2016).

The focus on preservation strategies: Unlike the traditional road maintenance, the LCCA justifies the benefits of preservation activities that are normally performed before distress occurs or detectable. (Frangopol et.al., 1997) argue that the cost of routine maintenance is difficult to predict and the focus on prevention strategies are more likely viable in reducing life-cycle costs. In LCCA, the cheapest is not always taken for granted as the best strategy. By applying specific treatments before distress occurs, preservation activities delay the onset of deterioration and increase the useful lives of infrastructure investments, thereby reducing agency expenditures and lowering costs to users (FHWA, 2002).

In general, the major advantages of applying LCCA in road maintenance interventions are to forecast the whole life-cycle costs, evaluate the competing options, and judge the trade-offs between the costs and benefits (Baumann, 2006). He also argued that an integrated approach to design, construction, operation and maintenance can improve sustainability, design quality, reduce maintenance requirements and subsequently reduce life-time costs.

2.2.3 Steps and Components of the Life-Cycle Cost Analysis

The appropriate timing for conducting the life-cycle cost analysis is to start it as early as the project development or project design stage (Walls & Smith, 1998). The methodological steps involved in applying the life-cycle cost analysis to the road maintenance appeared to be similar in the literature with slight differences based on the purpose for which the analysis is required. As to the (FHWA,2002), LCCA involves five sequential steps that include:

- Establish alternative pavement design strategies for the analysis period;
- Determine performance periods and activity timing;
- Estimate costs (agency and user);
- Compute life-cycle costs; and
- Analyze the results.

The first step in the LCCA process is to define realistic design options. For every likely option, it is important to identify initial construction or rehabilitation activities, as well as to predict future rehabilitation and maintenance activities and the times of those individual actions. Hence, a plan of activities must be created for each design option.

The next step is to estimate costs for all activities. In this regard, it is recommended to include not only direct agency expenses (construction or maintenance activities) but also user costs, in order to get a better picture of the impact of maintenance/repair (Walls & Smith, 1998). After cost is defined for every possible option, then the total life-cycle costs for each competing alternative can be calculated. LCCA uses discounting to convert future costs to present values so that the lifetime costs of different alternatives can be directly compared (Babashamsi et.al., 2016). Figure 1 below represents costs that could be included in the calculation and LCCA process.

All costs in LCCA are divided into four groups: construction, agencies, users and environmental costs. These costs are individually calculated for each competing alternative. If one of the alternatives does not include a certain cost, then the others should also exclude this cost: only then can the alternatives be fairly compared. For example, if one alternative includes road markings into LCCA, then the other alternatives must include road markings too. Some of the costs can be difficult to quantify, so their inclusion in the project can be optional. To be able to fairly compare all opportunities, the discount rate and analysis period should be the same for all alternatives (FHWA, 2002).

There are different parameters to compare life-cycle costs and the most common ones are: Net Present Worth (NPW) method, Benefit Cost Ratio (B/C ratio), Internal Rate of Return (IRR), and Equivalent Uniform Annual Cost (EUAC) method, with the most popular being IRR and NPW parameters.

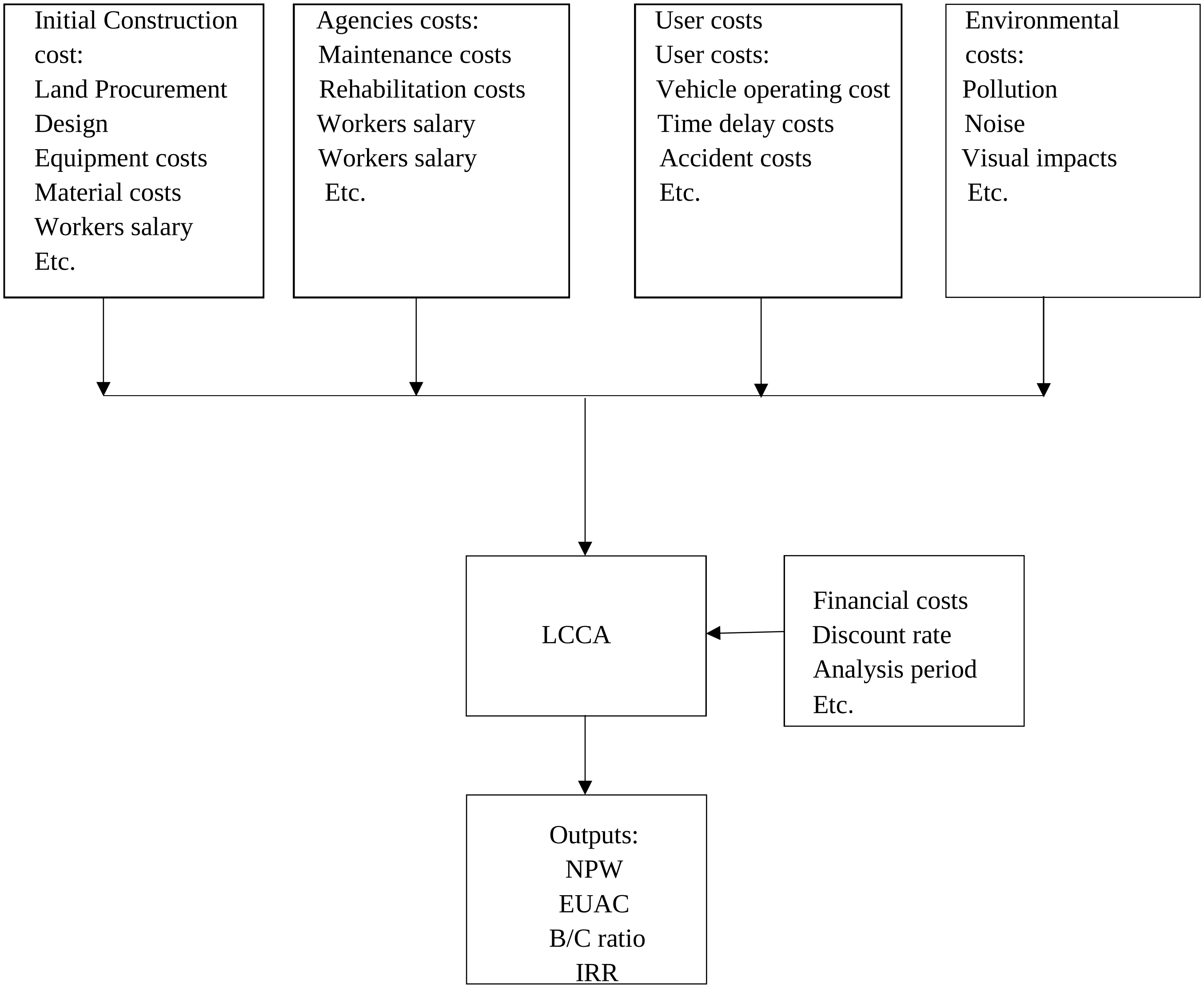

Figure 1: A flowchart describing LCCA process for pavement type selection
Source: (Babashamsi et.al., 2016).

2.3 Economic Analysis Components

2.3.1 Evaluation Methods

Life-cycle cost analysis as a decision-making tool takes into account the costs and benefits and help us to compare the economic viability of different alternative projects. There are different economic measures that are used by decision-makers. (Walls & Smith, 1998) states that net present value (NPV) or sometimes called Net Present Worth (NPW) is the most commonly used economic measure in road investment projects.

- **Net Present Value or Net Present Worth (NPW)**

Net present value (NPV) is the discounted present value of a stream of benefits and costs over time. The NPV represents the net gain in welfare to society from the construction of a project. The option with the highest NPV is considered the most viable option and is submitted for funding. The logic behind this assumption is that any increase in NPV is an increase in welfare over the next best alternative and it is the most appropriate measure for selecting from mutually exclusive project options (Ketema et.al., 2016).

As already mentioned, for evaluating the economic viability of road pavement, the NPV of costs is considered as commonly applied computation. Mathematically it can be represented as follows (Babashamsi et.al., 2016, p.248).

$$\text{NPV} = \text{Initial Cost} + \sum_{K=1}^{N} \text{Future Cost}_K \left|\frac{1}{(1+i)^{n_k}}\right| - \text{Salvage Value}\left|\frac{1}{(1+i)^{n_e}}\right|$$

Where:

N= number of future costs incurred over the analysis period;

i = discount rate in percent;

n_k = number of years from the initial construction to the K^{th} expenditure; and

n_e = analysis period in years.

Alternatively, (Ketema et al., 2016) also presents the formula for net present worth as follows.

$$\text{NPW} = \text{Ic} + \left|\sum_{n}^{N} \text{Mc}\right|\left|\frac{1}{(1+\text{dr})^{n}}\right| + \left|\sum_{n}^{N} \text{Rc}\right|\left|\frac{1}{(1+\text{dr})^{n}}\right| + \left|\sum_{n}^{N} \text{Uc}\right|\left|\frac{1}{(1+\text{dr})^{n}}\right| - \text{Sv}\left|\frac{1}{(1+\text{dr})^{n}}\right|$$

Where:

Ic = initial construction cost;

Mc = maintenance cost;

Rc = rehabilitation cost;

Uc = user cost (user time and fuel saving cost);

Sv = salvage value; n= number of years; and

N= analysis period in years; dr= discount rate.

2.3.2 Analysis Period

The outcomes of LCCA results are significantly affected by activity timing and performance period and it should be sufficiently long to reflect long-term cost differences associated with reasonable design strategies (FHWA, 2002). The analysis period should generally always be longer than the pavement design period, except in the case of extremely long-lived pavements. Normally, the analysis period should be long enough to incorporate at least one rehabilitation activity; and longer performance period for individual pavement designs require fewer rehabilitation projects and associated agency and work zones user costs (Walls & Smith, 1998).

A study conducted by (Babashamsi et.al., 2016) indicated that the overlays lasted 15 years and some lasted 20 years until significant distress signs were noted. Thus, they stated that most road-project evaluations use an evaluation period of thirty years, and ten to fifteen years for intersection evaluations. However, a shorter analysis period may be appropriate, particularly when pavement design alternatives are developed to buy time (say 10 years) until total reconstruction (Davies, 2012).

2.3.3 Discount Rate

Discount rate is a critical component of the discounted cash flow calculation, an equation that determines how much a series of future cash flows is worth as a single lump sum value today.

The estimated future costs and benefits need to be discounted to the present value using a discount rate for appropriate comparison. (Walls & Smith,1998) states that distinction has to be made in LCCA between the real and nominal discount rates. Real discount rates reflect the true time value of money with no inflation premium and should be used in conjunction with non-inflated monetary cost estimates of future investments. Nominal discount rates include an inflation component and should only be used in conjunction with inflated future monetary cost estimates of future investments. Discount rate is the rough difference between the interest and inflation rates and it indicates the real value of money over time (Babashamsi et.al., 2016).

2.3.4 Sensitivity and Risk Analysis

All road projects involve some degree of uncertainty in the outcome of the project. The decision to proceed with a project therefore includes some element of risk taken by road authorities. Many road projects will have a significant element of risk attached to them. These will in general be due to several factors among which the following are the main causes:

- Unforeseen events beyond the control of the engineer, for example, improved technology, political changes
- National economic changes; for example, future economic growth, traffic growth rates.
- Unpredictability of pavement performance due to environment, traffic, construction.
- Impact on socio-economic factors that cannot be evaluated (Kerali, 2002).

When we apply NPV in life-cycle cost analysis, there are some critical factors that could affect the result. In line with this, (Walls & Smith,1998) states that the LCCA should incorporate a sensitivity analysis to address the variability within major analyses input assumptions and estimates. For (Choi et.al., 2016), sensitivity analysis includes: maintenance costs and critical factors. The ultimate extension of sensitivity analysis is a probabilistic approach, which allows all significant inputs to vary simultaneously.

(Kelle et.al., 2013) suggest a methodology that includes risk measures combined with benefit and cost measures in road maintenance project selection processes. This is done using hazard efficiency score for each site and they identified three hazard types: total crashes, injury crashes, and run-off-road crashes. Moreover, the use of NPV in LCCA is sensitive to the analysis period, cost factors, traffic volume, and discount rates among others (Walls & Smith, 1998).

2.4 Cost Factors in LCCA

One major feature of LCCA in economic analysis is its suitability to include and support different cost components associated with road maintenance projects. There are different cost factors that are identified in the literature to consider in life-cycle cost analysis. For (Babashamsi et.al.,2016), the cost factors take two major categories in LCCA. These are: (1) Direct/owner or Agency costs – that includes initial construction or rehabilitation cost, sequence for future maintenance and rehabilitation costs, and salvage value; (2) Indirect/User costs highway lost revenue costs, and drivers/passengers delay costs.

In the Ethiopian context, the total transport cost includes the costs of road construction and maintenance, vehicle-operating costs, and any other external or third party costs of transport that are associated to the society at large and the environment (Office of Road Fund Administration of Ethiopia, 2001). Perhaps the most commonly used cost factors in road projects are the initial construction costs and the subsequent future maintenance and rehabilitation costs (Coe, 1981; Walls & Smith, 1998). Each of these are discussed in detail hereunder.

2.4.1 Initial Construction Cost

The initial investment costs of road construction have dominated both the attention and commitment of government road agencies in many countries (Baum & Tolbert, 1985). This is a cost component which includes costs related to design and construction of road projects (Sauter, 1967). These type of cost components are very common and take the largest share of road fund in countries prioritizing the expansion of road network infrastructure. It is apparent that construction or start-up costs need to be considered in the LCCA. The initial construction cost is presented in unit prices from bid records of projects constructed in previous years and only representative prices must be used (Babashamsi et.al., 2016). Unit prices may be taken out from the overall cost of previous projects if the representative costs are not available.

However, construction operations represent only the beginning of the process of accumulating a properly functioning highway system and the relevant costs to be considered in selecting the degree and type of addition to the road network must include maintenance costs along with construction costs (Coe, 1981). It has been widely mentioned in the literature that the economic rates of return on road maintenance are typically higher than on road construction (Baum & Tolbert, 1985). If highways are not adequately maintained their positive contributions to national economy and mobility may be erased or even reversed. Thus, the next section of the paper discusses the maintenance and rehabilitation costs.

2.4.2 Maintenance and Rehabilitation Costs

If already constructed roads have to serve for a longer time, they have to be maintained and rehabilitated. In line with this, (Mwase,1995) argue that returns to investment will be higher through maintenance than expanded road infrastructure. Another advantage of life-cycle cost analysis is not only considering the initial construction cost but also the accounting of road operation, maintenance, and rehabilitation costs. By doing so, the LCCA makes it possible the comparison of different road maintenance interventions in relation to their life-time costs and benefits. Consequently, maintenance and rehabilitation costs are another matter that require due attention in the process of life-cycle cost analysis.

Road infrastructure operating costs include maintenance and rehabilitation costs (Davies, 2012). As it will be discussed in the next section of this paper, there are different types of road maintenance and rehabilitation strategies or interventions. (Coe, 1981) states that costs associated with road maintenance vary depending on the type and scale of maintenance strategies.

As to the study conducted by (Baum & Tolbert,1985), one of the major continuing problems in transportation in developing countries, including Ethiopia, is the overemphasis on new construction and the inadequate attention to maintenance. As a result, the deterioration of roads and of the maintenance is becoming an urgent problem in these countries. Consequently, failure to act in good time raises the costs of rehabilitation and upgrading. For instance, in Kenya, the decline in disbursement for road maintenance expenditures due to increase in the total road network and the subsequent increase in the total number of kilometers of roads under maintenance have created pressure on the resources available (Nalo, 1993).

One of the difficulties in determining maintenance costs is the unavailability of cost data due to poor of inefficient record keeping thereby making the differentiation between maintenance actions challenging (Babashamsi et.al., 2016). They also recommend that historical records of the actual pavement costs and activities must be utilized if these costs have to be considered in the LCCA procedure.

2.4.3 Agency Costs

Another essential cost factor in the computation of LCCA is to estimate and include the costs incurred by agency or road agencies. Agency costs include all costs incurred directly by the agency over the life of the project (i.e., costs directly related to the initial design and subsequent rehabilitation strategy). Agency costs commonly include initial preliminary engineering, contract administration, construction supervision and construction costs, as well as future routine and preventive maintenance, resurfacing and rehabilitation cost, and the associated administrative cost (Walls and Smith, 1998).

2.4.4 User Costs

Road user costs may be defined as the costs incurred by vehicle operators and by the travelling public at large. The four types of road user costs usually considered are associated with vehicle operation, travel time, accidents and discomfort. The last two costs are difficult to quantify in monetary terms, although accident costs can be estimated in several ways in terms of both resource content (for example, cost of spares and vehicle replacement), and the injuries and fatalities (Nalo, 1993; Walls & Smith, 1998). However, the lack of acceptable methods of estimating accident and discomfort costs in developing countries are the main reason why these two components of road user costs are not included in existing road investment appraisal models for developing countries.

The vehicle Operating Cost components are: fuel and lubricating oil consumption, tyres and spare parts, vehicle maintenance labor costs, vehicle crew wages, vehicle depreciation and interest on capital. The other costs and components are: construction costs, maintenance and rehabilitation costs and discount rate (Walls & Smith, 1998; Tillotson et.al, 1998).

2.4.5 Salvage Values

The economic evaluation of a given road asset in life-cycle cost analysis often include the salvage value of that asset. Salvage value is the term commonly used to indicate the remaining service life of a road network after its normal life-time has expired (Walls & Smith, 1998). It is the value of the road asset computed based on the remaining life of an alternative at the end of the analysis period as a prorated share of the last rehabilitation cost; can also be taken as the percentage of initial pavement construction cost (Babashamsi et.al., 2016; Coe, 1981).

2.5 Road Maintenance

Road maintenance is an activity that is designed to keep a road network serviceable by reducing the deterioration of pavements (FHWA, 1996). Suitable preventive maintenance providing the greatest benefit at the lowest cost in the network is the most effective approach. On the other hand, (Rouse & Chiu, 2009) stated that road maintenance involves activities performed by road agencies in order to maintain the condition of the road above an acceptable quality level. Still other writers in the field describe road maintenance as involving several categories of activities executed in order to increase the productivity and return to investments on such projects (Baum & Tolbert, 1985; Poister, 1983). All these definitions lead us to describe the purposes of road maintenance under the section that follows.

Preventive maintenance has the potential to improve network condition by retarding future pavement deterioration. Road maintenance is essential in order to:

- Preserve the road in its originally constructed condition;
- Protect adjacent resources and user safety; and
- Provide cost-effective, shortest time, and environmentally friendly travel on the routes.

The main purpose of road maintenance is to preserve the asset, not to upgrade it. Unlike major road works, maintenance must be done regularly. The major activities in road maintenance are "keeping pavement, shoulders, slopes, drainage facilities and all other structures and property within the road margins as near as possible to their as-constructed or renewed condition" (Poister, 1983). It helps to make minor repairs and improvements to eliminate the causes of defects and to avoid excessive repetition of maintenance efforts.

For management and operational convenience, road maintenance activities are categorized as routine, periodic, and urgent are explained below:

- **Routine maintenance** comprises small-scale works conducted regularly, aims "to ensure the daily pass ability and safety of existing roads in the short-run and to prevent premature deterioration of the roads" (Rouse & Chiu, 2009). Frequency of activities vary but is generally once or more a week or month. Typical activities include roadside verge clearing and grass cutting, cleaning of silted ditches and culverts, patching, and pothole repair. For gravel roads, it may include regarding every six months.

- **Periodic maintenance** covers activities on a section of road at regular and relatively long intervals, aims "to preserve the structural integrity of the road" (Rouse & Chiu, 2009). These operations tend to be in large scale, requiring specialized equipment and skilled personnel. They cost more than routine maintenance works and require specific identification and planning for implementation and often even design. Activities can be classified as preventive, resurfacing, overlay, and pavement reconstruction. Resealing and overlay works are generally undertaken in response to measured deterioration in road conditions. For a paved road, repaving is needed about every eight years; for a gravel road as re-graveling is needed about every three years. Periodic maintenance is an activity that is undertaken every 3-8 yrs. and is concerned with rectifying defects which are outside the scope of routine maintenance.
- **Urgent maintenance** is undertaken for repairs that cannot be foreseen but require immediate attention, such as collapsed culverts or landslides that block a road (Wilde et.al., 2014). Rouse & Chiu (2009) clearly put that the strategic aim of road maintenance should focus on performing the right types of maintenance activities (i.e. routine, periodic, or emergency maintenance), at the right time on a road so as to optimize the total benefit-cost relationships of a road over its lifetime. Figure 2 below illustrates the performances of routine and periodic maintenance.

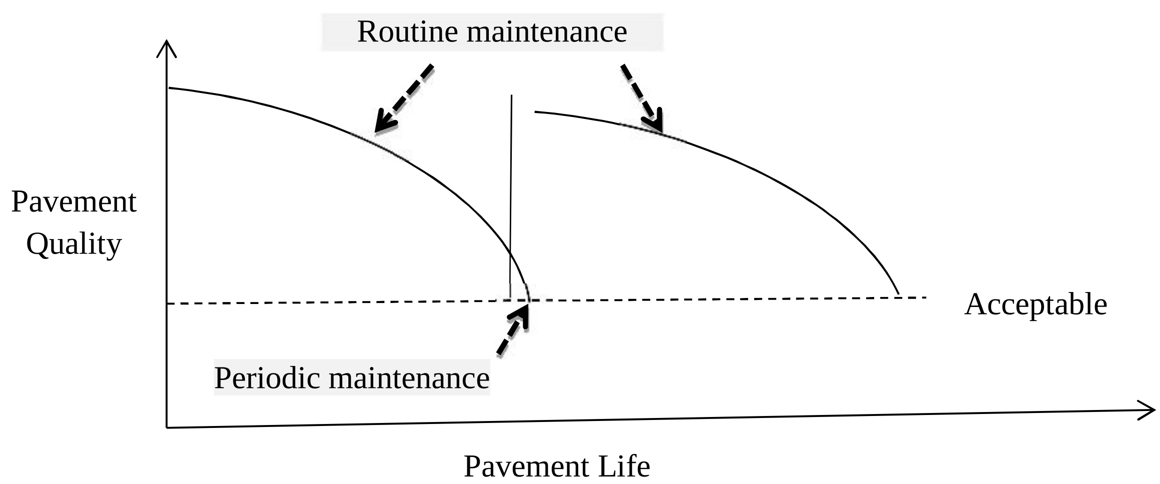

Figure 2: Typical life cycle of road asset
Source (Rouse & Chiu,2009)

2.5.1 Road Defects and Corresponding Preventive Methods

Table 1: Road defects and corresponding preventive methods Source: (Abelson et.al., 2000)

Code 1	*Condition* 2	*Action* 3	*Classification* 4
SURFACED ROADS			
A1	Potholes minor $2\frac{1}{2}$ per cent	Light patching	Routine or Repair
A2	Potholes moderate 5 per cent	Heavy patching	Repair
A3	Potholes severe 10 per cent	Patch and reseal	Repair
A4	Potholes severe 10 per cent	Patch and resurface $1\frac{1}{2}''$ pavement[a]	Repair
A5	Surface bleeding	Blind with sand	Repair
B1	Surface deformation and pavement failure	Dig out (scarify), recompact and seal[a]	Repair or Improve
B2	Ditto	Ditto and resurface $1\frac{1}{2}''$[a]	Ditto
C1	Edge ravelling, minor 6″	Tack coat and premix	Routine or Repair
C2	Edge ravelling, moderate 12″	Ditto, heavier	Repair
C3	Edge ravelling, severe 24″+	Cut out and reconstruct	Repair
D1	Shoulder worn, minor 1″	Hand spread, level off	Routine or Repair
D2	Shoudler worn, moderate 2″	Import, compact, level	Repair
D3	Shoulder worn, severe 4″+	Ditto, heavier	Repair
E1	Pavement sound but zero to a little surface deformation	Reseal	Periodic or Repair

2.6 Road Fund Administration

Problems of roads and road transportation include not only inadequate financial resource but also inefficient institutional provision for road maintenance and lack of rational planning of road investment (Baum & Tolbert, 1985). (Mwase,1995) noted that the Eastern and Southern African (ESA) sub-region has, since late 1970s, experienced rapid, sustained and regular deterioration in transportation infrastructure primarily because of scarcity of resources for recurrent and capital expenditure. The presence of proper and strong road fund administration is closely associated with productive highway maintenance programs (Poister, 1983).

