Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Stream

THIN BITUMINOUS SURFACING AS AN ALTERNATIVE SURFACING TYPE FOR LOW VOLUME GRAVEL ROADS IN ETHIOPIAN ROADS AUTHORITY;LIFE CYCLE COST COMPARISON AND ECONOMIC ANALYSIS

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

By:

ABONESH BEDANE

June, 2017

Jimma, Ethiopia

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DECLARATION

I, the undersigned, declare that this thesis entitled "**Thin Bituminous Surfacing as an alternative Surfacing type for Low Volume Gravel Roads on Life Cycle Cost Comparison and Economic Analysis**: **A Case of Ethiopian Roads Authority**" Is my original work, and has not been presented by any other person for any award of a degree in this or any other University, and all sources of material used for these have been dually acknowledged.

Candidate:

Abonesh Bedane

Signature___________________

As Masters research Advisors, we hereby certify that we have read and evaluate this MSc research prepared under our guidance, by Abonesh Bedane entitled: Thin Bituminous Surfacing as an alternative Surfacing type for Low Volume Gravel Roads on Life Cycle Cost Comparison and Economic Analysis: A Case of Ethiopian Roads Authority.

We recommended that it can be submitted as fulfilling the MSc Thesis requirements.

Prof. Emer T. Quezon ___________________ ____________________

Advisor Signature Date

Engr. Getachew Kebede ___________________ ____________________

Co-Advisor Signature Date

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ABSTRACT

Road infrastructure is one of the most important assets for the Economical, Political and Social development of one country. And there are unsurfaced or lightly surfaced low volume roads. Huge investments are made annually to maintain and improve their functions. Double otta Seal is one type of thin bituminous surfacing and usually has a design life span of 15 to 16 years whereas gravel road has design life span of 8 to 10 years. Considering their life span it is necessary to determine which surfacing is more economical for entire life. The objective of this research was to identify which type of surfacing is economical for low volume roads in Ethiopia on selected sections of Ethiopian Roads Authority namely, Woito - Turmi, Agbe - Sekota and Metu – Alge by using the existing road condition. Life cycle cost comparison and economic analysis carried out for three selected sections of ERA, cost break down analysis for initial costs of double otta seal surfacing, traffic analysis, and user costs were performed for carrying out economic evaluation of the three sections and the present worth method was used for the evaluation of life cycle costs of both surfacing. The life cycle cost comparison and economic analysis was conducted by using HDM-4 model software. From the result, the double otta seal had the total cost of 15,362,00.00 birr, 25,520,000.00 and 30,678,000.00 birr per km during their design period for Woito – Turmi, Metu – Alge and Agbe – Sekota road section respectively. Whereas gravel roads had the total cost of 19,522,000.00 birr, 31,435,000.00 birr and 37,810,000.00 birr per km during their design period for Woito – Turmi, Metu – Alge and Agbe – Sekota road section respectively. The roughnesses of the selected roads were improved and the road user costs of double otta seal were smaller than gravel roads.

It was found that Double otta seal surfacing was found more economical and feasible than gravel roads. Implementing Authorities should be give consideration to the use of the Otta seal as an alternative rather than continuous gravelling/re-gravelling.

Keywords: *Gravel roads, double otta Seal, life cycle cost.*

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LIST OF ABBREVIATION

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ACPA	American Concrete Pavement Association
BCA	Benefit Cost Analysis
BRB	Bituminous Road Base
CBR	California Bearing Ratio
DOT	Department of Transportation
EF	Equivalent Factor
EIRR	Economic Internal Rate of Return
EPA	Environmental Protection Agency
ERA	Ethiopian Roads Authority
ESA	Equivalent standard axles
ETB	Ethiopian Birr
EUAC	Equivalent Uniform Annual Cost
FHWA	Federal Highway administration
GB	Granular Base
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
GWC	Gravel Wearing Course
HDM-4	Highway Development Model – 4
IMF	International Monitory Fund
IRI	International Roughness Index
KN	Kilo Newton
LCCA	Life Cycle Cost Analysis
MDOT	Michigan Department ofTransportation
MoFED	Ministry of Finance and Economic Development
NPV	Net Present Value
OS	Otta Seal

PW	Present Worth
RSDP	Road Sector Development Program
SB	Sub-Base
TRL	Transport Research Laboratory
URRAP	Universal Rural Road Access Program
US	United States
VOC	Vehicle Operating Cost
VPD	Vehicles per day

CHAPTER ONE

INTRODUCTION

1.1 Background

More than 90 percent of all the roads in the world are unsurfaced or lightly surfaced low volume roads. Huge investments are made annually to maintain and improve their functions by expanding the network and carrying out routine maintenance and rehabilitation on existing road infrastructure [1].

According to the American Association of State Highway and Transportation Officials (AASHTO), annual capital outlay spending should be increased to maintain and improve the physical conditions of roads. The situation is expected to become more severe as many of the components of the interstate highways built in the 1960s under the Federal-aid Highway approach the end of service life and need reconstruction [3].

The failure to provide adequate funding to improve the road conditions will lead to serious roadway safety and operational concerns and affect the national economy. Effective management of roadway investment becomes exceptionally important. Besides the financial management issue, huge resource use is associated with maintaining and expanding the road infrastructure [5].

When we see the two types of surfacing, thin bituminous surface treatment and gravel roads have been compared intensively in terms of life-cycle cost and road user cost.
Rural and most highway roads in Ethiopia have relatively low traffic volume. Paving helps to seal the surface from rainfall, and thus protects the base and sub grade material. It eliminates dust problems, has high user acceptance because of increased smoothness, and can accommodate many types of vehicles such as tractor-trailers that do not operate as effectively on unsurfaced roads.

Unsealed roads usually have a running surface consisting of earth or natural gravel and require relatively high levels of regular maintenance. Often there are insufficient resources or capacity to provide adequate maintenance of these unsealed routes and users and communities consequently suffer poor access and/or high transport costs. It is, therefore, increasingly important to encourage further development of rural road networks in an affordable and sustainable way by efficiently utilizing local resources to provide cost-effective transport infrastructure [4].

1.2 Statement of the Problem

In road construction industries initial cost is an important consideration, however, in many cases it is not the only factor that should be considered when evaluating whether a road should be paved or not.

Gravel roads have lower initial construction cost, but have higher maintenance costs, and higher road user costs, and lower operational speeds. On the other hand, sealed roads are smoother, provide greater protection of the base and subgrade material, and able to accommodate a wider range of vehicle types.

In the study area, those road sections are gravel roads and they need to reduce the magnitude impact from poor condition which affects the travelling public. It was for this reason this study would address that the economical types of surfacing for low volume gravel roads in Ethiopian Roads Authority on life cycle cost comparison and economic analysis.

1.3 Research Questions

1. Which gravel roads need frequent maintenance in Ethiopian Roads Authority?
2. Which type of surfacing is