In response to the problem, countries have set different institutional frameworks for road fund administration. Accordingly, Ethiopia also established a body that is responsible for road fund administration in 1997 by issuing a proclamation named as, "Road Fund Establishment

Proclamation No. 66/1 997" (Federal Democratic Republic of Ethiopia, 1997). The fund is administered by the Board and its main objective was to finance the maintenance of roads and road safety measures. The stated proclamation also mentions sources of road funds as:

- budget allocated by the Government;
- road maintenance fuel levy;
- annual vehicle license renewal fee based on axle load;
- overloading fine; and
- any other road tariff levied as may be necessary (FDRE, 1997).

Insufficient funds for road maintenance, unreliable timing of funds and inefficient implementation of works are the conditions that justify the establishment of road fund (Gwilliam & Shalizi, 1999).

The report of the Office of the (Road Fund Administration, 2001) showed that the allocation of road fund by the government is based on the recommendations of the Road Fund Board on fund budget allocation and redistribution criteria for Road agencies; i.e. seventy percent (70%) for federal ERA, twenty percent (20%) for the regional roads administrations (RRAs) and ten percent (10%) for the selected municipalities. The Federal ERA takes seventy percent (70%) of the Road Fund budget and then distribute it to the ten districts for allocation by road segments. Payments to ERA are effected on performance agreement bases as per agreed maintenance activity unit rate. Performance payment certificates for each month are sent to the Road Fund Office from ERA. The other Road agencies' payments are effected based on quarterly cash flow program bases (Office of Road Fund Administration, 2001).

It is inevitable that as the road network increases, the maintenance need increases accordingly, thereby increasing the required budget. However, due to the insufficiency of the yearly allocated maintenance budget, it is difficult to provide adequate and timely maintenance to the entire road network. This will have associated impact on the road users such as increase in vehicle operating costs and hence reluctance to use the road in addition to increasing the maintenance cost. Table 2 presents the requested versus allocated budgets for road administration in Ethiopia between 2011/11 and 2015/16.

Table 2: Allocated & requested budget for road maintenance in Ethiopia

Item No.	Budget Year	Requested Budget (ETB)	Allocated Budget by RF (ETB)	Difference Birr (ETB)
1	2010/11	1,772,214,171	715,000,000	1,057,214,171
2	2011/12	1,075,906,663	846,500,000	229,406,663
3	2012/13	1,637,424,806	931,150,000	706,274,806
4	2013/14	1,927,200,000	931,150,000	996,050,000
5	2014/15	2,023,560,000	808,316,705	1,215,243,295
6	2015/16	2,666,600,000	889,148,375	1,777,451,625
Total		11,102,905,640	5,121,265,080	5,981,640,560
Average Budget Difference				996,940,093

Note: -RF=Road Fund
Source: ERA, 2015.

As indicated in the above Table 2, the yearly-allocated budget for maintenance work is much less than the requested budget. This could be due to the limited amount of income that office of the road fund collects from fuel levy, axle weight based vehicle license renewal fee, and overloading fines. Based on the fund office's budget allocation scheme, which shows yearly budgets allocation by increasing 10% on the previous year's allocated budget, the expected maintenance budget to be allocated for the next four years have been forecasted and a comparison is made with the expected maintenance need.

In relation to this, (Levinson, 2005) pointed that if roads deteriorate to the point, at which they need reconstruction, restoring them to the original level of service costs three to five times more than timely and effective maintenance costs. Consequently, postponing road maintenance increases not only total costs but also the present value of the future cost stream at any reasonable rate of discount.

2.7 Road Condition Survey

Road condition survey involves the collection of data about the status of road network for further improvement actions. In the words of (Poister, 1983), road condition surveys precisely involve identifying deficiencies in surface, shoulder, drainage, and ancillary condition in order to rate and categorize the road into different condition status thereby indicating whether maintenance is required and with what scale. Whereas surface conditions mainly relate to potholes and prevalence of pattern cracking, shoulder and drainage conditions emphasizes on shoulder slope and shoulder drop-off, obstructed cross-pipes and nonfunctional inlets and end walls (Newbery, 1989).

Road condition survey should be carried out annually on the whole network. This is an important survey as it collects the data necessary for preparing the annual work program. It is also the management tool to assist in the decision to maintain or program for rehabilitation (ERA, 2014).

Since pavement distresses are generally taken as a function of traffic loads, environmental conditions, and their interaction, the road condition survey should provide information on the nature and causes of distress in selecting an appropriate treatment (FHWA, 1996). In the Ethiopian context, it has been mentioned that the absence of reliable database on the country's road conditions remained as a threat on decision-making process of Road Funds both at central and Road agency levels (Office of Road Fund Administration, 2001).

Since allocation and prioritization is made based on available data source, there is a critical need for having road condition survey results and reliable information on road stock.

2.8 Road Network Types

The road network types are based on the functional classification of the roads. The network types are as follows:

- **Primary***:* Arterial, main, trunk, or national roads, which are roads outside urban areas that belong to the top-level road network and generally, have higher design standards than other roads. These roads generally provide the highest level of mobility, at the highest speed, for long interrupted traffic. These roads form the principal avenue of communication between and through major regions of the country, between regional capitals and key towns that have significant national economic and social interaction, and between the country and adjoining countries, whose main function is to provide access to major freight terminals, including ports.

- **Secondary**: Collectors, classified as rural or regional roads, which are the main feeder routes into primary roads, and provide the main links between primary roads. These roads generally provide a lower degree of mobility than primary roads, being designed for travel at lower speeds and for shorter distances. These roads form the principal avenue of communication between primary roads and key towns and between primary roads and important centers, which have a significant economic, social tourist, or recreation role (for example, tourism and resource development).

- **Tertiary***:* Local roads, which are classified as rural or local roads. The roads are characterized by a comparatively low-level design standard and traffic. These roads provide basic access between residential and commercial properties, connecting with higher-order roads. The function of these roads is to provide the only access to scattered rural settlements and primarily serve local social services, as well as provide access to markets and generally form the first phase of the journey for commuters.

- **Unclassified***:* Unclassified roads, which are roads that do not fall into any of the previous categories. These roads comprise special-purpose public roads that cannot be assigned to any other class above, and which are provided almost exclusively for one specific activity or function, such as recreational, forestry, mining, national parks, or dam access.

- **Urban***:* Urban roads, streets, and avenues, which are located within the boundaries of cities or towns (Rodrigo Archondo,2007).

2.9 Highway Development and Management (HDM-4)

2.9.1 General

In managing the road network under the jurisdiction of a given authority, it is important that actions taken at different management levels are justified from all relevant perspectives to ensure that sustainable road network will result which minimizes long-term transportation costs (given budget constraints) and which creates conducive environment to economic growth and development. This has implications for analyses at the strategy level, the program level and the project level (Schuttee, 2008).

2.9.2 Purpose of the HDM-4

The Highway Development and Management (HDM-4) tool is aimed at facilitating the analysis of alternatives in respect of road maintenance and investment activities. It focuses on the technical and economic appraisal of road projects, the preparation of road investment Programs as well as the analysis of road network strategies (Schuttee, 2008)

- **Strategy Analysis**

Typical examples of strategy analysis by road agencies would include the following:

- ✓ 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; and
- ✓ Policy studies such as impact of changes to the axle load limit, pavement maintenance standards, energy balance analysis, provision of non-motorized traffic (NMT) facilities, sustainable road network size, evaluation of pavement design standards, etc. (Kerali, 2002).

- **Program Analysis**

Program analysis "... 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" (Kerali, 2002).

- **Project Analysis**

Project analysis deals with the "...evaluation of one or more road projects or investment options; application analyses a road link or section with user-selected treatments, with associated costs and benefits; projected annually over the analysis period. Economic indicators are determined for the different investment options". Projects may typically include "... the maintenance and rehabilitation of existing roads, widening or geometric improvement schemes, pavement upgrading and new construction (Kerali, 2002).

HDM-4 is a tool for economic optimization of maintenance of road networks and has been adopted or applied in many different countries for economic analysis and prioritization It utilizes road network inventory and condition, traffic and economic data to feed a series of road deterioration and cost models, and to formulate candidate work programs for road networks (Schuttee, 2008).

2.9.3 HDM4 System for LCCA

the HDM4 has required a huge amount of data. While collecting data, it should be aimed that the collected data, directly or in its derived form should meet the requirements of HDM-4 system general. The data types can be categories as;

- ✓ Inventory data,
- ✓ Pavement Condition data (ERA method),
- ✓ Traffic/Loads,
- ✓ Costs - Construction, Rehabilitation, Reconstruction
- ✓ History Initial Construction, Rehabilitation, Reconstruction, (Last Treatment) and etc.

- **Inventory Data**; the inventory data includes the following details about the selected pavement sections: Name of road, category of road, carriageway and shoulder width and its number of lanes, drainage conditions, surface type and thickness, pavement layer details, Country, legislative district and etc.

- **Pavement Condition Evaluation;** in general, under this data collection type the Pavement Roughness or Ride Quality, Surface Distress, Rutting, Skid Resistance and Structural Capacity can be determined. These data can be used to determine the need for annual condition surveys, ride quality, surface distress, rutting, friction, and to evaluate the current condition of pavement, determining rates of deterioration, project future conditions and to determine current and future maintenance & rehabilitation needs and its future cost of repairs. In general term, it can be sub divided into three categories;

a) **Structural Evaluation:** The magnitude of pavement rebound deflection is an indicator of the ability of the pavement to withstand traffic loading. Higher the rebound deflection, poor is the structural capacity and performance. The practice hitherto is to use the Benkelman Beam deflection method for evaluating the structural condition of the flexible pavement.

b) **Functional Evaluation:** Functional evaluation of pavements consists of collection of road data pertinent to surface distress (crack area, raveled area, pothole area), rut depth, surface roughness etc. having observed the type and extent of distress developed at the surface i.e. cracking, raveling, patch work, potholes, rut depth, edge break and etc. based on the visual condition survey. The extent and type of distress developed in quantitative terms will also be measured, in addition to the visual recording of the pavement surface condition.

c) **Road Roughness;** is the irregularities in the pavement surface affecting user comfort and safety due to variations in horizontal, vertical, and transverse profiles ride quality user perception of Pavement Roughness. This roughness can be measured using profiler. The instrument measure pavement wheel path profile(s) to assess pavement ride quality and convert pavement wheel path profile (l&r) to Pavement Ride Quality Indices (IRI).

- **Surface Distress;** while evaluating and collecting data on surface distress one has to consider;

✓ Type of Distress *(*Cracking, Patching, Rutting*)*
✓ Severity (Crack Width, Condition Assessment)
✓ Extent (Percentage of the Pavement Length

- **Rut Depth Measurement;** the transverse deformation across the wheel path is defined as the rut.
- **Structural Load Capacity;** It is assessment of the load carrying capacity of the pavement structure using coring/borings/lab tests (destructive type) or Falling Weight Deflectometer (fwd) (non-destructive test)

CHAPTER THREE

MATERIALS RESEARCH METHODOLOGY

3.1 General

This chapter deals with the research design and methodology employed in the study. It presents design of the study, description of the study area, case study, data type and procedures of data collection, and methods of data analysis.

3.2 Design of the Study

Research design involves the overall guiding approach for conducting a study and selection of a particular design that depends on the purpose of the study under investigation (Creswell, 2009). Accordingly, the main purpose of this study is to conduct the life-cycle cost analysis for road maintenance interventions being undertaken by the Ethiopian Federal Roads Authority, the case of selected roads under the ARMD. The ultimate objective is to carry out the cost-benefit analysis of three road maintenance interventions (i.e., routine, periodic, and emergency road maintenance) and perform comparative analysis thereby recommend the optimum alternative with lifetime costs resulting in higher NPV and other economic parameters like internal rate of return (IRR), benefit-cost ratio (B-CR) etc.

In order to achieve this objective, a case study was conducted by focusing on the road networks currently administered under ARMD of the ERA. According to (Creswell, 2009), case study design is appropriate for a study that involves an in-depth investigation of a particular case by collecting multiple data on the issue being studied.

3.3 Description of the Study Area

Currently, the Federal road maintenance in Ethiopia is administered by the Ethiopian Roads Authority, which is organized under five regional areas and ten districts on the bases of geographical proximity and convenience for effective and efficient management. Table 3 below shows the regional areas and respective districts.

Table 3: Federal road maintenance regional areas and districts in Ethiopia

S. No.	Federal Road Maintenance Regional Areas	Road Maintenance Districts Under Each Regional Areas
1	Northern ERA Regional areas	1. Gonder District
		2. Adigrat District
		3. DebreMarkos District
		4. Combolcha District
2	Southern ERA Regional areas	5. Shashemene District
		6. Sodo District
3	Eastern ERA Regional areas	7. Dire Dawa District
4	Western ERA Regional areas	8. Jimma District
		9. Nekempte District
5	Central ERA Regional areas	10. Alemgena District

Among these five regional areas with ten districts, this study focused on the Alemgena District under which is the ERA Central Regional area is located. The ARMD is responsible for undertaking the construction and maintenance activities of the Federal roads comprising of the regions of Oromia, Amhara and Southern Peoples Regional States. The road network under the district comprises of five major outlets from the capital city of Addis Ababa. which have high economic and social importance. Alemgena District serves as the main gate to peoples of the surrounding regions, agricultural produce, and industrial products to and from Addis Ababa (the capital city of Ethiopia). It is also the main inlet and outlet of imports and exports between Addis Ababa and the Djibouti port.

The Road Network under Alemgena District compromises of 2,406 km of Asphalt and 2,086 km of gravel roads, aggregating to 4,492 km. Road maintenance activities of nine road sections are undertaken under the Alemgena District and these road sections are: Modjo Section; Butajira Section; Endiber Section; Muketuri Section; Ambo Section; Weliso Section; Debre Birhan Section;

Robit Section; and Huruta Section. In 2016 FY, 2,291 km and 117 km of roads were maintained under Alemgena District with routine and periodic treatments respectively.

3.4 Case Study

As indicated in the preceding section, a case study design was employed for this study focusing on sample roads under the Alemgena District. There are 85 sub-sections under 9 sections of the ARMD as stipulated below:

- Mukaturi Section (Ten sub section of paved and unpaved roads);
- Ambo Section (Eight sub section of paved and unpaved roads);
- Wolliso Section (Nine sub section of paved and unpaved roads);
- Huruta Section (Thirteen sub section of paved and unpaved roads);
- Robit Section (Eight sub section of paved and unpaved roads);
- Debre Brhan Section (Nine sub section of paved and unpaved roads);
- Modjo Section (Nine sub section of paved and unpaved roads);
- Butajera Section (Eleven sub section of paved and unpaved roads); and
- Emdiber Section (Eight sub section of paved and unpaved roads).

From the above nine section, 10 paved roads were selected for analysis in this study. The selected roads are presented in Table 4 below, which presents the study road in respect of name, length, maintenance and surface types.

Table 4: Selected roads from Alemgena Maintenance District

No	Road Name	Length (km)	Type of Maintenance	Surface Type
Butajira Section				
1.	Butajira-Wolbareg	54	Routine & Periodic	Asphalt
2.	Wolbareg-Hossana	46	Routine & Periodic	Asphalt
3.	Alemgena-Lemon	42	Routine & Periodic	Asphalt
4.	Lemon-Butajira	74	Routine & Periodic	Asphalt
Mukature Section				
1.	Commando-Fiche	7	Routine & Periodic	Asphalt
Ambo Section				
2.	Ambo-Gedo	64	Routine & Periodic	Asphalt
Robit Section				
1.	Robit-Ataye	48	Routine & Periodic	Asphalt
2.	Gudobert-D/Sina	30	Routine & Periodic	Asphalt
Endberi Section				
1.	Kosi-G/Gibe No.2	35	Routine & Periodic	Asphalt
2.	Butajera-Zeway	54	Routine & Periodic	Asphalt

3.5 Data Collection

3.5.1 General

In this study, the data for the above selected roads is based on the condition surveys and bill of quantities by considering the period from 2004 E.C. (2011/12 G.C.) to 2008 E.C. (2015/16 G.C.). Then, Life-Cycle Cost Analysis (LCCA) was conducted under different road maintenance interventions by using the HDM4 software.

3.5.2 Data Type and Procedures of Data Collection

3.5.2.1 Data Type

Both qualitative and quantitative data were used in this study. The qualitative data used in this study related with the description of selected road condition status and review of different road maintenance interventions. The quantitative data focused on the numerical measures involved in LCCA. The data were collected from ERA's road condition surveys on Alemgena Road Network and from reviewed literatures. The secondary data were identified and presented under different input categories, which are discussed under the following sub-sections.

3.5.2.2 Procedures of Data Collection

The procedures of data collection followed two major phases. In the first phase, all the required input data type was identified for LCCA using HDM-4. In the second phase, identified data were collected by reviewing ERA's road condition survey for the selected road networks.

3.5.2.3 Input Data Required for HDM-4

HDM-4 is a powerful system for the analysis of road management alternatives (Chopra et.al., 2017). With different application tools, HDM-4 can be applied in project analysis, program analysis, strategy analysis, research, and policy studies. The project analysis tool of the HDM-4 is used for comparing the NPV of the three road maintenance alternatives (i.e., routine, periodic, and emergency maintenance) for the selected road network in this study.

- **Input Data Required for HDM-4**

In this study the type of data required for HDM-4 were categorized into five types and are stated as follows:

- ✓ Road network:
- ✓ Traffic volume and vehicle composition;
- ✓ Road user cost (RUC); and
- ✓ Works Standards (Maintenance Standard and Improvement Standard).

Each of these data components are discussed hereunder by specifically focusing on type and measure used that are directly relevant to this study.

- **Road Network Data**

Road Network data refer to inventory, pavement history, and pavement condition data etc.

- **Road Inventory Data**

Road inventory data collection consists of road length (m), lane width (m), shoulder width (m), geometries of road sections, traffic flow pattern, design speed (km/h), flow direction and climate zone. Road sections have been visually inspected to get relevant information. Accordingly, the researcher was started by collecting secondary data which includes names of the road network, the section to which the road belongs, survey year, its current condition, road type and road length. Table 5 shows the road network data.

Table 5: Study roads network data

Year	Name of the road	Section	Pavement Condition	Road Type	Road Length (km)	Data Processed
2012	Butajira-Wolebareg	Butajira	Good	Link	54	Condition Survey &Boq
	Wolbareg-Hossana	Butajira	Poor	Link	64	Condition Survey &Boq
2013	Alemgena-Lemon	Butajira	Poor	Link	42	Condition Survey &Boq
	Lemon-Butajira	Butajira	Poor	Link	74	Condition Survey &Boq
2014	Commando-Fiche	Mukatri	Poor	Trunk	7	Condition Survey &Boq
	Ambo-Gedo	Ambo	Poor	Trunk	64	Condition Survey &Boq
2015	Robit-Ataye	Robit	Poor	Trunk	48	Condition Survey &Boq
	Gudobert-D/sina	Robit	Good	Trunk	30	Condition Survey &Boq
2016	Kosi-GlGibeNo.II	Endberi	Fair	Feeder	35	Condition Survey &Boq
	Butajira-Zeway	Butajira	Fair	Access	54	Condition Survey &Boq

Note:

- ✓ Primary road (main, trunk or national roads outside urban areas);
- ✓ Secondary road (the main feeder routes of primary roads the main link);
- ✓ Tertiary (Local roads or rural roads provide access);
- ✓ Collector - Unclassified road; and
- ✓ Feeder- urban which are within the boundary.

Table 6: Geometry data for HDM-4 source (HDM4 version 1.1,2000)

Geometry Class	Rise +Fall (m/km)	Number of Rise & Fall per km	Horizontal Curvature (deg/km)	Superelevation (%)	Speed limit (km/hr)
Bendy and generally level	3	2	50	2.5	100
Bendy and gently undulating	15	2	75	3	80
Bendy and severely undulating	25	3	150	5	70
Windy and gently undulating	20	3	300	5	60

Bendy and gently undulating was used in the study, since it represents the Ethiopian road conditions. Road specific data were not available at ERA. However, actual design speed limit and altitudes were used in the study.

- **Pavement History Data**

Pavement history data (type of pavement, year of last construction, surfacing and maintenance) were collected from Alemgena Road Maintenance District. Table 7 presents the pavement history data for the selected road network used in this study.

Table 7: The condition of Paved Roads Source: (HDM4 version 1.1,2000)

Paved road condition	Cracking (%)	Ravelling (%)	No. potholes per km	Edge break (m^2 per km)	Mean rut depth (mm)
New	0	0	0	0	0
Good	0	1	0	0	2
Fair	5	10	0	10	5
Poor	15	20	5	100	15
Bad	25	30	50	300	25

- **Functional and Structural Evaluation of Road Pavements**

The functional evaluation like roughness measurement survey has been conducted to assess the riding comfort and safety over the pavement section as experienced by road users. The data is shown in Table 8 below.

- **Primary***:* Arterial, main, trunk, or national roads, which are roads outside urban areas that belong to the top-level road network and generally, have higher design standards than other roads.
- **Secondary**: Collectors, classified as rural or regional roads, which are the main feeder routes into primary roads, and provide the main links between primary roads. These roads generally provide a lower degree of mobility than primary roads,
- **Tertiary***:* Local roads, which are classified as rural or local roads. The roads are characterized by a comparatively low-level design standard and traffic. These roads provide basic access between residential and commercial properties, connecting with higher-order roads.
- **Unclassified***:* Unclassified roads, which are roads that do not fall into any of the previous categories. These roads comprise special-purpose public roads that cannot be assigned to any other class above, and which are provided almost exclusively for one specific activity or function, such as recreational, forestry, mining, national parks, or dam access.
- **Urban***:* Urban roads, streets, and avenues, which are located within the boundaries of cities or towns.

Table 8: Riding Quality in IRI in m/km (Bituminous surface)
Source; HDM4 version 1.1 (2000).

Road Class	Good	Fair	Poor	Bad
Primary or Trunk	2	4	6	8
Secondary or Main	3	5	7	9
Tertiary or Local	4	6	8	10

- **Traffic Volume and Vehicle Composition**

Vehicle fleet data contains the characteristics of the vehicle fleet that will be operating on the road network being analyzed. It comprises a mix of several vehicle types that use a road network. It uses a set of representative vehicles for which a number of physical and performance characteristics are defined. The vehicles can be grouped using two levels of classification as follows:

✓ **Categories** include motorized and non-motorized vehicles.

- ✓ **Types** are vehicle type that represent a set of vehicles within a class, which has different characteristics. There are 16 types of which 12 motorized vehicle types and 4 non-motorized vehicles within HDM-4.

Traffic data are not input in one folder; they are rather incorporated in several modules. Traffic includes the following:

- ✓ 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.

Table 9 below presents traffic band and surface class including AADT.

Table 9: Traffic band and surface class AADT source:(HDM4 version 1.1,2000)

Traffic Band	Surface class AADT		
	Bituminous	Unsealed	Concrete
Low	0-750	0-75	0-3000
Medium	750-3000	75-175	3000-7500
High	3000-75000	175-800	7500-15000

However, Actual AADT were used in the study roads.

- **Road User Cost (RUC) Data**

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

- ✓ Vehicle operation costs (fuel, tyres, oil, spare parts, vehicle deprecation, 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). In developing countries, it is difficult to quantify road accidents in monetary value (Kerali, 2002). In this study, although there is a provision for road accidents, no accident data were included since they were not available in Ethiopia.

- **Works Standards**

In HDM4 Maintenance and Improvement Standards are used to represent targets or levels of condition and maintenance responses that are aimed to achieve the required standards.

✓ **Maintenance Standards**

The maintenance standards are 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 works item is defined in terms of the road surface class to which it applies, an intervention level, an operation type (e.g. reseal, overlay, etc.), and the resultant effect on the pavement (Wighman et.al., 2000).

✓ **Improvement Standards**

Improvement standards are defined as road improvement works to be carried out should the state of the road network fall below a certain level. Each Improvement Standard is defined in terms of the road surface class to which it applies, an intervention level, an improvement type, the cost and duration of the works, and the resultant effect on the pavement in terms of its condition, geometry, strength, etc. Supported improvement types include: lane addition, partial widening, reconstruction, and upgrading (Wighman et.al., 2000).

3.5.3 Alternatives for Maintenance Intervention

The proposed maintenance for asphalt road interventions are indicated in the following table.

Table 10: Asphalt Interventions source: (Wilde et.al.,2014)

Alternatives	Roughness Range (IRI in m/km)	Damage Area (%)	Traffic Range (MT AADT)				
			<500	501-1500	1501-3000	3001-5000	>5000
1	IRI≤3.5	≤ 30	Routine	Routine	Routine	Routine	Routine
		>30	15mm SBSD	15mm SBSD	15mm SBSD	25mm DBSD	25mm DBSD
2	3.5 ≤IRI ≤5.5	All	15mm SBSD	15mm SBSD	25mm DBSD	25mm DBSD With shape correction	50mm Overlay
3	5.5 ≤IRI≤ 8	All	15mm SBSD With shape correction	25mm DBSD with shape correction	50mm Overlay	60mm Overlay	70mm Overlay
4	8 ≤ IRI≤ 10.5	All	25mm DBSD With shape correction	50mm Overlay	Strength. with 60mm ACS	Strength. with 70mm ACS	Strength. with 70mm ACS
5	IRI>10.5	All	Strength. with 25mm DBSD	Strength. with 50mm ACS	Recon. with 60mm ACS	Recon. with 70mm ACS	Recon. with 70 ACS
6	IRI>11.5	All	Recon. with 25mm DBSD	Recon. with 50mm ACS	-	-	-

Note: SBSD = Single Bituminous Surface Dressing.
DBSD = Double Bituminous Surface Dressing.
ACS = Asphalt Concrete Surface.

3.5.4 Preventive Maintenance Treatment

As indicated below in Table 11, the most common flexible pavement distresses are shown along with their corresponding best practices for rehabilitation. Also in Table 11, recommended applications are specified for crack sealers and fillers, surface treatments, and pothole patching. List of maintenance techniques and the reasons for using each and treatment life is also given in the table below.

Table 11: Maintenance interventions (Asphalt Maintenance Techniques)

Technique	Reason for use							Average Treatment Life
	Friction	Reveling	Rutting	Pothole	Cracking			
					L	M	H	
Crack Treatments								
Crack repair with sealing								
Clean & seal					x	x		3
Saw & seal								7-10
Rout & seal					x	x		3
Crack filling						x	x	2-3
Full-depth crack repair							x	5
Surface treatment								
Fog seal		x						1-2
Seal coat	x	x						3-6
Double chip seal	x	x						7-10
Slurry seal	x	x						3-5
Micro surfacing	x	x	x					5-8
Thin Hot-mix-overlay		x	x					5-8
Pothole and patching repair								
Cold-mix asphalt				x				1
Spray injection-patching				x				1-3
Hot-mix asphalt				x			x	3-6
Patching w/slurry or micro surfacing material				x			x	1-3

Note: L = Low; M = Medium; H = High

Source: Wilde et.al, (2014).

The cost values are considered to vary depending on the project location and its environmental condition (Wilde et.al., 2014).

3.5.4.1 Selecting Potential Project Alternatives for Comparison

There are different types of road maintenance alternatives that would be applied by road authorities. For this study, three maintenance alternatives were identified and included in the comparison of LCCA. These are: 'Do minimum', 'Do something', and 'Do major works' (UK Roads Liaison Group, 2011). These maintenance strategies are discussed below separately by indicating the maintenance alternatives they include and associated cost implications.

- **'Do Minimum'**. Under a 'Do Minimum' strategy, the highway authority would undertake reactive repairs to safety defects only. These are likely to be superficial repairs and would possibly be temporary in nature. The repairs would not arrest the decline of the asset and frequent re-visits are likely to be required. In the short term, routine maintenance costs are likely to be high due to the ongoing liability to repair the defects. There is also an increased risk of personal injury accidents (resulting from road users' interface with the defective asset) and the resulting legal consequences.

- **'Do Something'.** This approach seeks to do the minimal amount of routine maintenance work to keep the asset safe and serviceable. Works will normally be restricted to the repair of critical defects. However, the works effort will be slightly enhanced in comparison to the 'Do minimum' as repairs will normally be permanent in nature although they will add no value to the asset. In the context of a pavement scheme a 'Do something' approach might be limited to the permanent repair of potholes only. These would be undertaken on an isolated basis or may extend to small patches.

- **'Do Major Works'** or Periodic maintenance is likely to involve capital expenditure by an authority rather than routine expenditure. It may include wholesale replacement or major repair of an asset to a level that will enhance its long-term durability and minimize future routine maintenance. A pro-active approach may also be adopted which means that repair takes place before the condition intervention level is reached. In the context of maintenance scheme this could see the treatment of a section of pavement classified as being in the 'poor' condition category.

3.5.5 The Current Budget and Maintenance Options

The other factor that determines possible options of road maintenance interventions, in Ethiopia, is the amount and availability of budget. Since there are limited resources in the Country, the use of available budget by applying proper cost effective road maintenance intervention is recommended. Since 1999, the road maintenance costs used by ERA have been based on the cost breakdown that were prepared and used by the Ethiopian Road Construction Corporation (ERCC). The ERCC is a government development agency, established under the ERA to carry out mainly road and bridge construction, maintenance and enhancement works. The maintenance cost used by ERCC has remained constant from year to year, despite the apparent increase in the desired maintenance costs over time.

3.6 Methods of Data Analysis

In this study, the data analysis was carried out for LCCA involving different road maintenance interventions by using the HDM-4 software package. The collected data were analyzed through the following procedural steps. Firstly, the collected data under different input type were entered manually into the HDM-4 software to make it ready for analysis. Secondly, the analyses were carried out by following the project analysis approach of the HDM-4.

Project analysis is concerned with the evaluation of one or more road projects or investment options. It includes the appraisal of maintenance and rehabilitation options for existing roads, widening or geometric improvement schemes, pavement upgrading, new road construction, etc. In HDM-4, project analysis involves performing three interrelated activities as follows;

- **Specifying Alternatives:** the given alternatives are with the project (with the improvements) and without the project (without improvements).
- **Conducting Analysis**: the economic analysis was conducted based on specified alternatives (i.e., with or without project) using the current discount rate. Ten percent (10%) was included in the analysis as commonly used in Ethiopia.
- **Generating the Report**. Finally, the economic parameters were identified after running the HDM-4 software and generating the reports.

Thirdly, based on the results, different road maintenance interventions, interpretations and discussions of the findings were presented. Finally, summary of the findings, conclusions, and recommendations were forwarded. Based on the findings, directions for future research are also indicated in the last section of the paper.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

This chapter presents the analysis, results and discussions of the research in accordance to the objectives of the study.

- Identifying different road maintenance interventions with corresponding defects;
- Comparing cost and benefits of different maintenance interventions within 20 years;
- Determine an appropriate preventive maintenance methods for different road sections based on the results of the LCCA; and
- For studied road sections propose different road maintenance preventive methods based on currently allocated budget.

At district level the data collector personnel conduct condition survey (visual Condition survey) every three months for budgeting purpose to maintain the damaged roads or spots at the section. In this level of condition survey the personnel uses visual inspection to determine/survey the extent and type of distress and etc. The visual condition survey used to measure various types and degrees or severity of distress. The components which can be measure using visual Condition survey are surface defects (such as longitudinal joint cracks, potholes, raveling, bleeding and lacy edge), permanent deformation or distortion, fatigue cracking and patch deterioration. However, as the data on the condition survey of the ERA is collected by visual inspection it can be subjected to certain level inaccuracy. The unit rate on table 12 below, is based on the data from ARMD.

The following are criteria indicators used in HDM-4 version 1.1 (2000)

- Good roads have no cracking, Ravelling, Potholes Edge break and Mean rut depth.
- Fair roads have 5% cracking, 10%Ravelling, no. of potholes per km,10m^2/km for edge break and 5mm mean rut depth.
- Poor roads have 15% cracking, 20%Ravelling, 5 no. of potholes per km,100m^2/km for edge break and 15mm mean rut depth.
- Bad roads have 25% cracking, 30%Ravelling, 50 no. potholes per km,300m^2/km for edge break and 25mm mean rut depth.

4.2 Maintenance Intervention Activities with Corresponding Defects of Roads

One of the specific objectives of this study is to identify maintenance interventions that correspond with the current road condition status. In doing so, the current study identified the condition status of the selected roads under Alemgena Maintenance District of the Ethiopian Roads Authority, based on road condition survey. As shown in Table 12 below, most of the proposed road sections were in poor conditions (2012-2015 GC). Accordingly, from the selected ten roads, six of them were in poor condition. These roads were: Wolbareg-Hosana, Alemgena-Lemon, Lemon-Butajira, Commando-Fiche, Ambo-Gedo, and Robit-Ataya. Only two roads (Butajira-Wolbareg and Gudober-D/Sina) were in good condition (2012&2015GC). On the other hand, Kosse-G/Gibe No.2 and Butajira-Zeway routes were in fair condition (2016EFY) during the specified Fiscal Years. The same table also shows that the AADT of the road sections ranged from less than 500 (low) to 501-1500 (medium). Based on the road condition status, the corresponding maintenance activities were also identified for each road section along with its unit price per km/ETB.

As per our intervention criteria for each road section its maintenance activities with corresponding defects are as shown in the table 12 below.

Table 12: Maintenance intervention with corresponding defects of the study roads

Year	Route Name	Road Length (km)	Pavement condition	Roughness (IRI)	Damage Area (%)	AADT			Unit Price per km (ETB) 2009EC
						<500	501-1500	1500-3000	
2012	Butajira-Wolbareg	54	Good	3	≤ 30	Routine	-	-	322,000
					>30	15mm SBSD			
	Wolbareg-Hosana	46	Poor	7	All	-	25mm DBSD with shape correction	-	630,000
2013	Alemgena-Lemon	42	Poor	7	All	-	-	50mm Overlay	1,925,000
	Lemon-Butajira	74	Poor	7	All		-	50mm Overlay	1,925,000
2014	Commando-Fiche	7	poor	6	All	-	25mm DBSD with shape correction	-	630,000
	Ambo- Gedo	64	poor	6	All	-	25mm DBSD with shape correction	-	630,000
2015	Robit-Ataya	48	Poor	6	All	-	25mm DBSD with shape correction	-	630,000
	Gudober-D/Sina	30	Good	2	≤ 30	Routine	-	-	322,000
					>30	15mm SBSD			
2016	Kosse-G/GibeNo.2	35	Fair	6	All	-	25mm DBSD with shape correction	-	630,000
	Butajira-Zeway	54	Fair	6	All	-	25mm DBSD with shape correction	-	630,000

Note: ETB= Ethiopian Birr
DBSD=Double Bituminous Surface Dressing
SBSD=Single Bituminous Surface Dressing
Source: Wilde et.al. (2014).

4.3 Determine an Appropriate Preventive Maintenance Methods for Different Road Sections Based on the Results of the LCCA

One of the characteristics of road asset management is that it involves life cycle performance. decisions on road maintenance investments should be considered in terms of serviceability over its lifetime. Road agencies seek to make more informed and comprehensive maintenance investment decisions, because the selection of a particular road maintenance activity will have a big impact on future costs and the level of service for the users. Another core objective of this study was to compute and compare the life-cycle costs-benefits of different road maintenance activities.

Therefore, in this study, the economic analysis of road maintenance interventions was carried out using the HDM-4 by comparing with and without project scenarios for each of the project road sections. With project scenario was defined based on pavement condition and capacity analysis improvement options (i.e., pavement rehabilitation/reconstruction and capacity improvements like widening to standard two lane configuration). The without project scenario involves basic maintenance and periodic surface renewals to the existing roads.

Analysis period of 21 years including one (1) year of construction was considered. In order to compute the economic parameter or the net present value (NPV) of the identified maintenance interventions, a discount rate of 10% was used as normally used by the ERA. Results of the economic analysis interms of NPV (ETB million) for the proposed road maintenance options are presented in Table 13 below.

To achieve each treatment optimum intervention criteria, several criteria were chosen for a treatment in HDM runs that were based on roughness, road condition and traffic volume (see Khan, 2005 for details). This approach was repeated for all the criteria for a section and then different road sections were used to obtain an optimal solution. In each HDM run, two alternative treatment intervention criteria were used for a section, and then two output NPV values were compared to achieve better solutions. Thus, all the selected sections were optimized to obtain the best solution. Benefit (NPV/cost) and road condition maximization objectives can be chosen together to obtain the better optimum maintenance standards, which can be carried out using linear programming or general algorithm.

Table 13: Economic analysis results of road maintenance intervention

Road No.	Road Name	NPV (ETB Million)
1	Butajira-Wolbareg	413
2	Wolbareg-Hosana	413
3	Alemgena-Lemon	520
4	Lemon-Butajira	520
5	Commando-Fiche	710
6	Ambo-Gedo	987
7	Robe-Eteye	710
8	Gudober-D/Sina	178
9	Kosse-G/GibeNo.2	57
10	Butajira-Zeway	86
Average		456

Note: NPV = Net present value

Based on HDM4 analysts have calculated the present value of all benefits and costs associated with a road project, they can divide benefits by costs to calculate a benefit-cost ratio. A ratio greater than one indicates that estimated benefits exceed estimated costs.

The results of the analysis presented in Table 13 indicate that the proposed option (with and without-project) are all economically viable with overall average NPV at Birr 456 million the thresholds for the above parameter is "0" in the case of NPV; "

AS depicted in Table 13, above the NPVs are much higher for the roads in the case of Ambo-Gedo (NPV=987), Commando-Fiche(NPV=710), Robe-Eteye (NPV=710), Alemgena-Lemon(NPV=520), Lemon-Butajira (NPV=520), Butajira-Wolbareg (NPV=413), Wolbareg-Hosana (NPV=413), and Gudober-D/Sina (NPV=178). Nevertheless, the NPVs are lower for Kosse-G/Gibe No.2 and Butajira-Zeway roads as compared to other routes. The details are attached in annex-L.

In general, the proposed maintenance interventions in this study are economically worthwhile, if implemented by the ERA in the case of Alemgena Road Maintenance District.

4.4 Comparing Cost and Benefits of Different Maintenance Interventions within 20 years

The comparison of life-cycle cost of different road maintenance interventions is one basic aspects of decision-making for road authorities. In this study, the total costs of the current road maintenance practice by ERA and the total cost of the proposed maintenance alternative were compared over the analysis period of 20 years. Accordingly, Table 13 below shows the proposed road maintenance options, the expected life in years and associated costs for one case study (i.e., Butajira-Wolbareg, is depicted below. The corresponding data for the remaining nine roads is presented in Annex-B. Table 14 presents the summary of road maintenance costs current used by ERA and proposed maintenance costs over 20 years.

As shown on the table 14 the road maintenance options are classified in to four.

- ✓ Initial condition the road assumed to be at good condition and it needs no maintenance activity.
- ✓ On the years between Two to Four it is recommended to do minimum routine maintenance activities. (minor repair each year)
- ✓ On the years between Five to Seven it is recommended to do something routine maintenance activities (activities of greater than do minimum like permanent repair of potholes).
- ✓ On the years eight it is recommended to do major maintenance activities (periodic maintenance it involves capital expenditure).

This maintenance option repeats themselves in a cycle every eight years until the end of the design life, which is twenty years.

The cost estimated for routine and periodic maintenance is based on an average cost per kilometer per year of ERA road condition survey data. In the case of Butajira-Wolbareg the average cost per kilometer for routine maintenance has been ETB 35,136.11 and that of periodic maintenance has been ETB 237,236.08. According to the analysis made because of budget limitation, more than 90% of the maintenance by ERA has been routine. Table 14 shows a simple of road maintenance options of Butajira-Wolbareg road section in ARMD. The remaining road sections are attached in Annex-B.

Table 14: Road maintenance options, expected life years and associated costs for the selected roads

Butajira-Wolbareg						
No.	Options of Maintenance	Years	Road Length (km)	Cost for Routine and Periodic(ETB)		Total Cost Discounted Cost(ETB)
				Routine Maintenance	Periodic Maintenance	
1	Construction	1	54	0.00	0.00	0.00
2	Do Minimum	(2-4)		5,270,416.50	0.00	3,971,741.140
3	Do Something	(5-7)		5,834,351.10	0.00	3,302,264.110
4	Do major works	8		0.00	2,705,749.80	1,262,252.26
5	Do nothing	9		0.00	0.00	0.0
6	Do Minimum	(10-13)		7,027,222.00	0.00	2,361,730.53
7	Do Something	(14-17)		7,729,944.20	0.00	1,774,403.10
8	Do major works	18		0.00	2,705,749.80	486,652.89
9	Do Minimum	(19-20)		3,513,611.00	0.00	548,389.68
	Discounted cost					13,707,433.72

Table 15: Summary of the current road maintenance costs by ERA and proposed maintenance cost for 20 years (ETB)

Total summary of costs under ERA Road Maintenance				
S.No.	Project	Km	Total Currently practiced maintenance cost	Total Proposed Maintenance cost for 20 years
1	Butajira-Wolbareg	54	23,035,573.67	13,707,434.00
2	Wolbareg-Hosana	46	49,637,853.44	18,825,753.00
3	Alemgena-Lemon	42	84,263,957.42	16,523,531.00
4	Lemon-Butajira	74	54,754,117.11	52,313,349.00
5	Commando-Fiche	7	1,702,712.74	1,286,163.00
6	Ambo-Gedo	64	93,249,892.56	15,891,741.00
7	Robe-Etaye	48	97,329,597.49	42,103,614.00
8	Gudober-D/Sina	30	7,478,688.97	3,459,344.00
9	Kosse-G/GibeNo.2	35	3,568,573.04	5,426,308.00
10	Butajira-Zeway	54	42,790,579.91	14,525,394.00
	Total discounted cost		457,811,564.34	184,062,631.00
	The difference discounted cost(ETB)			273,748,915.34

As can be seen from table 15, the total lifetime 20 years of analysis period cost of road maintenance currently practiced by ERA indicates 457,811,564.34 ETB, whereas the total cost of the proposed maintenance alternative is 184,062,631 ETB. This indicates that the total cost of maintaining roads under the current ERA's practice is much higher than the proposed maintenance option. This could imply that ERA has to evaluate and adapt a new way of practice in selecting road maintenance intervention, by considering lifetime costs and expected economic returns.

The comparison the cost difference shows that the current maintenance interventions activities by ERA is causing higher life time costs. This implies that the maintenance interventions by ERA are inappropriate as they have resulted in higher costs than benefits.

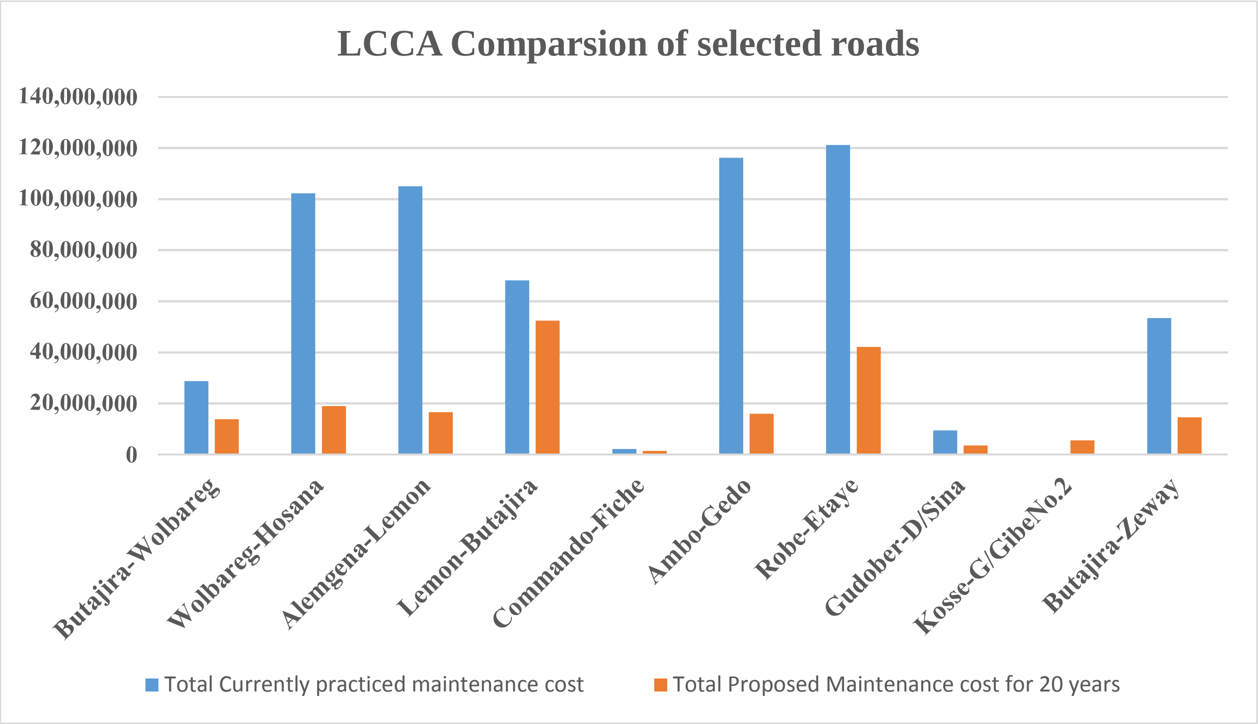

Figure 3: Road maintenance cost comparison for the current and proposed interventions

4.5 Road Maintenance Preventive Methods for Different Road Conditions in ERA and the Current Allocated Budget

The government report on road maintenance activities in Ethiopia demonstrates that the amount of budget allocated in the last two decades were much lower than what has been required for proper maintenance options (National Planning Commission, 2015). Due to such limited resources for road maintenance in Ethiopia, the use of available budget by applying proper cost effective road maintenance intervention is recommended.

As presented in Table 16 below, the ERA in 2003, set up different maintenance activities for paved roads corresponding to routine and periodic maintenance alternatives along with the needed unit price in ETB. The unit price presented on table 16 is based on ERCC contract price. This unit price much lower compared to unit price of other contractors. As it has been figured out during data collection stage, most of the maintenance works ERA road project are undertaken by ERCC with a relatively lower price.

Table 16: Maintenance Activities set by the Ethiopian Road Authority Source: (ERA, 2003)

Category	Scope	Ref. No.	Maintenance Activity Type	Unit	Unit Price ETB for the year (2003)
Routine Maintenance	Pavement	210	Asphalt Patching (Seal Coat)	m^2	25.15
		211	Asphalt Patching (Single Surface Treatment	m^2	28.81
		212	Asphalt Patching (Double Surface Treatment)	m^2	49.74
		213	Asphalt Patching (Cold Mix)	m^3	2,137.12
		214	Asphalt Patching (Hot mini-mix))	m^3	2,433.69
		215	Crack Sealing (Individual cracks)	lm	22.85
		216	Pothole Reinstatement (Double Surface Treatment)	m^2	48.09
		217	Pothole Reinstatement (Cold mix)	m^3	2,264.72
		218	Pothole Reinstatement (Hot mini- mix)	m^3	2,541.69
	Drainage	230	Ditch Cleaning (Machine)	km	2,814.99
	Road side	240	Shoulder Blading	km	463.38
		241	Shoulder Rehabilitation	m^3	94.29
Periodic Maintenance	Pavement	309	Sand seal coat	m^2	13.8
		310	Single Bituminous Surface Treatment(SBST)	m^2	1.01
		311	Double Bituminous Surface Treatment(DBST)	m^2	35.29
		312	Mix-in-place overlay (cold mix)	m^3	1,414.29
		313	Asphalt Concrete overlay	m^3	2,064.46
		314	Bitumen Prime Coat	Lt	15.8
		315	Bitumen Tack Coat	Lt	16.72

From the identified road maintenance interventions for each road condition in the Table 16, we can see that for each of road cases, appropriate maintenance interventions are needed to improve and sustain its lifetime serviceability. The results, in this study, appeared to support that applying routine and periodic maintenance in a proactive manner at appropriate time will likely reduce the total lifetime costs of road maintenance.

For a particular type of maintenance activities acting in a timely manner with appropriate intervention will have a significant role to minimize costs of road maintenance and mitigate associated social economic problems.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the Major Findings

The main purpose of this study was to conduct the life-cycle cost analysis for road maintenance interventions at the Ethiopian Federal Roads Authority, the case of the Alemgena Road Maintenance District. The ultimate objective was to compare the cost-benefit analysis of different road maintenance interventions thereby recommending the optimum total lifetime costs. The specific objectives of the study were to:

- identify different maintenance activities with corresponding defects of roads;
- compare life cycle cost-benefits of different road maintenance activities;
- determine an appropriate preventive method for different road sections based on the result of Life Cycle Cost Analysis; and
- determine different road maintenance methods for different road conditions in ERA on current allocated budget.

In order to meet the objectives of the study specified above, a case study was conducted and both quantitative and qualitative data were collected from ERA's road condition survey at Alemgena Road Maintenance District. In total, the Alemgena Road Maintenance District consists of nine (9) road sections and various sub-sections of paved and unpaved roads. From these, 5 (five) road maintenance sections 10 (ten) paved roads were selected and included in this study.

The qualitative data used in this study considered the description of the selected road condition and review of different road maintenance interventions. The quantitative data focused on numerical measures required in life-cycle cost analysis and HDM-4 software package. The collected input data were entered into the HDM-4 and the analysis of LCCA was carried out in order to determine the economic parameters of the net present value (NPV), for the study roads maintenance interventions. As a result, of the LCCA using HDM-4, the following major findings were observed:

- The results of data analysis indicated that, from the selected ten roads, six of them were in poor condition; two were in fair condition; and only two were in good condition. Thus, based on the road condition status, the maintenance activities corresponding with defects of the roads were identified for each road sections.
- The results from the LCCA using the HDM-4 model, comparing with and without project alternatives for each of the project road section indicated that under with-project cases all economically viable with the NPV greater than zero.
- The results of analysis showed that applying the routine and periodic maintenance at appropriate time for roads with poor/fair conditions, in a proactive manner, will significantly decrease the total lifetime costs and improve the conditions of those roads.
- In terms of budget, the current total cost of road maintenance implemented by ERA seems to be focused on short-term reaction and much higher in long-term life cycle of the road asset. On the contrary, the proposed maintenance interventions in this study was found to be lower by 273,748,915.34 ETB of total lifetime cost of maintenance than the one currently practiced by ERA.

5.2 Conclusions

The LCCA is a decision-making tool widely applied by road agencies in the selection of economically viable road maintenance interventions that would result in higher NPV and less lifetime costs of road projects. From the findings of this study, it can be concluded that the empirical analysis of the data collected from the ARMD supported the theoretical proposition that LCCA using rational maintenance interventions would generate positive and sound economic parameter (NPV) by accounting for lifetime costs and benefits. Thus, the LCCA can be a reliable and preferable tool for ERA to optimize its road maintenance interventions.

As it can be seen from the findings of this study, for a particular type of maintenance activity acting in a timely manner with appropriate intervention will have a significant role to minimize costs of road maintenance and mitigate associated social economic problems. It can also be concluded that the least cost investment option for road maintenance is not always economically a viable option. In addition to these, in this study, it was found that, applying both routine and periodic maintenance at appropriate time is needed in order to improve and sustain serviceability of road asset thereby reduces the total lifetime costs of maintaining roads. This is in line with that selecting appropriate maintenance activities will decrease the lifetime costs of the roads while increasing the economic return with less road user costs. As a result, the proposed maintenance interventions based on the outputs of HDM-4 for the study roads under ARMD were all found to be economically viable and cost-effective to invest on.

The comparison of the LCCA from the currently practiced maintenance options of the ERA with the proposed options has shown a considerable difference in such a way that the current practice is causing as significantly higher costs.

5.3 Recommendations

Based on the findings of this study, the following recommendations are forwarded for considerations by the ERA and pertinent policy makers:

- It was found that selecting and implementing road maintenance interventions corresponding with road condition status (road defects) by using LCCA would help to decrease the lifetime costs of road assets by increasing serviceability over the lifetime. Therefore, ERA has to reconsider improvement of its current practice of selecting least cost maintenance intervention, without considering lifetime costs and expected economic returns of those options.
- It is the economic principle of LCCA that postponing the currently needed road maintenance or switching to inappropriate maintenance intervention in the name of budget shortage will likely increase the lifetime cost of maintaining the road. Thus, the Road Fund Office has to increase its financing capacity by applying more revenue options and by diversifying its funding sources.
- If ERA needs to increase the lifetime benefits of its road network, it has to give proper attention to appropriate and timely road maintenance interventions by applying decision-making tools like LCCA and HDM-4 in its road asset management.
- Policy makers and planners directly working on road infrastructure development need to incorporate the LCCA into the budget allocation parameters for road maintenance.

5.4 Future Research Needs

- Due to lack of data, the LCCA was not addressed for gravel road maintenance interventions in this study. Thus, future studies are needed by collecting data on both paved and gravel road maintenance options for proper decision-making.

- Since the cost of road maintenance depends on such factors like climate zone, traffic volume, topography, and others, future research is needed on LCCA of road maintenance in Ethiopia by taking representative sample roads from all ERA's road maintenance regional areas and ten maintenance districts.

- Given the limited amount of budget for road maintenance in Ethiopia, determining the possible optimal mix of different maintenance interventions using the LCCA and HDM-4 was left to future studies in the area.

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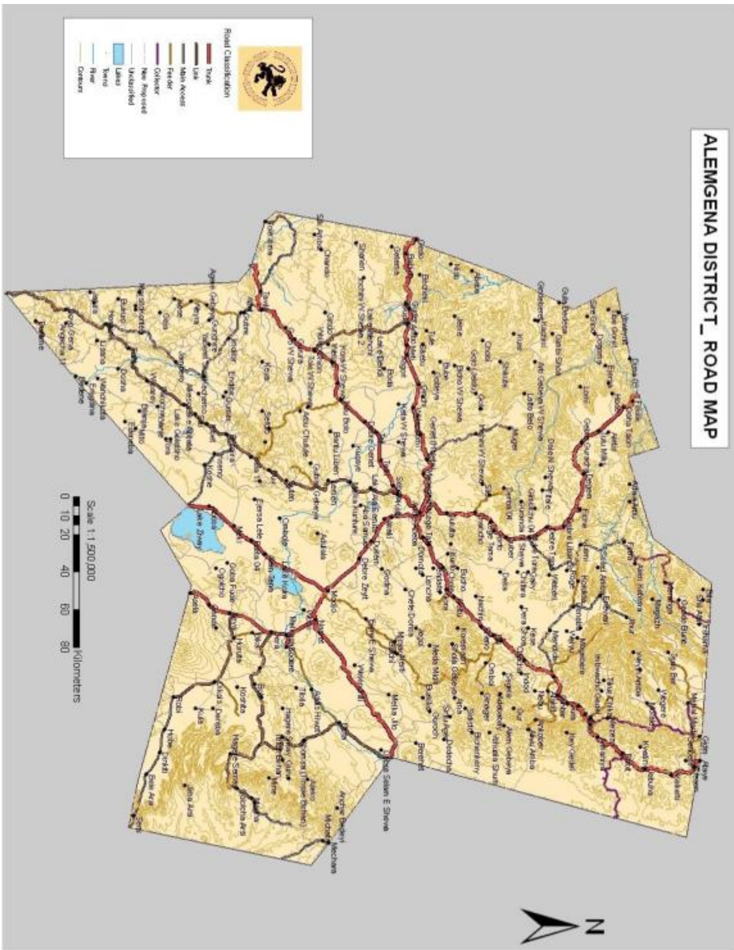
Annex A: Geographical Map of Alemgena Road Maintenance District



Annex B: Road maintenance options, expected life years and associated costs for the selected roads

S.No.	Options of Maintenance	Life Years	Road Length	Cost		Discounted Cost
				Routine Maintenance	Periodic Maintenance	
Butajira-Wolbareg						
1	Construction	1	54	0.0	0.0	0.0
2	Do Minimum	(2-4)		5,270,416.50	0.0	3,971,741.14
3	Do Something	(5-7)		5,834,351.07	0.0	3,302,264.11
4	Do major works	8		0.0	2,705,749.82	1,262,252.26
5	Do nothing	9		0.0	0.0	-
6	Do Minimum	(10-13)		7,027,222.00	0.0	2,361,730.53
7	Do Something	(14-17)		7,729,944.20	0.0	1,774,403.10
8	Do major works	18		0.0	2,705,749.82	486,652.89
9	Do Minimum	(19-20)		3,513,611.00	0.0	548,389.68
10	Total cost of the project					**13,707,433.72**
Wolbareg-Hosana						
1	Construction	1	46	0	0	0
2	Do Minimum	(2-4)		7516460.013	0	5664340.469
3	Do Something	(5-7)		8320721.103	0	4709558.679
4	Do major works	8		0	2712817.167	1265549.23
5	Do nothing	9		0	0	0
6	Do Minimum	(10-13)		10021946.68	0	3368206.875
7	Do Something	(14-17)		11104567.3	0	2548081.748
8	Do major works	18		0	2712817.167	487924.0129
9	Do Minimum	(19-20)		5010973.342	0	782091.7204
10	Total cost of the project					**18,825,752.73**
Alemgena-Lemon						
1	Construction	1	42	0.00	0.00	0.00
2	Do Minimum	(2-4)		4628096.55	0.00	3487694.28
3	Do Something	(5-7)		5090906.21	0.00	2882391.97
4	Do major works	8		0.00	9344295.77	4359182.94
5	Do nothing	9		0.00	0.00	0.00
6	Do Minimum	(10-13)		6170795.40	0.00	2073900.03
7	Do Something	(14-17)		6787874.94	0.00	1558151.79
8	Do major works	18		0.00	9344295.77	1680653.73
9	Do Minimum	(19-20)		3085397.70	0.00	481555.94
10	Total cost of the project					**16,523,530.67**

Annex B: Continued...

S.No.	Options of Maintenance	Life Years	Road Length	Cost		Total Cost
				Routine Maintenance	Periodic Maintenance	
Lemon-Butajira						
1	Construction	1	74	0	0	0
2	Do Minimum	(2-4)		22000891.17	0	16579684.85
3	Do Something	(5-7)		24200980.29	0	13702218.89
4	Do major works	8		0	3831130.789	1787250.788
5	Do nothing	9		0	0	0
6	Do Minimum	(10-13)		29334521.56	0	9858836.843
7	Do Something	(14-17)		32267973.72	0	7407090.04
8	Do major works	18		0	3831130.789	689062.5477
9	Do Minimum	(19-20)		14667260.78	0	2289204.598
10	Total cost of the project					**52,313,348.55**
Commando-Fiche						
1	Construction	1	7	0	0	0
2	Do Minimum	(2-4)		549219.24	0	413886.9577
3	Do Something	(5-7)		604141.164	0	342055.337
4	Do major works	8		0	65065.618	30353.59099
5	Do nothing	9		0	0	0
6	Do Minimum	(10-13)		732292.32	0	246111.0705
7	Do Something	(14-17)		805521.552	0	184906.8899
8	Do major works	18		0	65065.618	11702.62332
9	Do Minimum	(19-20)		366146.16	0	57146.55829
10	Total cost of the project					**1,286,163.03**
Ambo-Gedo						
1	Construction	1	64	0	0	0
2	Do Minimum	(2-4)		6040056.87	0	4551735.592
3	Do Something	(5-7)		6644062.557	0	3761764.952
4	Do major works	8		0	3418549.929	1594778.771
5	Do nothing	9		0	0	0
6	Do Minimum	(10-13)		8053409.16	0	2706614.689
7	Do Something	(14-17)		8858750.076	0	2033519.676
8	Do major works	18		0	3418549.929	614856.2535
9	Do Minimum	(19-20)		4026704.58	0	628471.1766
10	Total cost of the project					**15,891,741.11**

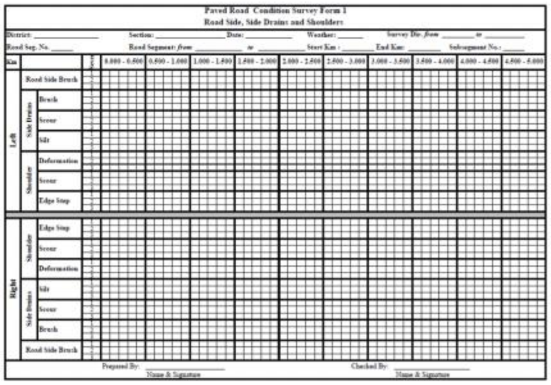
Annex B: Continued...

S.No.	Options of Maintenance	Life Years	Road Length	Cost		Total Cost
				Routine Maintenance	Periodic Maintenance	
Robe-Etaye						
1	Construction	1	48	0.00	0.00	0.00
2	Do Minimum	(2-4)		8,229,743.04	0.00	6,201,864.50
3	Do Something	(5-7)		12,264,324.38	0.00	6,943,869.84
4	Do major works	8		0.00	31,963,375.24	14,911,150.44
5	Do nothing	9		0.00	0.00	0.00
6	Do Minimum	(10-13)		10,972,990.72	0.00	3,687,836.70
7	Do Something	(14-17)		16,352,432.51	0.00	3,753,689.06
8	Do major works	18		0.00	31,963,375.24	5,748,893.99
9	Do Minimum	(19-20)		5,486,495.36	0.00	856,309.20
10	Total cost of the project					**42,103,613.75**
Gudober-D/Sina						
1	Construction	1	30	0.00	0.00	0.00
2	Do Minimum	(2-4)		1,372,204.80	0.00	1,034,081.89
3	Do Something	(5-7)		1,509,425.28	0.00	854,613.13
4	Do major works	8		0.00	543,016.26	253,321.09
5	Do nothing	9		0.00	0.00	0.00
6	Do Minimum	(10-13)		1,829,606.40	0.00	614,899.78
7	Do Something	(14-17)		2,017,141.06	0.00	462,888.25
8	Do major works	18		0.00	543,016.26	97,666.25
9	Do Minimum	(19-20)		914,803.20	0.00	142,778.65
10	Total cost of the project					**3,460,249.05**
Kosse-G/GibeNo.2						
1	Construction	1	35	0.00	0.00	0.00
2	Do Minimum	(2-4)		2,296,285.32	0.00	1,730,461.13
3	Do Something	(5-7)		2,525,913.85	0.00	1,430,133.16
4	Do major works	8		0.00	347,632.12	162,172.95
5	Do nothing	9		0.00	0.00	0.00
6	Do Minimum	(10-13)		3,061,713.76	0.00	1,028,990.24
7	Do Something	(14-17)		3,375,539.42	0.00	774,609.96
8	Do major works	18		0.00	347,632.12	62,524.69
9	Do Minimum	(19-20)		1,530,856.88	0.00	238,929.73
10	Total cost of the project					**5,427,821.86**

Annex B: Continued...

Butajira-Zeway						
S.No.	Options of Maintenance	Life Years	Road Length	Cost		Total Cost
				Routine Maintenance	Periodic Maintenance	
1	Construction	1	54	0.00	0.00	0.00
2	Do Minimum	(2-4)		4,964,928.66	0.00	3,741,528.10
3	Do Something	(5-7)		5,461,421.53	0.00	3,092,171.98
4	Do major works	8		0.00	5,072,509.24	2,366,363.00
5	Do nothing	9		0.00	0.00	0.00
6	Do Minimum	(10-13)		6,619,904.88	0.00	2,224,838.13
7	Do Something	(14-17)		7,281,895.37	0.00	1,671,553.82
8	Do major works	18		0.00	5,072,509.24	912,335.37
9	Do Minimum	(19-20)		3,309,952.44	0.00	516,603.51
10	Total cost of the project					**14,525,393.91**
Grand discounted total cost for the ten roads over 20 Years = 184,062,629.07						

Annex C: Paved Road Condition Survey Form 1: Road side, Side drains & Shoulders



Paved Road Condition Survey Form 1

Road Side, Side Drains and Shoulders

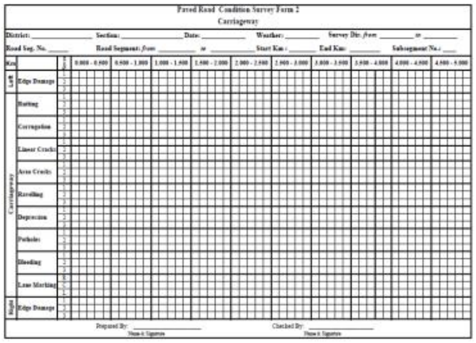
District: ______ Section: ______ Date: ______ Weather: ______ Survey Dir. *from* ______ *to* ______

Road Seg. No. ______ Road Segment: *from* ______ *to* ______ Start Km : ______ End Km: ______ Subsegment No.: ______

Km				0.000 - 0.500	0.500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Road Side Brush												
	Side Drains	Brush											
		Scour											
		Silt											
	Shoulder	Deformation											
		Scour											
		Edge Step											
Right	Shoulder	Edge Step											
		Scour											
		Deformation											
	Side Drains	Silt											
		Scour											
		Brush											
	Road Side Brush												

Prepared By: ______ Name & Signature Checked By: ______ Name & Signature

Annex D: Paved Road Condition Survey Form 2: Carriageways



Paved Road Condition Survey Form 2

Carriageway

District: ______ Section: ______ Date: ______ Weather: ______ Survey Dir. from ______ to ______

Road Seg. No. ______ Road Segment: from ______ to ______ Start Km: ______ End Km: ______ Subsegment No.: ______

Km			0.000 - 0.500	0.500 - 1.000	1.000 - 1.500	1.500 - 2.000	2.000 - 2.500	2.500 - 3.000	3.000 - 3.500	3.500 - 4.000	4.000 - 4.500	4.500 - 5.000
Left	Edge Damage	1 2 3										
Carriageway	Rutting	1 2 3										
	Corrugation	1 2 3										
	Linear Cracks	1 2 3										
	Area Cracks	1 2 3										
	Ravelling	1 2 3										
	Depression	1 2 3										
	Potholes	1 2 3										
	Bleeding	1 2 3										
	Lane Marking	1 2 3										
Right	Edge Damage	1 2 3										

Prepared By: ______ Name & Signature

Checked By: ______ Name & Signature

Annex E: Alemgena Road Maintenance Districts Sections

Mukatiri Section

I/No	Road No	Segment No.	Segment Name	Station start	Station End	Length km	Surface type
1	A3-1	804/1	Addis-Chancho	9+000	37+000	28	AC
2	A3-1	804/2	Chancho- Commando	37+000	110+000	73	AC
3	A3-2	804/3	Commando-G/Guracha	110+000	155+000	45	AC
4	A3-2	804/4	G/Guracha-Abaye wonze	155+000	206+000	51	AC
5	A3-3	804/5	Abaye wonz-Dejen	206+000	227+000	21	AC
6	A3a	804/6	Commando-Fitche	0+000	7+000	7	CM
7	C31	804/7	Mukaturi-Lemi	0+000	50+000	50	NG
8	C31	804/8	Lemi-Alemketema	50+000	105+000	55	NG
9	D31-1	804/9	Alemketema-Dogollo	105+000	180+000	75	NG
10	D31-2	804/10	Dgollo-Beto wonz	180+000	215+000	38	NG
11	E31	804/11	Chancho-Derba	0+000	23+000	23	under construction
12	E35	804/12	Chagel-Debrelibanos	0+000	5+000	5	CM

Note that: - AC=Asphalt concrete
CM=Cold Mix
NG=Natural ground

Ambo Section

I/No.	Road No.	Segment No.	Segment Name	Station start	Station End	Length km	Surface type
1	A4-1	805/1	Addis - Holeta	10+000	50+000	40	AC
2	A4-2	805/2	Holeta - Ginchi	50+000	98+000	48	AC
3	A4-2	805/3	Ginchi - Ambo	98+000	135+000	37	AC
4	A4-3	805/4	Ambo - Gedo	135+000	200+000	65	AC
5	C41	805/5	Holeta - Muger	0+000	57+000	57	AC
6	E43	805/6	Ginchi - Busa - Tulubolo	0+000	48+000	48	NG
7	B41	805/7	Ambo - Wolliso	0+000	63+000	63	NG
8		805/8	Addis - Tatek	0+000	14+000	14	CM

Wolliso Section

I/No.	Road No.	Segment No.	Segment Name	Station start	Station End	Length km	Surface type
1	A5-1	806/1	Addis - Tulubollo	14+000	91+000	77	AC
2	A5-1	806/2	Tulubollo- Woliso	91+000	126+000	35	AC
3	A5-2	806/3	Woliso- Wlokite	126+000	169+000	43	AC
4	A5-3	806/4	Wolkite - Gibe wonze	169+000	199+000	30	AC
5	E51	806/5	Tulubollo- Robgebeya	0+000	62+000	62	NG
6	E51	806/6	Robgebeya - Kela	62+000	82+000	20	NG
7	New	806/7	Kegne - Zemute- Beke	0+000	18+000	18	NG
8	C53	806/8	Tolay Junction- Tolay	0+000	64+000	64	NG
9	New	806/9	Holeta- Sebeta	0+000	29+000	29	NG

Note that: - AC=Asphalt concrete, CM=Cold Mix and NG=Natural ground

Huruta Section

I/No	Road No	Segment No	Segment Name	Station start	Station End	Length km	Surface type
1	A9	807/1	Nazrete- Melkasa	0+000	17+000	17	AC
2	A9	807/2	Melkasa-Eteya	17+000	50+000	33	AC
3	A9	807/3	Eiteya-Assela	50+000	78+000	28	AC
4	A9a	807/4	Melkasa-Sodere	0+000	7+000	7	MC
5	B92-1	807/5	Eiteya-Dicsis-Robe	0+000	76+000	76	NG
6	C92-1	807/6	Robe-Seru	0+000	74+000	74	NG
7	C92-2	807/7	Seru-Shekhussein	74+000	139+000	65	NG
8	E91	807/8	Nuraera Junction-Methara	0+000	89+000	89	NG
9	New	807/9	Nuraera bole-Awragodana	0+000	24+000	24	NG
10	B91-1	807/10	Dera-Sire	0+000	23+000	23	CG
11	B91-2	807/11	Sire-Chole	23+000	95+000	72	CG
12	C91-1	807/12	Chole-Barsalia	95+000	135+000	40	NG
13	C91-2	807/13	Magena-Mechara	0+000	120+000	120	CG

Note that: - AC=Asphalt concrete
CG=Crushed Aggregate
NG=Natural ground

Robit Section

I/ No	Road No	Segment No	Segment Name	Station start	Station End	Length km	Surface type
1	A2-2	808/1	Gudoberet - Debresina	163+000	193+000	30	Ac
2	A2-3	808/2	Debresina - Robit	193+000	225+000	32	Ac
3	A2-3	808/3	Robit - Ataye	225+000	273+000	48	Ac
4	D22	808/4	Robit - Awash	0+000	44+000	44	NG
5	D21	808/5	Taremaber-Meleya	0+000	59+000	59	NG
6	D21	808/6	Meleya - Mehalmeda	59+000	99+000	40	NG
7	D21a	808/7	Meleya - Molale	0+000	14+000	14	NG
8	E24	808/8	Taremaber-Sladengaye	0+000	21+000	21	NG

Debrebirhan Section

I/ No	Road No	Segment No	Segment Name	Station start	Station End	Length km	Surface type
1	A2-1	809/1	Addis-Aleltu	18+000	58+000	40	AC
2	A2-1	809/2	Aleltu-Senbo	58+000	93+000	35	AC
3	A2-1	809/3	Sembo-Debrebirhan	93+000	130+000	37	AC
4	A2-2	809/4	Debrebirhan-Gudoberet	130+000	163+000	33	AC
5	E23	809/5	Debrebirhan-Ankober	0+000	40+000	40	NG

6	C21	809/6	Debrebirhan-Jihur	0+000	86+000	86	NG
7	E21	809/7	Aleltu-Etesa	0+000	12+000	12	NG
8	E22	809/8	Sembo-Kesem wonz	0+000	85+000	60/25	NG/TBST
9	E23a	809/9	Miak junction - Mitak	0+000	13+000	13	NG

Modjo Section

I/ No	Road No	Segment No	Segment Name	Station start	Station End	Length km	Surface type
1	A1-1	801/1	Addis-Modjo	24+000	79+000	55	AC
2	A1-2	801/2	Modjo-Nazrete	79+000	98+000	19	AC
3	A1-3	801/3	Nazrete-Mathara	98+000	182+000	84	AC
4	A1-4	801/4	Methara-Awash	182+000	228+000	46	AC
5	A7-1	801/5	Modjo-Zewaye	79+000	166+000	87	AC
6	E11	801/6	Modjo-Ejere-Arerti	0+000	60+000	60	TBST
7	E11	801/7	Arerti-Kesem wonz	60+000	85+000	25	TBST
8	E11a	801/8	Balchi Junction-Aranbuti	0+000	23+000	23	NG
9	E72	801/9	Meki-Kella	0+000	60+000	60	NG

Note that: - AC=Asphalt concrete
TBST=Triple Bituminous Surface Treatment
NG=Natural Ground

Butajera Section

I/ No.	Road No.	Segment No.	Segment Name	Station start	Station End	Length km	Surface type
1	B51-1	802/1	Alemgena-Lemen	0+000	42+000	41	DBST
2	B51-1	802/2	Lemen-Butajera	42+000	116+000	74	DBST
3	B51-2	802/3	Butajera-Wolbareg	116+000	170+000	54	DBST
4	B51-2	802/4	Wolbareg-Hossana	170+000	216+000		DBST
5	B51-3	802/5	Hossana-Areka	216+000	285+000	69	DBST
6	C52-2	802/6	Butajera-Zewaye	0+000	51+000	51	DBST
7	E54	802/7	Tere-Amawote	0+000	19+000	19	NG
8	E55	802/8	Tiya-Amowete	0+000	12+000	12	NG
9	New	802/9	Tiya Gereno-Amowete	0+000	18+000	18	NG
10	New	802/10	Bui Aymelel-Robgebeya	0+000	36+000	36	NG
11	New	802/11	Bui-Midrekebd-Dugda	0+000	41+000	41	NG

Note that: - DBST= Double Bituminous Surface Treatment
CM=Cold Mix
NG=Natural ground

Emdiber Section

I/ No	Road No	Segment No	Segment Name	Station start	Station End	Length km	Surface type
1	C51	803/1	Wolkite-Mazoria	0+000	56+000	56	NG
2	C51	803/2	Mazoria-Hossana	56+000	125+000	69	NG
3	E56	803/3	Mazoria-Bojobar	0+000	20+000	20	NG
4	E52	803/4	Atate Junction-Kose	0+000	46+000	46	NG
5	E52-1	803/5	Kose-Gilgel gibeII	46+000	81+000	35	CM
6	E59	803/6	Gunchire Junction-Gunchire	0+000	7+000	7	NG
7	E53	803/7	Gubre Junction-Bojobar	0+000	61+000	61	DBST
8			Bojobar-Butajira	0+000	21+000	21	DBST

Annex F: Sample of Bill of Quantity and Condition Survey

2004 EFY **Bill of Quantity**

Project Name Butajira-Wolbarge (Butajira Section) Length **54km** Road type **Asphalt**

Act. Code	Description	Unit	Unit rate	Quantity	Amount (ETB)
121	Culvert Cleaning	m3	170.13	1820	309636.6
122	Ditch Cleaning by manual	Lm	30.6	3640	111,384.00
213	Asphalt patching(SST)	m3	158.4	5209.4	825,168.96
215	Cracking sailing (Individual cracks)	Lm	475.41	238	113,147.58
216	Pothole Reinstatement(DBST)	m2	730.21	462.224	337,520.59
510	over haul	km-m3	5.55	118192.48	655,968.26
	Sub-Total				2,352,825.99
	VAT (15%)				352,923.90
	Total				2,705,749.89
	Cost per km				50,106.48

Project Name Wolbarge -Hossana (Butajira Section) Length **46km** Road type **Asphalt**

Act. Code	Description	Unit	Unit rate	Quantity	Amount (ETB)
121	Culvert Cleaning	m3	170.13	84	14,290.92
122	Ditch Cleaning by manual	Lm	30.6	1680	51,408.00
213	Asphalt patching(SST)	m3	158.4	12563.6	1,990,074.24
215	Cracking Sailing (Individual cracks)	Lm	475.41	42	19,967.22
216	Pothole Reinstatement(DBST)	m2	730.21	130.718	95,451.59
219	pothole Reinstatement (base failure)	m3	634.34	1437.744	912,018.53
241	Shoulder rehabilitation	m3	190.28	3011.4	573,009.19
510	over haul	km-m3	5.55	254726.36	1,413,731.30
	Sub-Total				5,069,950.99
	VAT (15%)				760,492.65
	Total				5,830,443.64
	Cost Per km				126,748.77

2004 Condition survey

Project: -Butajira Section

Item . No	Project Name	Segment Name	Road Length		Brief Description of Defects or problems	Proposed Remedial Solution	Status
			Paved	Unpaved			
1	Butajira-Areka-Sodo	Butajira-Wolbareg	54		Carriage way wear, pothole	Asphalt patching, Pothole Reinstatement	Good condition
					Cracking, and Shoulder damaged	Crack sealing, and shoulder rehabilitation	
					Pothole (base failure), Carriage wearing and Shoulder damaged	Pothole Reinstatement, Asphalt Patching and Shoulder rehabilitation	
					Pothole (base failure), Carriage way wear and traffic sign missing	Pothole Reinstatement, Asphalt Patching and traffic sign Installment	
2	Butajira-Areka-Sodo	Wolbareg-Hossana	46		Carriage way wear, pothole	Asphalt patching, Pothole Reinstatement	Bad condition
					Cracking, and Shoulder damaged	Crack sealing, and shoulder rehabilitation	
					Pothole (base failure), carriage wearing and Shoulder damaged	Pothole Reinstatement, Asphalt Patching and Shoulder rehabilitation	
					Pothole (base failure), Carriage way wear and traffic sign missing	Pothole Reinstatement, Asphalt Patching and traffic sign Installment	

Annex G: Vehicle Operating Cost for (2004-2008) EC

Vehicle Type	Car	L/Rover	S/Bus	L/Bus	S/Truck	M/Truck	H/Truck	T/Trailer
Physical Characteristics								
operating weight (kg)	1200	1600	5200	9000	5500	13000	22000	28000
Axels per vehicle (no.)	2	2	2	2	2	2	3	5
Tires per vehicle(no.)	4	4	4	6	4	6	10	18
Utilization								
Annual Run (km)	20000	40000	50000	60000	50000	60000	65000	65000
Annual Hours	500	900	1600	1800	1600	1800	2100	2100
Average service life (yrs)	12	12	15	15	12	15	15	15
private use (%)	85	20	15					
Passenger Occupancy (no.)	3	3	20	45	2	2	2	2
work relateed trips (%)	15	80	85	100	100	100	100	100
Time value								
Passenger working time	2.06	2.06	1.47	1.47	2.26	2.26	2.26	2.26
Passenger non-working time	0.72	0.72	0.52	0.52	0.79	0.79	0.79	0.79
Cargo					0.13	0.3	0.36	0.77

Unit Cost (Economic) 2004 E.C

Vehicle Type		One New Vehicle (Birr)	One Tyre (Birr)	One Liter Fuel (Birr)	One liter lubricant (Birr)	One Working Hour in Work Shop (Birr)	One Working Hour for crew (Birr)
Car	Toyota Corolla (sedan)	1,124,000	1411	19.82	85.88	21.15	16.50
Large car	Toyota Land cruiser	4,329,000	5180	17.60	73.28	22.43	22.50
Small bus	Iveco*	1,400,000	7632	17.60	73.28	19.65	20.57
Large bus	Iveco**	2,605,000	12351	17.60	73.28	15.05	37.09
Pick-up	Toyota (D/CAB)	1,587,000	2647	19.82	85.88	21.57	21.75
Small truck	Mitsubishi (70 quintals)	1,250,000	6956	17.60	73.28	21.28	26.44
Medium Truck	Iveco (246 quintals) ***	2,700,000	12351	17.60	73.28	28.48	31.67
Large Truck	Scania (400 quintals) ****	2,872,355	12351	17.60	73.28	30.57	37.60
Truck and Trailer	M. Truck + trailer (170 + 235 q)	4,300,000	12351	17.60	73.28	30.98	37.60

Unit Cost (Economic) 2005 E.C

Vehicle Type		Price (2012/13) - Birr					
		One New Vehicle (Birr)	One Tyre (Birr)	One Liter Fuel (Birr)	One Liter Lubricant (Birr)	One Working Hour in Work Shop (Birr)	One Working Hour for Crew (Birr)
Car	Toyota Corolla (sedan)*	1,098,000	1910	18.78	84.77	31.10	16.67
Large car	Toyota Landcruiser*	3,939,000	5377	16.91	84.65	30.69	34.00
Small bus	Iveco**	1,360,000	9129	16.91	84.65	30.23	21.57
Large bus	Iveco	2,650,000	13795	16.91	84.65	25.35	48.04
Pick-up	Toyota (D/CAB)	1,720,000	2617	18.78	84.77	30.84	25.50
Small truck	Mitsubishi (70 quintas)	1,310,000	8737	16.91	84.65	26.86	29.69
Medium Truck	Iveco (246 quintas)	3,100,000	13795	16.91	84.65	39.68	34.28
Large Truck	Scania (400 quintas)	3,324,273	13795	16.91	84.65	34.07	37.93
Truck and Trailer	M. Truck + trailer (170 + 235 q)	4,746,000	13795	16.91	84.65	35.45	37.93

Unit Cost (Economic) 2006 E.C

Vehicle Type		Price (2013/14) - Birr					
		One New Vehicle (Birr)	One Tyre (Birr)	One Liter Fuel (Birr)	One Liter Lubricant (Birr)	One Working Hour in Work Shop (Birr)	One Working Hour for Crew (Birr)
Car	Toyota Corolla (sedan)*	1,098,000	1910	18.78	84.77	31.10	16.67
Large car	Toyota Landcruiser*	3,939,000	5377	16.91	84.65	30.69	34.00
Small bus	Iveco**	1,360,000	9129	16.91	84.65	30.23	21.57
Large bus	Iveco	2,650,000	13795	16.91	84.65	25.35	48.04
Pick-up	Toyota (D/CAB)	1,720,000	2617	18.78	84.77	30.84	25.50
Small truck	Mitsubishi (70 quintas)	1,310,000	8737	16.91	84.65	26.86	29.69
Medium Truck	Iveco (246 quintas)	3,100,000	13795	16.91	84.65	39.68	34.28
Large Truck	Scania (400 quintas)	3,324,273	13795	16.91	84.65	34.07	37.93
Truck and Trailer	M. Truck + trailer (170 + 235 q)	4,746,000	13795	16.91	84.65	35.45	37.93

Unit Cost (Economic) 2007 EC

Vehicle Type		Price (2014/15) - Birr					
		One New Vehicle (Birr)	One Tyre (Birr)	One Litre Fuel (Birr)	One Litre Lubricant (Birr)	One Working Hour in Work Shop (Birr)	One Working Hour for Crew (Birr)
Car	Toyota Corolla (sedan)*	1,316,000	1996	18.60	78.00	41.54	19.17
Large car	Mitsubishi (Pajaro)*	3,673,000	4250	17.75	73.21	42.63	37.50
Small bus	Mitsubishi**	1,650,000	8000	17.75	73.21	41.27	62.86
Large bus	Iveco	2,650,000	14600	17.75	73.21	48.35	59.22
Pick-up	Toyota (D/CAB)	1,929,000	2900	18.60	78.00	39.79	42.00
Small truck	Mitsubishi (70 quintas)	1,644,000	7250	17.75	73.21	34.09	37.33
Medium Truck	Iveco (246 quintas)	3,150,000	14600	17.75	73.21	39.68	43.00
Large Truck	Scania (400 quintas)	3,581,727	14600	17.75	73.21	45.80	65.50
Truck and Trailer	M. Truck + trailer (170 + 235 q)	4,300,000	14600	17.75	73.21	47.51	89.00

Unit Cost (Economic Cost)2008EC

Vehicle Type		Price (2015/16) - Birr						
		One New Vehicle (Birr)	One Tyre (Birr)	One Liter Fuel (Birr)	Fuel Type	One Liter Lubricant (Birr)	One Working Hour in Work Shop (Birr)	One Working Hour for Crew (Birr)
Car	Toyota Corolla (sedan)*	1,378,000	2100	14.16	petrol	78.00	40.70	33.33
Large car	Mitsubishi (Pajero)*	4,594,000	4500	17.34	diesel	73.21	44.68	40.00
Small bus	Mitsubishi**	1,650,000	8450	17.34	diesel	73.21	41.44	65.00
Large bus	Iveco	2,650,000	15200	17.34	diesel	73.21	53.96	62.21
Pick-up	Toyota (D/CAB)	2,278,000	3200	14.16	petrol	78.00	31.39	43.00
Small truck	Mitsubishi (70 quintals)	1,850,000	7600	17.34	diesel	73.21	40.01	40.28
Medium Truck	Iveco (246 quintals)	3,150,000	14800	17.34	diesel	73.21	45.80	43.67
Large Truck	Scania (400 quintals)	3,581,727	15000	17.34	diesel	73.21	45.80	84.19
Truck and Trailer	M. Truck + trailer (170 + 235 q)	4,300,000	15700	17.34	diesel	73.21	50.97	88.75

Annex H: Average costs for five years (2004-2008) EFY

Average cost for 2004-2008EC			
	Project	Km	average Total cost for 5yrs
1	Butajira-Wolbareg	54	2,705,749.84
2	Wolbareg-Hosana	46	5,830,443.64
3	Alemgena-Lemon	42	9,897,612.82
4	Lemon-Butajira	74	6,431,398.05
5	Commando-Fiche	7	200,000.00
6	Ambo-Gedo	64	10,953,097.39
7	Robe-Etaye	48	11,432,298.00
8	Gudober-D/Sina	30	878,444.00
9	Kosse-G/GibeNo.2	35	419,163.25
10	Butajira-Zeway	54	5,026,165.46
	Total cost		**53,774,372.45**

Annex I: Discounted costs for 20years

$(n+1)^n$	The Discounted cost for 20yeras							
1.10	2,459,772.6	5,300,403.3	8,997,829.8	5,846,725.5	181,818.2	9,957,361.3	10,392,998.2	798,585.5
1.21	2,236,156.9	4,818,548.5	8,179,845.3	5,315,205.0	165,289.3	9,052,146.6	9,448,180.2	725,986.8
1.33	2,032,869.9	4,380,498.6	7,436,223.0	4,832,004.5	150,263.0	8,229,224.2	8,589,254.7	659,988.0
1.46	1,848,063.5	3,982,271.5	6,760,202.7	4,392,731.4	136,602.7	7,481,112.9	7,808,413.4	599,989.1
1.61	1,680,057.8	3,620,246.8	6,145,638.8	3,993,392.2	124,184.3	6,801,011.7	7,098,557.6	545,444.6
1.77	1,527,325.2	3,291,133.4	5,586,944.4	3,630,356.5	112,894.8	6,182,737.9	6,453,234.2	495,858.7
1.95	1,388,477.5	2,991,939.5	5,079,040.4	3,300,324.1	102,631.6	5,620,670.8	5,866,576.5	450,780.7
2.14	1,262,252.3	2,719,945.0	4,617,309.4	3,000,294.7	93,301.5	5,109,700.8	5,333,251.4	409,800.6
2.36	1,147,502.1	2,472,677.3	4,197,554.0	2,727,540.6	84,819.5	4,645,182.5	4,848,410.4	372,546.0
2.59	1,043,183.7	2,247,888.4	3,815,958.2	2,479,582.4	77,108.7	4,222,893.2	4,407,645.8	338,678.2
2.85	948,348.8	2,043,534.9	3,469,052.9	2,254,165.8	70,098.8	3,838,993.8	4,006,950.7	307,889.3
3.14	862,135.3	1,857,759.0	3,153,684.5	2,049,241.6	63,726.2	3,489,994.4	3,642,682.5	279,899.3
3.45	783,759.3	1,688,871.8	2,866,985.9	1,862,946.9	57,932.9	3,172,722.2	3,311,529.5	254,453.9
3.80	712,508.5	1,535,338.0	2,606,350.8	1,693,588.1	52,666.3	2,884,292.9	3,010,481.4	231,321.8
4.18	647,735.0	1,395,761.9	2,369,409.8	1,539,625.6	47,878.4	2,622,084.4	2,736,801.2	210,292.5
4.59	588,850.0	1,268,874.4	2,154,008.9	1,399,659.6	43,525.8	2,383,713.1	2,488,001.1	191,175.0
5.05	535,318.2	1,153,522.2	1,958,189.9	1,272,417.8	39,568.9	2,167,011.9	2,261,819.2	173,795.5
5.56	486,652.9	1,048,656.5	1,780,172.7	1,156,743.5	35,971.8	1,970,010.8	2,056,199.3	157,995.9
6.12	442,411.7	953,324.1	1,618,338.8	1,051,585.0	32,701.6	1,790,918.9	1,869,272.1	143,632.6
6.73	402,192.5	866,658.3	1,471,217.1	955,986.3	29,728.7	1,628,108.1	1,699,338.3	130,575.1
	23,035,573.7	49,637,853.4	84,263,957.4	54,754,117.1	1,702,712.7	93,249,892.6	97,329,597.5	7,478,689.0

Total discounted cost ERA Road Maintenance			
No.	Project	Km	Total Discounted cost
1	Butajira-Wolbareg	54	23,035,573.67
2	Wolbareg-Hosana	46	49,637,853.44
3	Alemgena-Lemon	42	84,263,957.42
4	Lemon-Butajira	74	54,754,117.11
5	Commando-Fiche	7	1,702,712.74
6	Ambo-Gedo	64	93,249,892.56
7	Robe-Etaye	48	97,329,597.49
8	Gudober-D/Sina	30	7,478,688.97
9	Kosse-G/GibeNo.2	35	3,568,573.04
10	Butajira-Zeway	54	42,790,579.91
	Total cost		457,811,546.34

Annex J: Altitude

No.	Place Name	Altitude (mts)
1	Addis Ababa	2,371
2	Debrezeit	2,006
3	Wonji	1,584
4	Ghion/Woliso	2,049
5	Ziway	1,643
6	Mojo	1,803
7	Butajira	2,123
8	Fiche	2,853
9	Holeta/Genet	2,381
10	Sebeta	2,405
11	Gebregurach	2,547
12	Guder/Ambo	1,947
13	Awash	876
14	Tulubolo	2,193
15	Addis Alem	2,178
16	Gedo	2,432
17	Debre Berhan	2,840

Annex J: HDM4 Annual Pavement Deterioration Summary (Combined)

Study Name: **Alemgena butajira**

Alternative: with
Section: Alemgena-Lemon

Run Date: **20-09-2017**

Surface: Bituminous

Road Class: **Secondary or Main**

Length: 42.00km

Width: **7.00m**

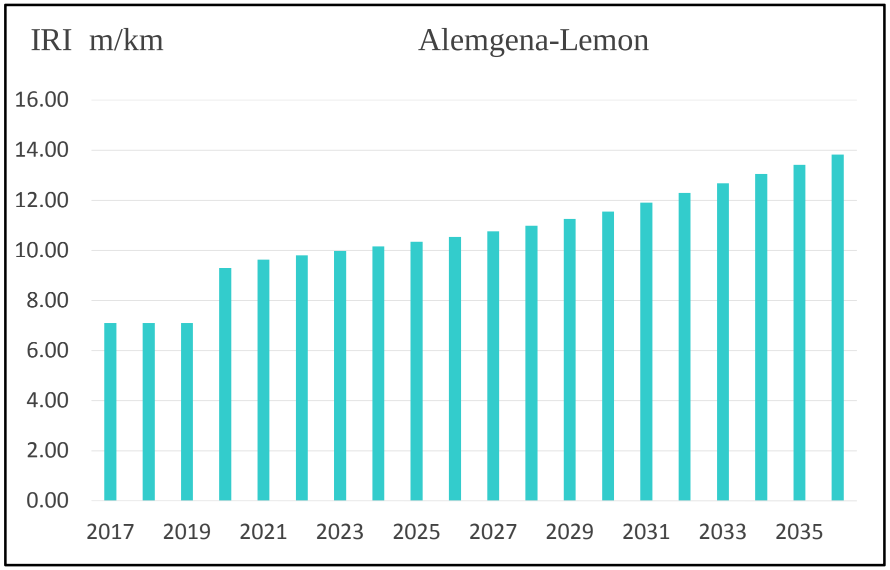
Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str Cracks %	All Str Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	650	0.10	7.19	7.10	32.96	39.95	100.08	15.30	5	2.88
2018	688	0.11	7.19	7.10	32.96	39.95	100.08	15.30	5	2.88
2019	727	0.11	7.19	7.10	16.48	19.98	50.04	7.65	3	2.88
2020	769	0.12	9.55	9.28	0.00	0.00	0.17	10.00	0	2.00
2021	828	0.13	9.71	9.63	0.00	0.00	0.40	10.59	0	2.00
2022	891	0.13	9.88	9.80	0.00	0.00	0.69	11.19	0	2.00
2023	960	0.14	10.06	9.97	0.00	0.00	1.03	11.79	0	2.00
2024	1,034	0.15	10.24	10.15	0.00	0.00	1.43	12.39	0	2.00
2025	1,114	0.16	10.43	10.34	0.00	0.00	1.90	13.00	0	2.00
2026	1,201	0.17	10.64	10.54	0.89	0.00	2.45	13.62	0	2.00
2027	1,278	0.18	10.86	10.75	3.42	0.00	3.10	14.24	0	2.00
2028	1,361	0.19	11.11	10.98	8.64	0.00	3.84	14.86	0	2.00
2029	1,449	0.20	11.39	11.25	17.58	0.92	4.69	15.48	0	1.99
2030	1,542	0.21	11.72	11.55	31.27	4.29	5.69	16.12	0	1.98
2031	1,642	0.23	12.09	11.91	50.66	12.86	6.84	16.76	0	1.96
2032	1,749	0.24	12.49	12.29	69.05	30.83	8.20	17.41	1	1.93
2033	1,833	0.25	12.86	12.67	82.06	17.79	9.73	18.07	4	1.90
2034	1,922	0.26	13.23	13.05	90.68	9.15	11.46	18.74	7	1.90
2035	2,015	0.27	13.61	13.42	95.88	3.91	13.42	19.42	12	1.90
2036	2,113	0.28	14.03	13.82	98.59	1.17	15.64	20.10	17	1.90

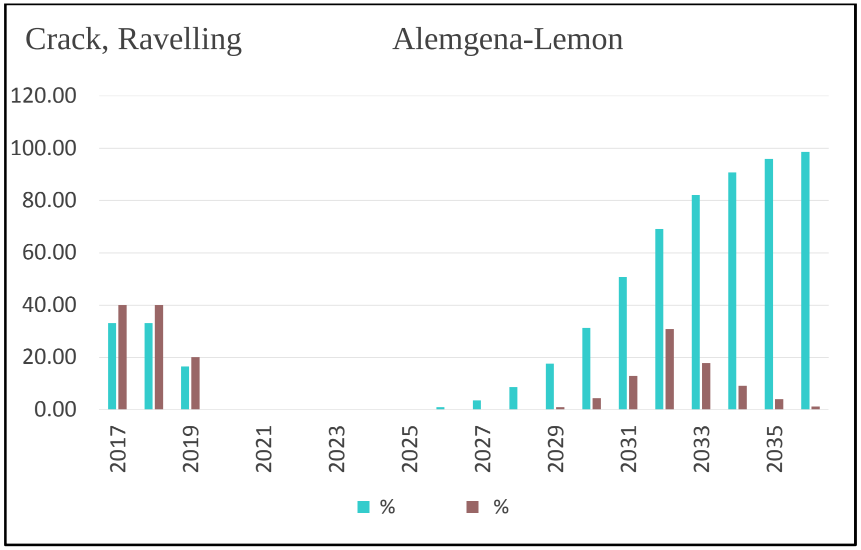
Alternative: **Without**
Section: **Alemgena-Lemon**
Surface Class: Bituminous

Length: **42.00km**

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	650	0.10	7.19	7.10	32.96	39.95	100.08	15.30	5	2.88
2018	688	0.11	7.50	7.34	63.40	35.12	100.21	15.61	38	2.66
2019	727	0.11	7.82	7.66	88.12	10.31	100.36	15.93	98	2.50
2020	769	0.12	8.13	7.98	98.31	0.00	100.54	16.27	180	2.50
2021	828	0.13	8.47	8.30	98.16	0.00	100.75	16.61	280	2.50
2022	891	0.13	8.91	8.69	97.99	0.00	101.00	16.96	394	2.50
2023	960	0.14	9.47	9.19	97.81	0.00	101.30	17.32	521	2.50
2024	1,034	0.15	10.17	9.82	97.60	0.00	101.67	17.68	666	2.50
2025	1,114	0.16	11.06	10.61	97.35	0.00	102.13	18.06	831	2.50
2026	1,201	0.17	12.18	11.62	97.07	0.00	102.70	18.45	1,021	2.50
2027	1,278	0.18	13.58	12.88	96.76	0.00	103.40	18.85	1,236	2.50
2028	1,361	0.19	15.35	14.47	96.39	0.00	104.29	19.26	1,483	2.50
2029	1,449	0.20	16.00	15.67	95.97	0.00	105.41	19.70	1,768	2.50
2030	1,542	0.21	16.00	16.00	95.48	0.00	106.79	20.15	2,096	2.50
2031	1,642	0.23	16.00	16.00	94.91	0.00	108.39	20.61	2,479	2.50
2032	1,749	0.24	16.00	16.00	94.25	0.00	110.20	21.08	2,926	2.50
2033	1,833	0.25	16.00	16.00	93.48	0.00	112.19	21.57	3,445	2.50
2034	1,922	0.26	16.00	16.00	92.58	0.00	114.38	22.06	4,050	2.50
2035	2,015	0.27	16.00	16.00	91.53	0.00	116.78	22.55	4,759	2.50
2036	2,113	0.28	16.00	16.00	90.30	0.00	119.43	23.06	5,594	2.50


IRI m/km
Alemgena-Lemon
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035

Year


Crack, Ravelling
Alemgena-Lemon
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Alternative: **with**

Road Class: Secondary or Main

Section: **Lemon-Butajira**

Width: **7.00m**

Surface Class: Bituminous

Length: **74.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	650	0.10	7.29	7.15	45.72	38.68	100.08	15.33	5	2.47
2018	688	0.11	7.29	7.15	45.72	38.68	100.08	15.33	5	2.47
2019	727	0.11	7.29	7.15	22.86	19.34	50.04	7.67	3	2.47
2020	769	0.12	9.55	9.28	0.00	0.00	0.17	10.08	0	2.00
2021	828	0.13	9.72	9.64	0.00	0.00	0.41	10.78	0	2.00
2022	891	0.13	9.90	9.81	0.00	0.00	0.69	11.49	0	2.00
2023	960	0.14	10.09	9.99	0.00	0.00	1.03	12.22	0	2.00
2024	1,034	0.15	10.29	10.19	1.92	0.00	1.43	12.96	0	2.00
2025	1,114	0.16	10.52	10.40	5.15	0.00	1.90	13.72	0	2.00
2026	1,201	0.17	10.76	10.64	10.13	0.00	2.46	14.49	0	1.99
2027	1,278	0.18	11.03	10.89	16.97	0.00	3.11	15.28	0	1.99
2028	1,361	0.19	11.32	11.17	25.76	0.00	3.86	16.09	0	1.98
2029	1,449	0.20	11.63	11.48	36.58	0.00	4.73	16.92	0	1.96
2030	1,542	0.21	11.98	11.81	49.49	0.00	5.74	17.77	2	1.95
2031	1,642	0.23	12.34	12.16	62.28	0.00	6.92	18.64	5	1.93
2032	1,749	0.24	12.73	12.54	73.03	0.00	8.30	19.55	9	1.91
2033	1,833	0.25	13.18	12.95	81.81	0.00	9.87	20.48	16	1.90
2034	1,922	0.26	13.79	13.48	88.71	0.00	11.64	21.43	26	1.90
2035	2,015	0.27	14.82	14.30	93.81	0.00	13.67	22.41	39	1.90
2036	2,113	0.28	16.00	15.41	97.25	0.00	16.03	23.42	57	1.90

Alternative: **without**

Section: **Lemon-Butajira**

Surface Class: Bituminous

Length: **74.00km**

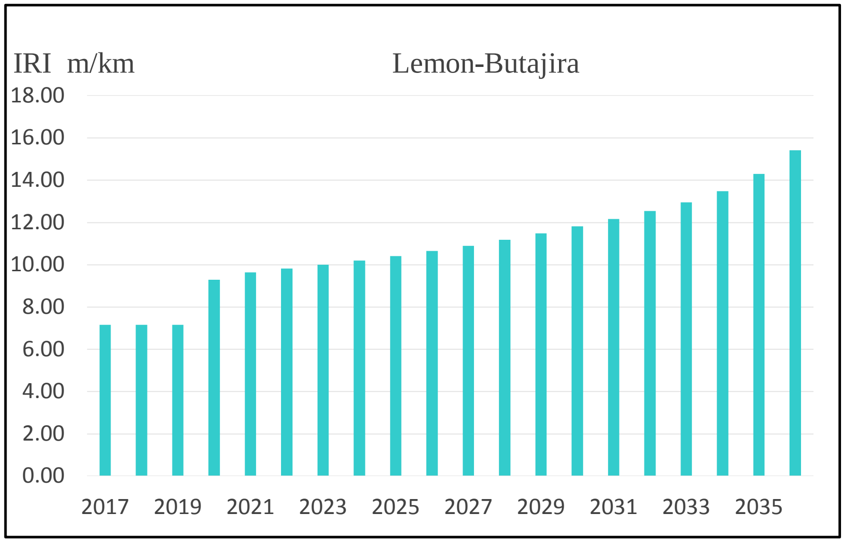
Road Class**: Secondary or Main**

Width: **7.00m**

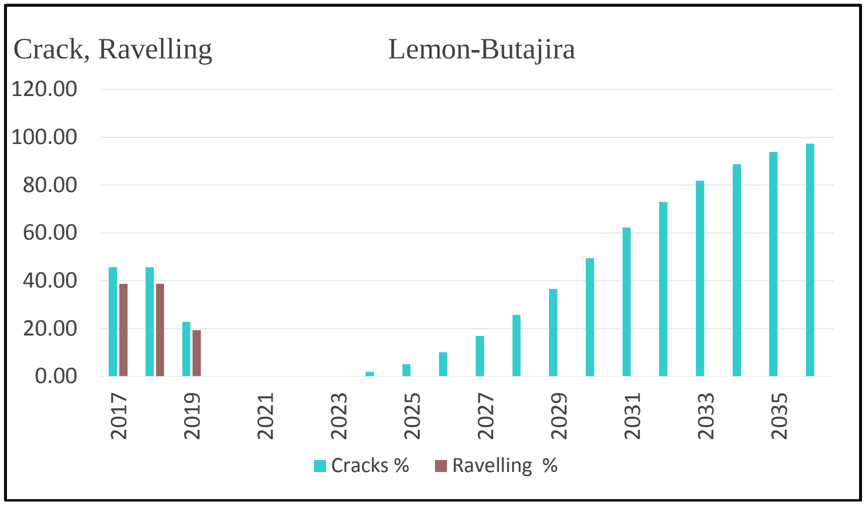
Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	650	0.10	7.29	7.15	45.72	38.68	100.08	15.33	5	2.47
2018	688	0.11	7.76	7.53	98.50	0.00	100.21	15.67	47	2.32
2019	727	0.11	7.98	7.87	98.38	0.00	100.37	16.02	130	2.29
2020	769	0.12	8.27	8.13	98.25	0.00	100.55	16.37	221	2.29
2021	828	0.13	8.65	8.46	98.10	0.00	100.76	16.73	322	2.29
2022	891	0.13	9.13	8.89	97.93	0.00	101.01	17.09	437	2.29
2023	960	0.14	9.73	9.43	97.74	0.00	101.32	17.46	565	2.29
2024	1,034	0.15	10.48	10.10	97.53	0.00	101.70	17.82	711	2.29
2025	1,114	0.16	11.41	10.94	97.29	0.00	102.17	18.19	877	2.29
2026	1,201	0.17	12.58	11.99	97.01	0.00	102.76	18.56	1,068	2.30
2027	1,278	0.18	14.03	13.30	96.69	0.00	103.48	18.93	1,284	2.30
2028	1,361	0.19	15.85	14.94	96.32	0.00	104.40	19.31	1,532	2.30
2029	1,449	0.20	16.00	15.92	95.90	0.00	105.56	19.69	1,816	2.30
2030	1,542	0.21	16.00	16.00	95.41	0.00	106.96	20.07	2,145	2.30
2031	1,642	0.23	16.00	16.00	94.84	0.00	108.55	20.45	2,527	2.30
2032	1,749	0.24	16.00	16.00	94.18	0.00	110.37	20.83	2,973	2.30
2033	1,833	0.25	16.00	16.00	93.41	0.00	112.36	21.22	3,489	2.30
2034	1,922	0.26	16.00	16.00	92.52	0.00	114.54	21.60	4,091	2.30
2035	2,015	0.27	16.00	16.00	91.48	0.00	116.95	21.99	4,794	2.30
2036	2,113	0.28	16.00	16.00	90.26	0.00	119.59	22.38	5,620	2.30

HDM-4 Version 1.1


IRI m/km
Lemon-Butajira
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017 2019 2021 2023 2025 2027 2029 2031 2033 2035

Year


Crack, Ravelling
Lemon-Butajira
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017 2019 2021 2023 2025 2027 2029 2031 2033 2035
Cracks %
Ravelling %

Year

Alternative: **with**

Study Name: **Ambo-Gedo**

Section: **Ambo-Gedo**

Run Date: **20-09-2017**

Surface Class: Bituminous

Width: 7.00m

Length: **64.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	892	0.21	6.32	6.16	45.72	52.84	100.15	15.35	5	2.44
2018	939	0.22	6.32	6.16	45.72	52.84	100.15	15.35	5	2.44
2019	988	0.23	6.32	6.16	22.86	26.42	50.08	7.68	3	2.44
2020	1,040	0.24	8.41	8.20	0.00	0.00	0.28	5.66	0	3.00
2021	1,104	0.25	8.51	8.46	0.00	0.00	0.66	6.06	0	3.00
2022	1,171	0.26	8.62	8.57	0.00	0.00	1.10	6.46	0	3.00
2023	1,242	0.28	8.73	8.68	0.00	0.00	1.60	6.87	0	3.00
2024	1,318	0.29	8.85	8.79	0.00	0.00	2.17	7.28	0	3.00
2025	1,399	0.31	8.97	8.91	0.00	0.00	2.82	7.69	0	3.00
2026	1,485	0.33	9.09	9.03	0.00	0.00	3.57	8.11	0	3.00
2027	1,562	0.34	9.23	9.16	1.82	0.00	4.40	8.53	0	3.00
2028	1,644	0.36	9.38	9.30	5.50	0.00	5.33	8.95	0	3.00
2029	1,730	0.37	9.55	9.47	12.36	2.42	6.37	9.37	0	2.99
2030	1,820	0.39	9.76	9.66	23.43	11.13	7.55	9.79	0	2.98
2031	1,915	0.41	10.01	9.89	39.76	31.50	8.88	10.22	0	2.96
2032	2,016	0.43	10.30	10.16	60.04	39.81	10.38	10.66	1	2.92
2033	2,100	0.45	10.56	10.43	75.77	24.05	12.05	11.10	4	2.89
2034	2,187	0.46	10.81	10.69	86.60	13.19	13.91	11.55	7	2.88
2035	2,278	0.48	11.06	10.93	93.49	6.27	15.97	12.01	11	2.88
2036	2,373	0.50	11.34	11.20	97.40	2.31	18.26	12.47	17	2.88

Alternative: **without**

Section: **Ambo-Gedo**

Road Class: Primary or Trunk

Surface Class: Bituminous

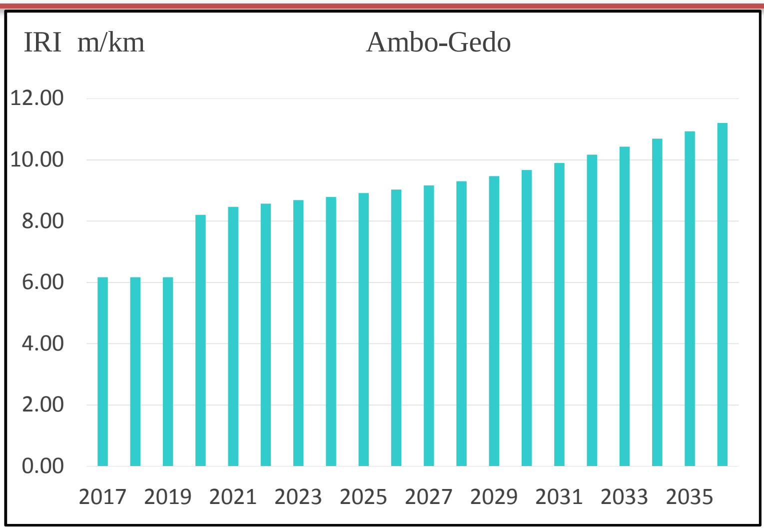
Width: **7.00m**

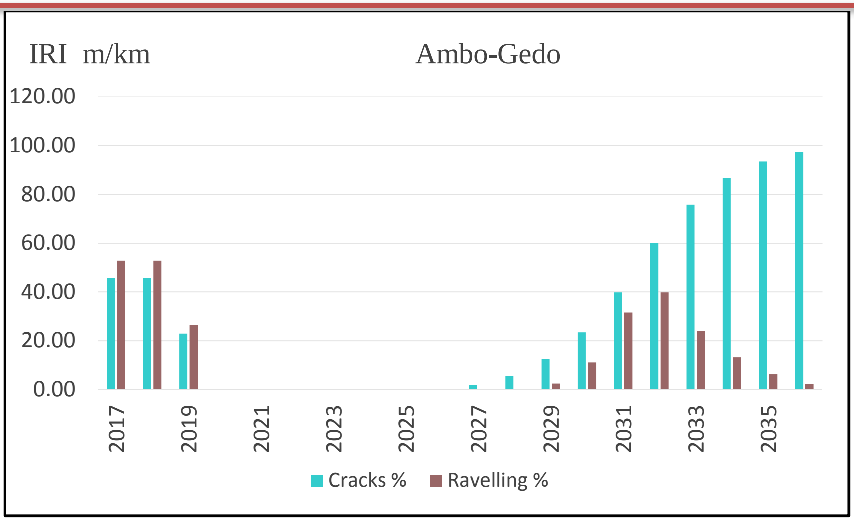
Length: **64.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	892	0.21	6.32	6.16	45.72	52.84	100.15	15.35	5	2.44
2018	939	0.22	6.84	6.58	98.50	0.00	100.38	15.72	49	2.21
2019	988	0.23	7.12	6.98	98.38	0.00	100.64	16.10	131	2.15
2020	1,040	0.24	7.48	7.30	98.24	0.00	100.94	16.49	220	2.15
2021	1,104	0.25	7.93	7.71	98.10	0.00	101.29	16.87	320	2.15
2022	1,171	0.26	8.49	8.21	97.93	0.00	101.70	17.26	431	2.15
2023	1,242	0.28	9.16	8.82	97.75	0.00	102.18	17.66	555	2.15
2024	1,318	0.29	9.97	9.56	97.54	0.00	102.76	18.05	693	2.15
2025	1,399	0.31	10.96	10.46	97.31	0.00	103.46	18.45	849	2.15
2026	1,485	0.33	12.16	11.56	97.05	0.00	104.32	18.84	1,024	2.15
2027	1,562	0.34	13.62	12.89	96.75	0.00	105.37	19.24	1,222	2.15
2028	1,644	0.36	15.39	14.50	96.41	0.00	106.66	19.64	1,445	2.15
2029	1,730	0.37	16.00	15.69	96.03	0.00	108.26	20.05	1,697	2.15
2030	1,820	0.39	16.00	16.00	95.59	0.00	110.19	20.45	1,984	2.15
2031	1,915	0.41	16.00	16.00	95.09	0.00	112.36	20.86	2,312	2.15
2032	2,016	0.43	16.00	16.00	94.52	0.00	114.77	21.27	2,687	2.15
2033	2,100	0.45	16.00	16.00	93.87	0.00	117.38	21.68	3,115	2.15
2034	2,187	0.46	16.00	16.00	93.13	0.00	120.21	22.10	3,605	2.16
2035	2,278	0.48	16.00	16.00	92.28	0.00	123.28	22.51	4,168	2.16
2036	2,373	0.50	16.00	16.00	91.31	0.00	126.62	22.92	4,817	2.16

HDM-4 Version 1.1


IRI m/km
Ambo-Gedo
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017 2019 2021 2023 2025 2027 2029 2031 2033 2035


IRI m/km
Ambo-Gedo
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017 2019 2021 2023 2025 2027 2029 2031 2033 2035
Cracks %
Ravelling %

Year

Year

Alternative: **with**
Section: **Butajira-Wolbareg**
Surface Class: Bituminous

Length: **54.00km**

Study Name: **Butajira-Hosana**
Run Date: **20-09-2017**
Road Class: Primary or Trunk

Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	400	0.09	3.06	3.03	0.50	2.63	0.03	2.32	0	2.54
2018	424	0.09	3.06	3.03	0.50	2.63	0.03	2.32	0	2.54
2019	450	0.10	3.06	3.03	0.25	1.32	0.02	1.16	0	2.54
2020	476	0.10	3.23	3.12	0.00	0.00	0.05	3.10	0	3.50
2021	511	0.11	3.28	3.26	0.00	0.00	0.11	3.33	0	3.50
2022	548	0.12	3.32	3.30	0.00	0.00	0.18	3.56	0	3.50
2023	588	0.12	3.36	3.34	0.00	0.00	0.27	3.79	0	3.50
2024	631	0.13	3.41	3.39	0.00	0.00	0.36	4.02	0	3.50
2025	676	0.14	3.45	3.43	0.00	0.00	0.46	4.26	0	3.50
2026	726	0.15	3.50	3.48	0.00	0.00	0.59	4.49	0	3.50
2027	785	0.16	3.55	3.53	0.00	0.00	0.73	4.73	0	3.50
2028	848	0.18	3.60	3.58	0.00	0.00	0.90	4.97	0	3.50
2029	918	0.19	3.65	3.63	0.00	0.00	1.10	5.21	0	3.50
2030	992	0.20	3.71	3.68	0.93	0.00	1.33	5.46	0	3.50
2031	1,073	0.22	3.78	3.75	3.49	0.00	1.60	5.70	0	3.50
2032	1,161	0.23	3.87	3.83	8.78	0.50	1.91	5.95	0	3.49
2033	1,229	0.25	3.99	3.93	17.80	2.96	2.27	6.20	0	3.49
2034	1,300	0.26	4.14	4.07	31.61	9.61	2.67	6.45	0	3.48
2035	1,376	0.27	4.33	4.24	51.09	23.30	3.11	6.71	0	3.45
2036	1,456	0.29	4.52	4.43	69.37	30.58	3.61	6.97	1	3.41

Alternative: **Without**

Road Class: Primary or Trunk

Section: **Butajira-Wolbareg**

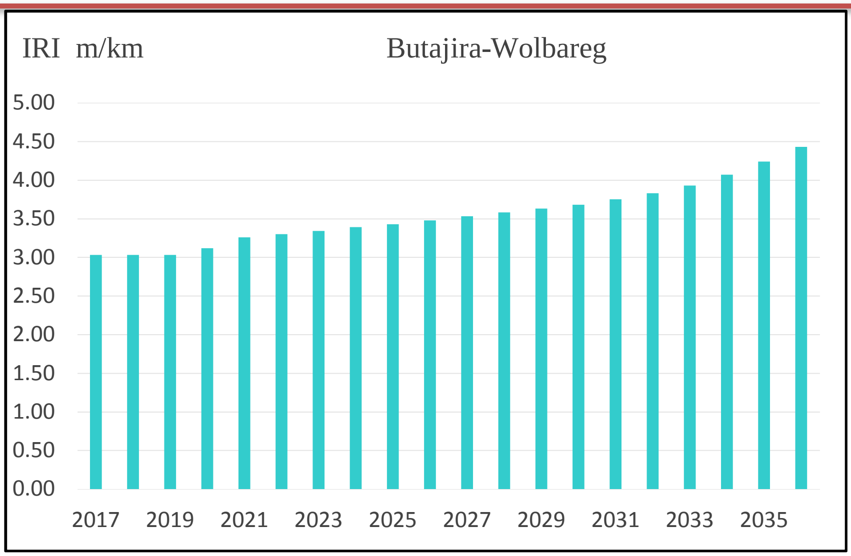
Width: **7.00m**

Surface Class: Bituminous

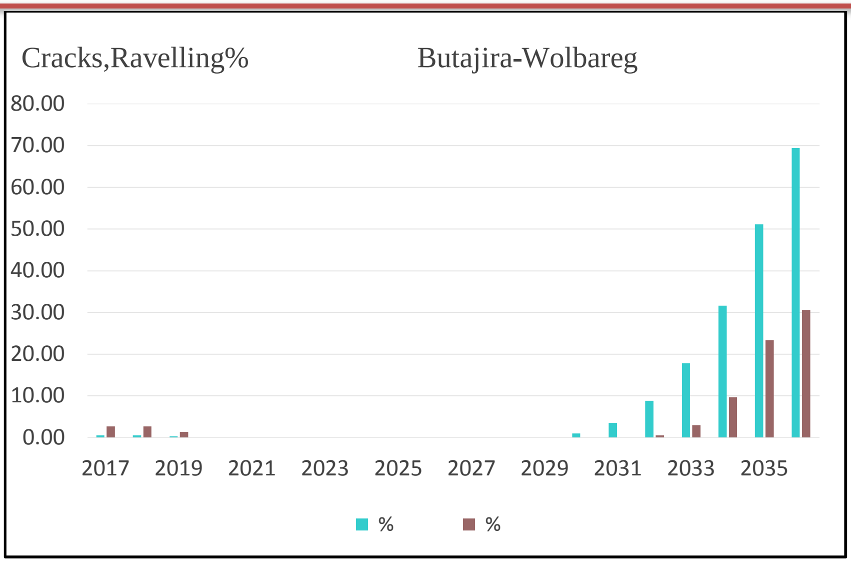
Length: **54.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	400	0.09	3.06	3.03	0.50	2.63	0.03	2.32	0	2.54
2018	424	0.09	3.15	3.11	4.05	5.22	0.07	2.64	0	2.54
2019	450	0.10	3.28	3.22	13.60	8.78	0.12	2.97	0	2.53
2020	476	0.10	3.47	3.38	31.98	13.27	0.17	3.29	0	2.51
2021	511	0.11	3.73	3.60	60.33	18.86	0.23	3.62	0	2.46
2022	548	0.12	3.96	3.84	81.92	18.08	0.30	3.97	0	2.38
2023	588	0.12	4.13	4.04	93.83	6.16	0.38	4.32	0	2.35
2024	631	0.13	4.25	4.19	98.89	1.11	0.48	4.68	0	2.35
2025	676	0.14	4.36	4.31	99.99	0.00	0.59	5.04	0	2.35
2026	726	0.15	4.49	4.42	99.92	0.00	0.71	5.41	48	2.35
2027	785	0.16	4.66	4.57	99.84	0.00	0.86	5.77	100	2.35
2028	848	0.18	4.87	4.77	99.76	0.00	1.03	6.15	158	2.35
2029	918	0.19	5.14	5.01	99.67	0.00	1.23	6.52	222	2.35
2030	992	0.20	5.45	5.29	99.56	0.00	1.47	6.90	293	2.35
2031	1,073	0.22	5.82	5.63	99.44	0.00	1.75	7.28	372	2.35
2032	1,161	0.23	6.26	6.04	99.31	0.00	2.08	7.66	459	2.35
2033	1,229	0.25	6.79	6.53	99.17	0.00	2.47	8.05	556	2.35
2034	1,300	0.26	7.40	7.09	99.01	0.00	2.92	8.44	662	2.35
2035	1,376	0.27	8.12	7.76	98.84	0.00	3.45	8.83	779	2.35
2036	1,456	0.29	8.98	8.55	98.64	0.00	4.08	9.22	909	2.35


IRI m/km
Butajira-Wolbareg
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035

Year


Cracks,Ravelling%
Butajira-Wolbareg
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Alternative: **with**

Road Class: Secondary or Main

Section: **Wolbareg-Hosana**
Surface Class: Bituminous

Width: **7.00m**

Length: **46.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	400	0.09	7.29	7.14	45.72	23.63	100.03	15.32	5	2.50
2018	424	0.09	7.29	7.14	45.72	23.63	100.03	15.32	5	2.50
2019	450	0.10	7.29	7.14	22.86	11.82	50.02	7.66	3	2.50
2020	476	0.10	9.54	9.27	0.00	0.00	0.06	9.77	0	2.00
2021	511	0.11	9.69	9.62	0.00	0.00	0.15	10.35	0	2.00
2022	548	0.12	9.85	9.77	0.00	0.00	0.26	10.94	0	2.00
2023	588	0.12	10.02	9.94	0.00	0.00	0.39	11.53	0	2.00
2024	631	0.13	10.19	10.11	0.00	0.00	0.54	12.13	0	2.00
2025	676	0.14	10.37	10.28	0.00	0.00	0.71	12.73	0	2.00
2026	726	0.15	10.55	10.46	0.00	0.00	0.91	13.34	0	2.00
2027	785	0.16	10.76	10.66	1.88	0.00	1.15	13.95	0	2.00
2028	848	0.18	10.99	10.87	5.63	0.00	1.44	14.56	0	2.00
2029	918	0.19	11.25	11.12	12.59	0.50	1.78	15.18	0	1.99
2030	992	0.20	11.55	11.40	23.78	2.00	2.18	15.81	0	1.98
2031	1,073	0.22	11.90	11.72	40.26	5.77	2.67	16.45	0	1.97
2032	1,161	0.23	12.29	12.09	60.51	13.82	3.26	17.09	1	1.94
2033	1,229	0.25	12.68	12.48	76.12	23.82	3.93	17.75	3	1.91
2034	1,300	0.26	13.05	12.86	86.83	13.10	4.71	18.42	5	1.90
2035	1,376	0.27	13.41	13.23	93.63	6.28	5.61	19.09	8	1.90
2036	1,456	0.29	13.79	13.60	97.48	2.40	6.65	19.78	12	1.90

Alternative: **Without**

Section: **Wolbareg-Hosana**

Surface Class: Bituminous

Length: **46.00km**

Road Class: Secondary or Main

Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	400	0.09	7.29	7.14	45.72	23.63	100.03	15.32	5	2.50
2018	424	0.09	7.75	7.52	98.50	0.00	100.08	15.66	50	2.41
2019	450	0.10	7.99	7.87	98.35	0.00	100.14	16.00	153	2.38
2020	476	0.10	8.33	8.16	98.19	0.00	100.21	16.35	268	2.38
2021	511	0.11	8.78	8.55	98.00	0.00	100.29	16.71	396	2.38
2022	548	0.12	9.36	9.07	97.79	0.00	100.39	17.06	542	2.38
2023	588	0.12	10.11	9.74	97.55	0.00	100.50	17.42	707	2.38
2024	631	0.13	11.06	10.59	97.28	0.00	100.65	17.78	896	2.39
2025	676	0.14	12.27	11.67	96.97	0.00	100.83	18.14	1,112	2.39
2026	726	0.15	13.80	13.04	96.61	0.00	101.06	18.51	1,362	2.39
2027	785	0.16	15.76	14.78	96.19	0.00	101.35	18.88	1,653	2.39
2028	848	0.18	16.00	15.88	95.70	0.00	101.75	19.25	1,994	2.39
2029	918	0.19	16.00	16.00	95.11	0.00	102.24	19.62	2,397	2.39
2030	992	0.20	16.00	16.00	94.42	0.00	102.83	20.00	2,878	2.39
2031	1,073	0.22	16.00	16.00	93.59	0.00	103.51	20.38	3,454	2.39
2032	1,161	0.23	16.00	16.00	92.58	0.00	104.31	20.76	4,152	2.39
2033	1,229	0.25	16.00	16.00	91.37	0.00	105.20	21.14	4,987	2.39
2034	1,300	0.26	16.00	16.00	89.92	0.00	106.20	21.53	5,995	2.39
2035	1,376	0.27	16.00	16.00	88.47	0.00	107.32	21.91	7,000	2.39
2036	1,456	0.29	16.00	16.00	88.45	0.00	108.58	22.30	7,000	2.39

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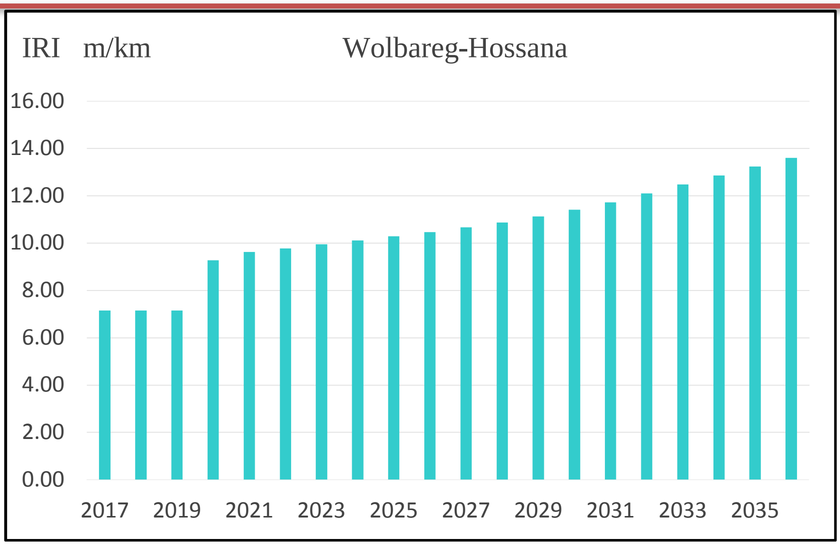
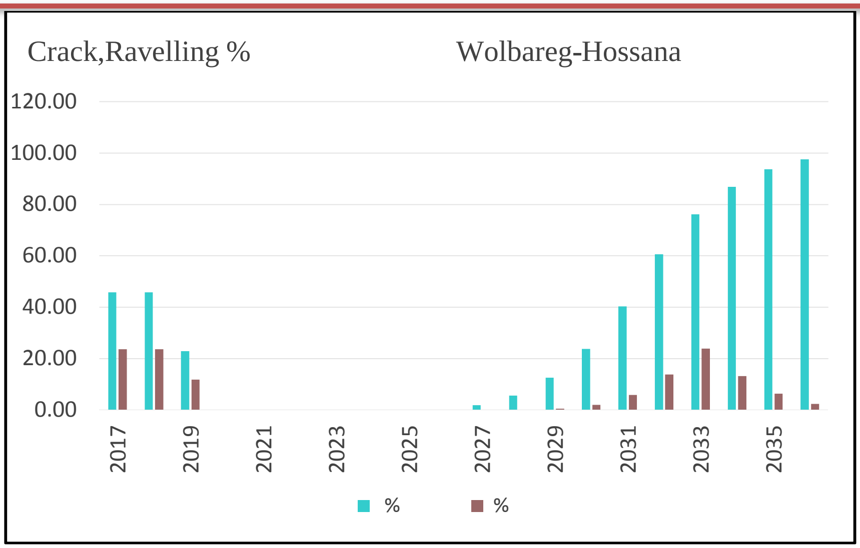

IRI m/km
Wolbareg-Hossana
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035

Year


Crack,Ravelling %
Wolbareg-Hossana
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Alternative: **with**

Section: **Butajira-Zeway**

Surface Class: Bituminous

Length: **54.00km**

Study Name: **Butajira-Zeway**

Run Date: **20-09-2017**

Road Class**: Tertiary or Local**

Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	722	0.07	6.33	6.16	13.52	14.08	10.09	8.48	0	3.01
2018	778	0.07	6.33	6.16	13.52	14.08	10.09	8.48	0	3.01
2019	838	0.08	6.33	6.16	6.76	7.04	5.05	4.24	0	3.01
2020	903	0.08	6.41	6.21	0.00	0.00	0.21	6.34	0	2.50
2021	984	0.09	6.50	6.46	0.00	0.00	0.46	6.79	0	2.50
2022	1,072	0.10	6.59	6.55	0.00	0.00	0.76	7.23	0	2.50
2023	1,168	0.10	6.69	6.64	0.00	0.00	1.11	7.68	0	2.50
2024	1,272	0.11	6.79	6.74	0.00	0.00	1.54	8.14	0	2.50
2025	1,386	0.12	6.89	6.84	0.00	0.00	2.05	8.60	0	2.50
2026	1,510	0.13	6.99	6.94	0.00	0.00	2.67	9.06	0	2.50
2027	1,618	0.14	7.10	7.05	0.00	0.00	3.38	9.53	0	2.50
2028	1,733	0.15	7.22	7.16	0.50	0.00	4.20	9.99	0	2.50
2029	1,856	0.16	7.35	7.28	2.38	1.83	5.15	10.47	0	2.50
2030	1,988	0.17	7.50	7.42	6.64	9.50	6.26	10.94	0	2.50
2031	2,130	0.18	7.67	7.58	14.30	28.22	7.55	11.42	0	2.49
2032	2,282	0.20	7.88	7.78	26.38	61.84	9.05	11.91	0	2.48
2033	2,411	0.21	8.14	8.01	43.94	55.90	10.75	12.40	1	2.47
2034	2,547	0.22	8.41	8.27	63.82	36.00	12.70	12.90	3	2.43
2035	2,692	0.23	8.67	8.54	78.43	21.34	14.94	13.41	6	2.40
2036	2,844	0.24	8.94	8.81	88.34	11.39	17.50	13.92	11	2.40

Alternative: **without**

Road Class: Tertiary or Local

Section: **Butajira-Zeway**

Width: **7.00m**

Surface Class: Bituminous

Length: **54.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	722	0.07	6.33	6.16	13.52	14.08	10.09	8.48	0	3.01
2018	778	0.07	6.49	6.41	28.18	18.96	10.25	8.74	0	2.95
2019	838	0.08	6.70	6.59	50.11	24.72	10.43	9.00	0	2.85
2020	903	0.08	6.90	6.80	70.57	29.27	10.65	9.26	0	2.69
2021	984	0.09	7.07	6.99	84.38	15.46	10.91	9.53	0	2.57
2022	1,072	0.10	7.21	7.14	92.89	6.95	11.22	9.81	0	2.54
2023	1,168	0.10	7.32	7.26	97.43	2.40	11.60	10.08	0	2.52
2024	1,272	0.11	7.42	7.37	99.34	0.49	12.05	10.36	0	2.51
2025	1,386	0.12	7.52	7.47	99.82	0.00	12.59	10.65	0	2.51
2026	1,510	0.13	7.61	7.56	99.81	0.00	13.24	10.93	0	2.51
2027	1,618	0.14	7.71	7.66	99.80	0.00	13.99	11.22	0	2.51
2028	1,733	0.15	7.81	7.76	99.79	0.00	14.86	11.51	0	2.51
2029	1,856	0.16	7.92	7.87	99.77	0.00	15.87	11.80	0	2.50
2030	1,988	0.17	8.03	7.97	99.76	0.00	17.04	12.10	0	2.50
2031	2,130	0.18	8.14	8.08	99.74	0.00	18.40	12.40	0	2.50
2032	2,282	0.20	8.26	8.20	99.71	0.00	19.98	12.70	0	2.50
2033	2,411	0.21	8.38	8.32	99.69	0.00	21.76	13.01	0	2.50
2034	2,547	0.22	8.51	8.45	99.66	0.00	23.76	13.32	0	2.50
2035	2,692	0.23	8.64	8.57	99.63	0.00	26.04	13.63	0	2.50
2036	2,844	0.24	8.86	8.75	99.47	0.00	28.61	13.95	87	2.50

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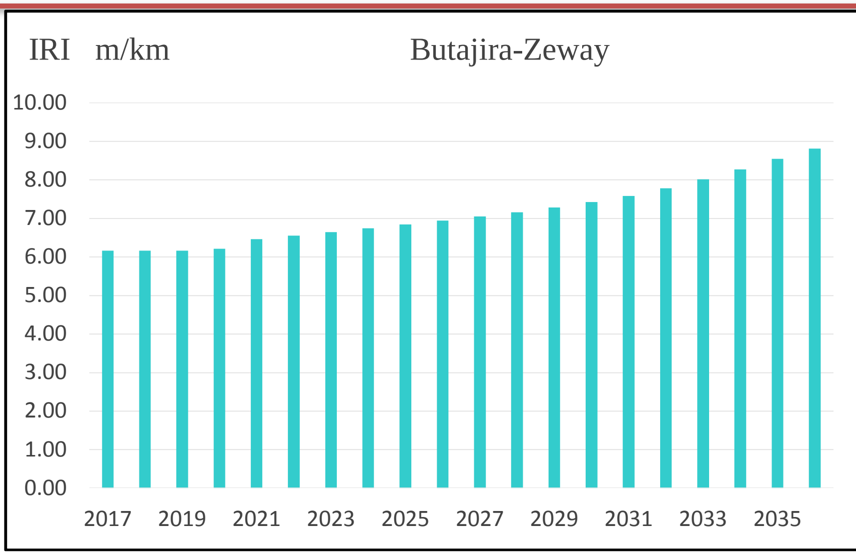
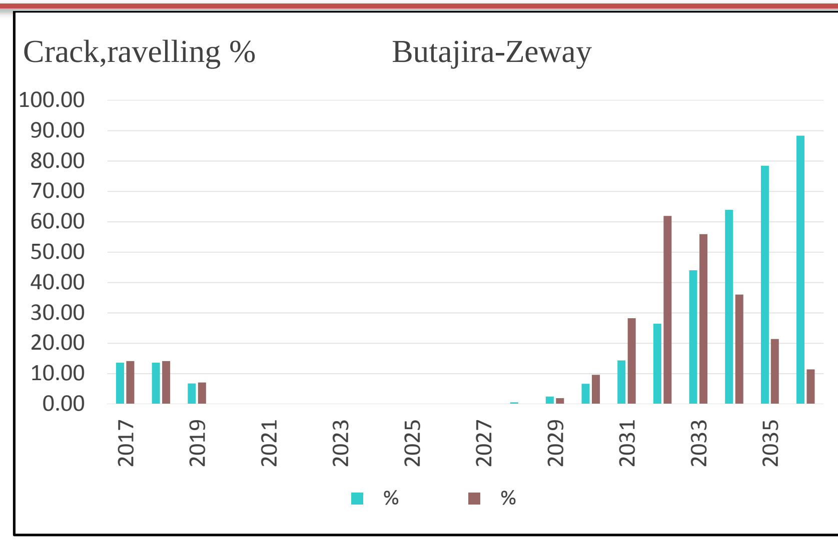

IRI m/km
Butajira-Zeway
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035


Crack,ravelling %
Butajira-Zeway
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Year

Alternative: **with**
Section: **Commando-Fiche**
Surface Class: Bituminous

Length: **74.00km**

Study Name: **Commando-Fiche**
Run Date: **20-09-2017**
Road Class: Primary or Trunk

Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	1,008	0.20	6.28	6.14	45.72	52.84	100.19	15.29	5	2.96
2018	1,038	0.21	6.28	6.14	45.72	52.84	100.19	15.29	5	2.96
2019	1,068	0.21	6.28	6.14	22.86	26.42	50.10	7.65	3	2.96
2020	1,100	0.22	8.61	8.30	0.00	0.00	0.31	11.10	0	2.00
2021	1,139	0.22	8.82	8.71	0.00	0.00	0.72	11.74	0	2.00
2022	1,179	0.23	9.04	8.93	0.00	0.00	1.18	12.37	0	2.00
2023	1,221	0.24	9.27	9.16	0.00	0.00	1.68	13.01	0	2.00
2024	1,265	0.25	9.51	9.39	0.50	0.00	2.23	13.64	0	2.00
2025	1,310	0.25	9.77	9.64	2.38	0.00	2.84	14.29	0	2.00
2026	1,356	0.26	10.04	9.90	6.65	0.00	3.50	14.93	0	2.00
2027	1,419	0.27	10.35	10.20	14.30	0.00	4.25	15.58	0	1.99
2028	1,485	0.29	10.70	10.53	26.39	0.00	5.09	16.23	0	1.98
2029	1,553	0.30	11.11	10.91	43.96	1.63	6.03	16.89	0	1.96
2030	1,625	0.31	11.55	11.33	63.84	6.84	7.10	17.56	1	1.93
2031	1,700	0.32	11.98	11.76	78.45	20.49	8.32	18.24	4	1.90
2032	1,779	0.34	12.40	12.19	88.36	11.49	9.70	18.93	7	1.90
2033	1,847	0.35	12.83	12.62	94.54	5.28	11.24	19.62	11	1.90
2034	1,917	0.36	13.29	13.06	97.94	1.85	12.96	20.32	16	1.90
2035	1,990	0.37	13.83	13.56	99.46	0.30	14.87	21.03	22	1.90
2036	2,066	0.38	14.48	14.15	99.71	0.00	17.02	21.73	30	1.90

Alternative: **without**

Road Class: Primary or Trunk

Section: **Commando-Fiche**

Width: **7.00m**

Surface Class: Bituminous

Length: **74.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	Rave-lling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	1,008	0.20	6.28	6.14	45.72	52.84	100.19	15.29	5	2.96
2018	1,038	0.21	6.77	6.53	98.47	0.00	100.47	15.58	66	2.80
2019	1,068	0.21	7.05	6.91	98.30	0.00	100.77	15.90	179	2.77
2020	1,100	0.22	7.46	7.26	98.12	0.00	101.11	16.21	304	2.77
2021	1,139	0.22	8.01	7.74	97.92	0.00	101.48	16.52	442	2.77
2022	1,179	0.23	8.71	8.36	97.69	0.00	101.89	16.83	595	2.77
2023	1,221	0.24	9.58	9.14	97.44	0.00	102.37	17.15	766	2.77
2024	1,265	0.25	10.67	10.13	97.16	0.00	102.92	17.46	957	2.77
2025	1,310	0.25	12.01	11.34	96.85	0.00	103.56	17.78	1,170	2.77
2026	1,356	0.26	13.66	12.84	96.50	0.00	104.34	18.10	1,409	2.77
2027	1,419	0.27	15.71	14.68	96.10	0.00	105.30	18.42	1,680	2.77
2028	1,485	0.29	16.00	15.85	95.64	0.00	106.49	18.74	1,989	2.77
2029	1,553	0.30	16.00	16.00	95.11	0.00	107.91	19.06	2,341	2.77
2030	1,625	0.31	16.00	16.00	94.51	0.00	109.47	19.38	2,746	2.77
2031	1,700	0.32	16.00	16.00	93.82	0.00	111.19	19.71	3,211	2.77
2032	1,779	0.34	16.00	16.00	93.03	0.00	113.06	20.03	3,750	2.77
2033	1,847	0.35	16.00	16.00	92.11	0.00	115.08	20.36	4,370	2.77
2034	1,917	0.36	16.00	16.00	91.06	0.00	117.25	20.69	5,087	2.77
2035	1,990	0.37	16.00	16.00	89.84	0.00	119.60	21.02	5,919	2.77
2036	2,066	0.38	16.00	16.00	88.42	0.00	122.13	21.35	6,888	2.78

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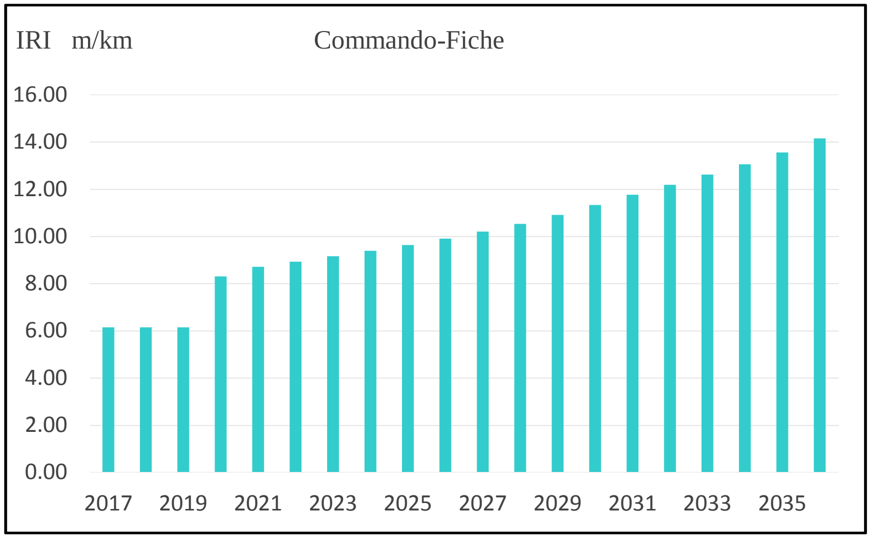
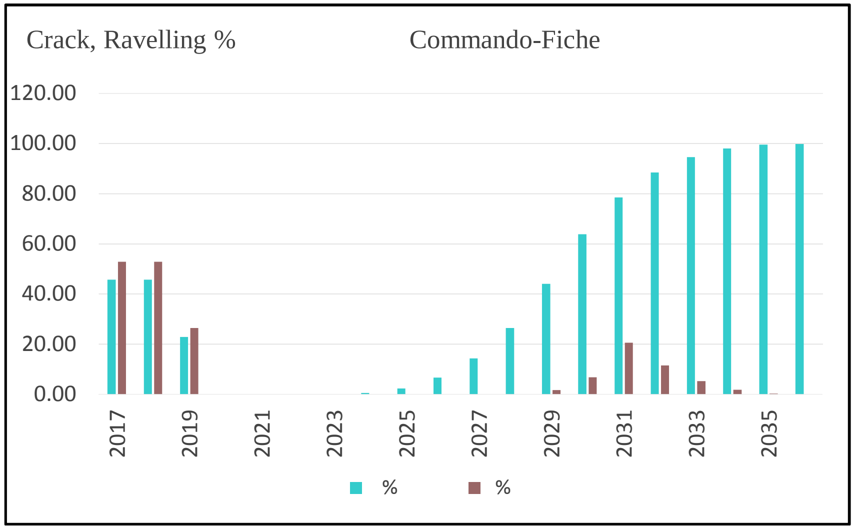

IRI m/km
Commando-Fiche
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035

Year


Crack, Ravelling %
Commando-Fiche
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Alternative: **with**
Section: **Gudober-D/Sina**
Surface Class: Bituminous
Length: **30.00km**

Study Name: **Gudober-D/Sina**
Run Date: **20-09-2017**
Road Class: **Primary or Trunk**
Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. IRI m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	885	0.19	2.06	2.03	0.00	3.95	0.15	2.28	0	3.04
2018	931	0.19	2.06	2.03	0.00	3.95	0.15	2.28	0	3.04
2019	979	0.20	2.06	2.03	0.00	1.98	0.08	1.14	0	3.04
2020	1,030	0.21	2.39	2.19	0.00	0.00	0.25	5.39	0	2.50
2021	1,100	0.23	2.49	2.44	0.00	0.00	0.53	5.75	0	2.50
2022	1,174	0.24	2.59	2.54	0.00	0.00	0.85	6.11	0	2.50
2023	1,252	0.26	2.70	2.65	0.00	0.00	1.22	6.48	0	2.50
2024	1,337	0.27	2.81	2.76	0.00	0.00	1.63	6.85	0	2.50
2025	1,427	0.29	2.93	2.87	0.00	0.00	2.11	7.22	0	2.50
2026	1,523	0.31	3.07	3.00	1.88	0.00	2.65	7.60	0	2.50
2027	1,603	0.33	3.23	3.15	5.63	0.00	3.25	7.98	0	2.50
2028	1,687	0.34	3.41	3.32	12.58	0.00	3.91	8.36	0	2.49
2029	1,776	0.36	3.63	3.52	23.77	2.66	4.65	8.74	0	2.48
2030	1,869	0.38	3.89	3.76	40.25	11.61	5.47	9.13	0	2.47
2031	1,968	0.40	4.20	4.05	60.51	32.74	6.38	9.52	1	2.44
2032	2,072	0.42	4.48	4.34	76.11	23.78	7.39	9.93	4	2.41
2033	2,148	0.43	4.76	4.62	86.82	13.05	8.49	10.34	8	2.40
2034	2,228	0.44	5.05	4.91	93.62	6.22	9.67	10.75	13	2.40
2035	2,310	0.46	5.39	5.22	97.48	2.34	10.96	11.17	20	2.40
2036	2,396	0.47	5.86	5.63	99.28	0.51	12.36	11.60	27	2.40

Alternative: **without**

Road Class: Primary or Trunk

Section: **Gudober-D/Sina**

Width: **7.00m**

Surface Class: Bituminous

Length: **30.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	885	0.19	2.06	2.03	0.00	3.95	0.15	2.28	0	3.04
2018	931	0.19	2.11	2.08	0.00	10.21	0.35	2.57	0	3.04
2019	979	0.20	2.17	2.14	0.00	21.21	0.57	2.85	0	3.04
2020	1,030	0.21	2.24	2.21	1.74	38.43	0.82	3.14	0	3.04
2021	1,100	0.23	2.35	2.30	7.97	61.49	1.10	3.43	6	3.04
2022	1,174	0.24	2.51	2.43	21.65	78.30	1.42	3.72	16	3.03
2023	1,252	0.26	2.75	2.63	45.59	54.35	1.79	4.02	30	2.99
2024	1,337	0.27	3.02	2.88	72.68	27.23	2.21	4.32	41	2.93
2025	1,427	0.29	3.21	3.12	89.00	10.90	2.68	4.64	44	2.89
2026	1,523	0.31	3.36	3.29	97.07	2.81	3.22	4.96	47	2.89
2027	1,603	0.33	3.64	3.50	99.61	0.12	3.82	5.28	149	2.89
2028	1,687	0.34	4.04	3.84	99.55	0.00	4.49	5.61	267	2.89
2029	1,776	0.36	4.58	4.31	99.35	0.00	5.23	5.94	400	2.89
2030	1,869	0.38	5.30	4.94	99.13	0.00	6.06	6.27	549	2.89
2031	1,968	0.40	6.23	5.76	98.88	0.00	6.99	6.60	717	2.89
2032	2,072	0.42	7.42	6.82	98.59	0.00	8.07	6.94	909	2.89
2033	2,148	0.43	8.91	8.16	98.26	0.00	9.33	7.28	1,123	2.89
2034	2,228	0.44	10.76	9.84	97.89	0.00	10.88	7.61	1,365	2.89
2035	2,310	0.46	13.07	11.92	97.48	0.00	12.84	7.95	1,638	2.89
2036	2,396	0.47	15.94	14.50	97.00	0.00	15.38	8.29	1,948	2.89

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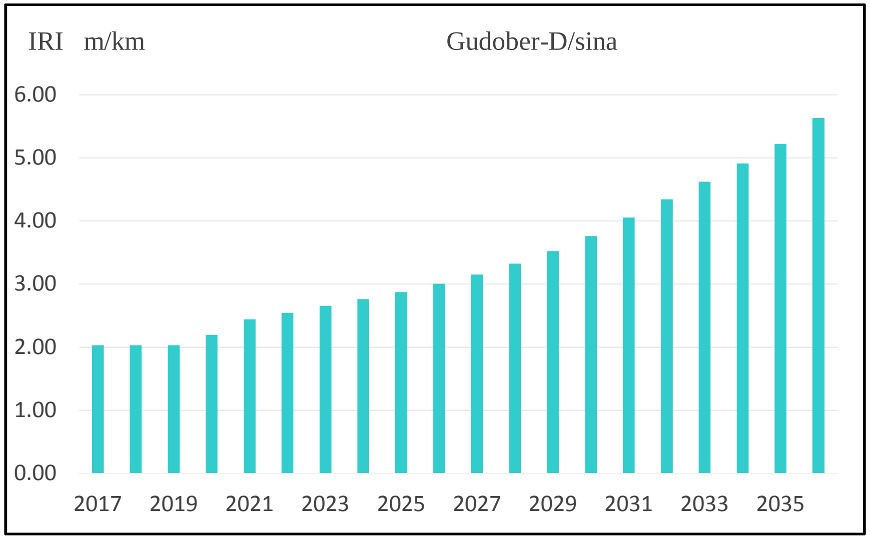
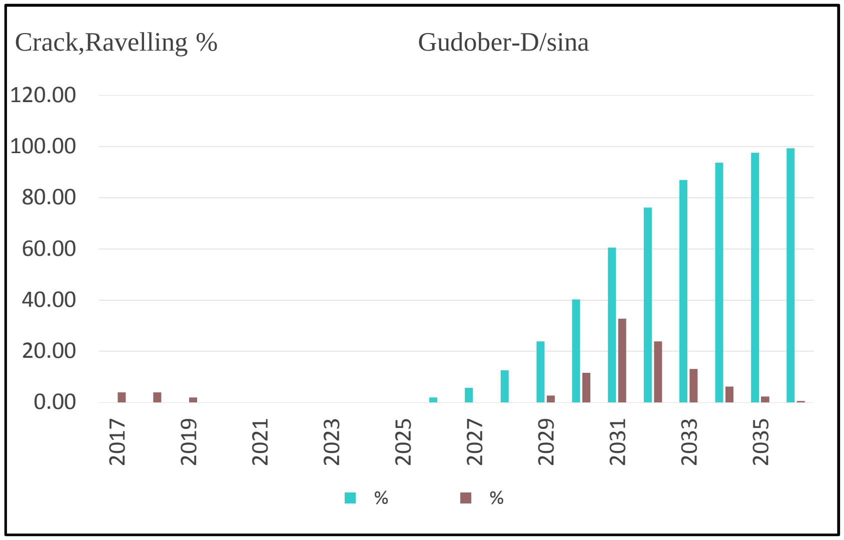

IRI m/km
Gudober-D/sina
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
Year


Crack,Ravelling %
Gudober-D/sina
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%
Year

Alternative: **with**
Section: **Kosse-G/GibeNo.2**
Surface Class: Bituminous
Length: **35.00km**

Study Name: **Kosse-G/GibeNo.2**
Run Date: **20-09-2017**
Road Class: Secondary or Main
Width: **7.00m**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. IRI m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	669	0.04	6.31	6.16	13.52	13.77	10.08	8.29	0	3.02
2018	721	0.05	6.31	6.16	13.52	13.77	10.08	8.29	0	3.02
2019	778	0.05	6.31	6.16	6.76	6.89	5.04	4.15	0	3.02
2020	840	0.06	6.36	6.18	0.00	0.00	0.18	5.14	0	2.50
2021	907	0.06	6.44	6.40	0.00	0.00	0.39	5.51	0	2.50
2022	980	0.07	6.51	6.47	0.00	0.00	0.64	5.87	0	2.50
2023	1,058	0.07	6.59	6.55	0.00	0.00	0.93	6.24	0	2.50
2024	1,142	0.08	6.68	6.64	0.00	0.00	1.27	6.62	0	2.50
2025	1,234	0.08	6.76	6.72	0.00	0.00	1.67	6.99	0	2.50
2026	1,332	0.09	6.85	6.81	0.00	0.00	2.14	7.37	0	2.50
2027	1,423	0.10	6.94	6.89	0.00	0.00	2.68	7.76	0	2.50
2028	1,521	0.11	7.03	6.99	0.00	0.00	3.31	8.14	0	2.50
2029	1,625	0.11	7.13	7.08	0.00	1.04	4.02	8.53	0	2.50
2030	1,736	0.12	7.24	7.18	1.88	6.08	4.85	8.92	0	2.50
2031	1,855	0.13	7.37	7.30	5.63	18.81	5.80	9.32	0	2.50
2032	1,982	0.14	7.52	7.44	12.58	43.72	6.90	9.71	0	2.49
2033	2,137	0.15	7.70	7.61	23.77	74.16	8.20	10.12	0	2.49
2034	2,305	0.17	7.93	7.82	40.24	59.62	9.73	10.53	1	2.47
2035	2,488	0.19	8.20	8.06	60.49	39.34	11.55	10.95	3	2.44
2036	2,687	0.20	8.45	8.32	76.09	23.70	13.72	11.38	7	2.41

Alternative: **without**

Road Class: Secondary or Main

Section: **Kosse-G/GibeNo.2**

Width: **7.00m**

Surface Class: Bituminous

Length: **35.00km**

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	669	0.04	6.31	6.16	13.52	13.77	10.08	8.29	0	3.02
2018	721	0.05	6.47	6.39	28.18	18.16	10.21	8.54	0	2.98
2019	778	0.05	6.67	6.57	50.11	23.24	10.37	8.79	0	2.91
2020	840	0.06	6.87	6.77	70.57	29.28	10.56	9.04	0	2.81
2021	907	0.06	7.03	6.95	84.38	15.46	10.77	9.30	0	2.73
2022	980	0.07	7.15	7.09	92.89	6.95	11.03	9.56	0	2.69
2023	1,058	0.07	7.26	7.21	97.43	2.40	11.34	9.83	0	2.67
2024	1,142	0.08	7.34	7.30	99.34	0.49	11.70	10.10	0	2.66
2025	1,234	0.08	7.42	7.38	99.83	0.00	12.13	10.37	0	2.66
2026	1,332	0.09	7.50	7.46	99.82	0.00	12.63	10.64	0	2.66
2027	1,423	0.10	7.58	7.54	99.81	0.00	13.21	10.92	0	2.66
2028	1,521	0.11	7.66	7.62	99.80	0.00	13.87	11.20	0	2.66
2029	1,625	0.11	7.75	7.70	99.79	0.00	14.63	11.48	0	2.66
2030	1,736	0.12	7.84	7.79	99.78	0.00	15.51	11.76	0	2.66
2031	1,855	0.13	7.93	7.88	99.76	0.00	16.51	12.05	0	2.66
2032	1,982	0.14	8.02	7.97	99.75	0.00	17.68	12.34	0	2.66
2033	2,137	0.15	8.12	8.07	99.73	0.00	19.04	12.64	0	2.66
2034	2,305	0.17	8.31	8.22	99.56	0.00	20.64	12.94	98	2.66
2035	2,488	0.19	8.70	8.51	99.37	0.00	22.54	13.25	215	2.66
2036	2,687	0.20	9.28	8.99	99.14	0.00	24.81	13.56	351	2.66

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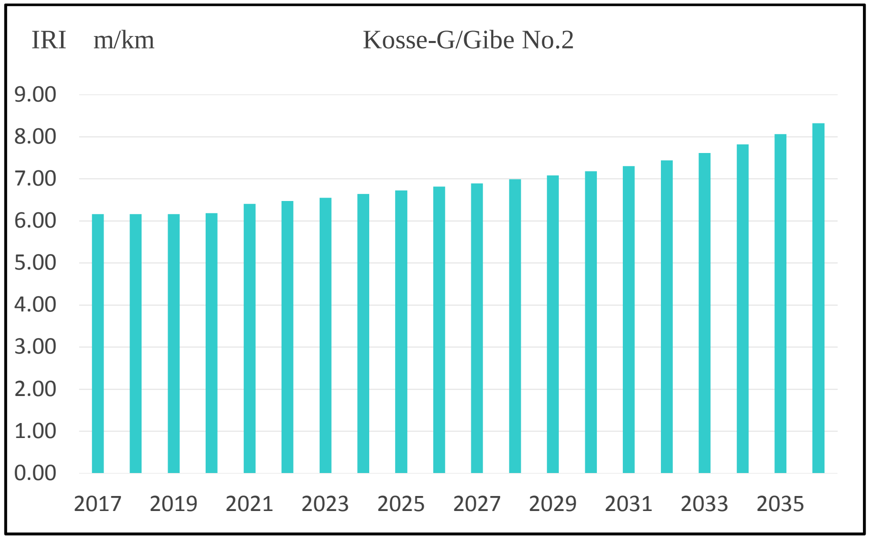
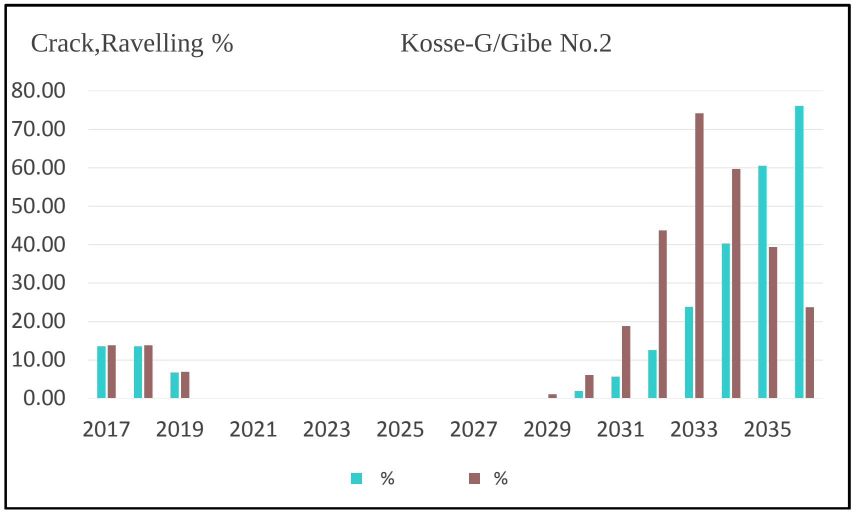

IRI m/km
Kosse-G/Gibe No.2
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035

Year


Crack,Ravelling %
Kosse-G/Gibe No.2
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
%
%

Year

Alternative: with
Section: Robe-Etaya

Study Name: Robe-Eteye
Run Date: **20-09-2017**

Surface Class: Bituminous

Road Class: Primary or Trunk

Length: 48.00km

Width: 7.00m

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	882	0.19	6.28	6.14	45.72	52.84	100.15	15.29	5	2.93
2018	927	0.20	6.28	6.14	45.72	52.84	100.15	15.29	5	2.93
2019	973	0.21	6.28	6.14	22.86	26.42	50.08	7.65	3	2.93
2020	1,022	0.22	8.40	8.20	0.00	0.00	0.27	5.59	0	3.00
2021	1,086	0.23	8.50	8.45	0.00	0.00	0.64	5.99	0	3.00
2022	1,153	0.24	8.61	8.56	0.00	0.00	1.07	6.39	0	3.00
2023	1,225	0.26	8.72	8.67	0.00	0.00	1.55	6.79	0	3.00
2024	1,302	0.27	8.83	8.78	0.00	0.00	2.11	7.20	0	3.00
2025	1,383	0.29	8.95	8.89	0.00	0.00	2.74	7.61	0	3.00
2026	1,470	0.30	9.06	9.00	0.00	0.00	3.47	8.02	0	3.00
2027	1,538	0.32	9.19	9.13	0.92	0.00	4.27	8.43	0	3.00
2028	1,609	0.33	9.33	9.26	3.47	0.00	5.16	8.85	0	3.00
2029	1,684	0.34	9.49	9.41	8.73	2.17	6.14	9.27	0	2.99
2030	1,762	0.36	9.68	9.59	17.73	10.25	7.24	9.69	0	2.99
2031	1,844	0.37	9.91	9.80	31.50	29.10	8.46	10.11	0	2.97
2032	1,929	0.39	10.18	10.04	50.94	48.92	9.82	10.54	0	2.95
2033	2,012	0.41	10.45	10.31	69.26	30.58	11.34	10.98	2	2.91
2034	2,098	0.42	10.69	10.57	82.20	17.61	13.03	11.42	5	2.88
2035	2,188	0.44	10.93	10.81	90.77	9.01	14.92	11.87	8	2.88
2036	2,282	0.46	11.17	11.05	95.93	3.81	17.01	12.32	13	2.88
2037	2,381	0.47	11.46	11.31	98.61	1.09	19.34	12.78	19	2.88

Alternative: without
Section: Robe-Etaya
Surface Class: Bituminous
Length: 48.00km

Road Class: Primary or Trunk
Width: 7.00m

Average Annual Values

Year	MT AADT	ESAL millions /ELANE	IRI bef. m/km	IRI Avg. m/km	All Str. Cracks %	All Str. Ravelling %	Edge Break sq.m	Rut Depth mm	No. of Pot-holes	Gravel Thick. mm
2017	882	0.19	6.28	6.14	45.72	52.84	100.15	15.29	5	2.93
2018	927	0.20	6.75	6.52	98.50	0.00	100.37	15.58	48	2.71
2019	973	0.21	6.97	6.86	98.38	0.00	100.62	15.89	129	2.65
2020	1,022	0.22	7.26	7.11	98.25	0.00	100.91	16.20	217	2.65
2021	1,086	0.23	7.63	7.44	98.10	0.00	101.24	16.52	315	2.65
2022	1,153	0.24	8.10	7.86	97.94	0.00	101.62	16.83	424	2.65
2023	1,225	0.26	8.68	8.39	97.76	0.00	102.08	17.15	546	2.65
2024	1,302	0.27	9.39	9.03	97.56	0.00	102.62	17.47	682	2.65
2025	1,383	0.29	10.27	9.83	97.33	0.00	103.27	17.79	835	2.65
2026	1,470	0.30	11.35	10.81	97.07	0.00	104.06	18.11	1,008	2.65
2027	1,538	0.32	12.67	12.01	96.78	0.00	105.01	18.44	1,201	2.65
2028	1,609	0.33	14.28	13.48	96.46	0.00	106.17	18.76	1,418	2.65
2029	1,684	0.34	16.00	15.14	96.09	0.00	107.58	19.09	1,662	2.65
2030	1,762	0.36	16.00	16.00	95.67	0.00	109.32	19.42	1,938	2.65
2031	1,844	0.37	16.00	16.00	95.20	0.00	111.33	19.75	2,250	2.65
2032	1,929	0.39	16.00	16.00	94.66	0.00	113.54	20.08	2,605	2.65
2033	2,012	0.41	16.00	16.00	94.05	0.00	115.93	20.41	3,009	2.65
2034	2,098	0.42	16.00	16.00	93.35	0.00	118.54	20.75	3,470	2.66
2035	2,188	0.44	16.00	16.00	92.55	0.00	121.38	21.08	3,998	2.66
2036	2,282	0.46	16.00	16.00	91.64	0.00	124.46	21.42	4,605	2.66
2037	2,381	0.47	16.00	16.00	90.59	0.00	127.82	21.76	5,306	2.66

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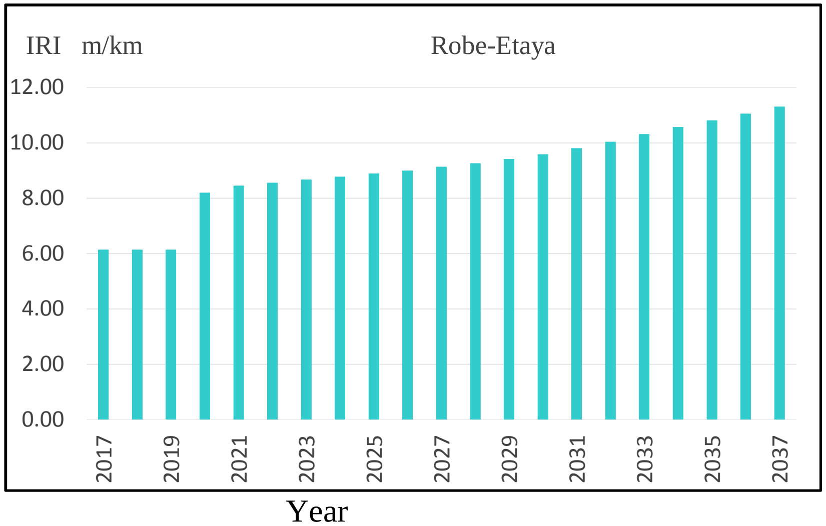
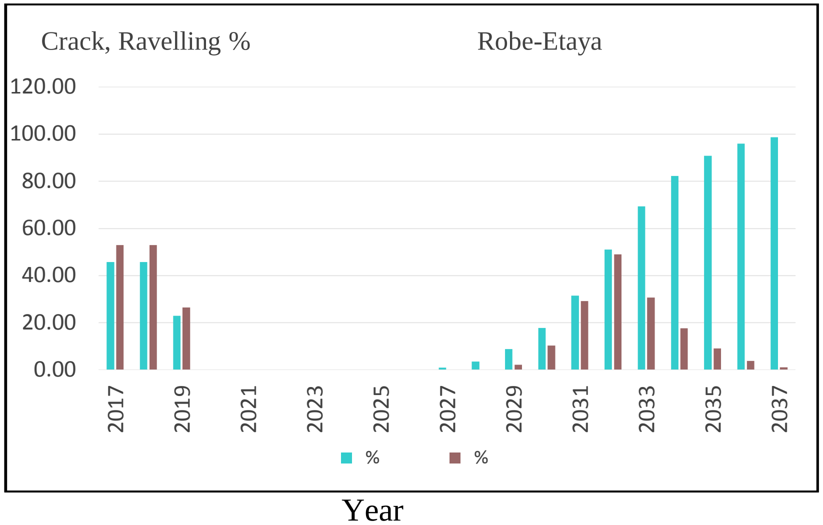

IRI m/km
Robe-Etaya
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
Year


Crack, Ravelling %
Robe-Etaya
120.00
100.00
80.00
60.00
40.00
20.00
0.00
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
%
%
Year

Annex K: HDM4 Economic Analysis Summary

Currency: Ethiopian Birr (millions).
Study Name: **Alemgena-Butajira**
Discount rate: 10.00%.
Run Date: **20-09-2017**
Analysis Mode: Analysis-by-Project

Alternative: with vs Alternative: without

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Cost	Savings in NMT Travel & Operating	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	231.12	-0.45	0.00	3,001.73	78.53	0.00	0.00	0.00	2,849.59
Discounted	252.60	-0.20	0.00	752.25	19.64	0.00	0.00	0.00	519.49

Economic Internal Rate of Return (EIRR) = 18.6% (No. of solutions = 1)

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Currency: Ethiopian Birr (millions).
Study Name: **Ambo-Gedo**
Discount rate: 10.00%.
Run Date: **20-09-2017**
Analysis Mode: Analysis-by-Project

Alternative: with vs Alternative: without

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Cost	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	41.73	-0.87	0.00	3,899.78	73.97	0.00	0.00	0.00	3,932.89
Discounted	45.61	-0.39	0.00	1,012.86	19.11	0.00	0.00	0.00	986.76

Economic Internal Rate of Return (EIRR) = 41.5% (No. of solutions = 1)

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Currency: Ethiopian Birr (millions).				Study Name:	**Butajira-Hosana**				
Discount rate: 10.00%.				Run Date:	**20-09-2017**				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	47.99	-0.05	0.00	1,774.47	29.11	0.00	0.00	0.00	1,755.63
Discounted	52.45	-0.02	0.00	458.04	7.29	0.00	0.00	0.00	412.90
			Economic Internal Rate of Return (EIRR) = 30.3% (No. of solutions = 1)						
HDM-4 Version 1.1									**Page -1 of 1**

Currency: Ethiopian Birr (millions).				Study Name:	**Butajira-Zeway**				
Discount rate: 10.00%.				Run Date:	**20-09-2017**				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	35.21	-0.68	0.00	296.43	6.09	0.00	0.00	0.00	267.99
Discounted	38.48	-0.31	0.00	121.58	2.40	0.00	0.00	0.00	85.81
			Economic Internal Rate of Return (EIRR) = 29.3% (No. of solutions = 2)						
HDM-4 Version 1.1									**Page -1 of 1**

Currency: Ethiopian Birr (millions).				Study Name:	**Commando-Fiche**				
Discount rate: 10.00%.				Run Date:	**20-09-2017**				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	48.25	-0.58	0.00	2,673.91	46.49	0.00	0.00	0.00	2,672.73
Discounted	52.74	-0.26	0.00	749.39	12.95	0.00	0.00	0.00	709.87
			Economic Internal Rate of Return (EIRR) = 36.6% (No. of solutions = 1)						
HDM-4 Version 1.1									**Page -1 of 1**

Currency: Ethiopian Birr (millions).				Study Name:	**Gudober-D/Sina**				
Discount rate: 10.00%.				Run Date:	**20-09-2017**				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	10.00	-0.58	0.00	942.65	14.83	0.00	0.00	0.00	947.48
Discounted	10.93	-0.26	0.00	185.56	2.72	0.00	0.00	0.00	177.35
			Economic Internal Rate of Return (EIRR) = 30.6% (No. of solutions = 1)						
HDM-4 Version 1.1									**Page -1 of 1**

Currency: Ethiopian Birr (millions).				Study Name:	Kosse-G/GibeNo.2				
Discount rate: 10.00%.				Run Date:	20-09-2017				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	22.82	-0.19	0.00	229.78	3.63	0.00	0.00	0.00	210.78
Discounted	24.94	-0.09	0.00	80.52	1.24	0.00	0.00	0.00	56.91
			Economic Internal Rate of Return (EIRR) = 27.3% (No. of solutions = 1)						
HDM-4 Version 1.1									**Page -1 of 1**

Currency: Ethiopian Birr (millions).				Study Name:	Robe-Eteye				
Discount rate: 10.00%.				Run Date:	20-09-2017				
Analysis Mode: Analysis-by-Project									
				Alternative: with vs Alternative: without					
	Increase in Road Agency Costs			**Savings in MT VOC**	**Savings in MT Travel Time Cost**	**Savings in NMT Travel & Operating**	**Reduction in Accident Costs**	**Net Exogenous Benefits**	**Net Economic Benefits (NPV)**
	Capital	**Recurrent**	**Special**						
Undiscounted	31.30	-2.44	0.00	3,072.96	60.15	0.00	0.00	0.00	3,104.26
Discounted	34.26	-1.00	0.00	727.44	14.21	0.00	0.00	0.00	708.39
				Economic Internal Rate of Return (EIRR) = 36.5% (No. of solutions = 1)					
HDM-4 Version 1.1									**Page -1 of 1**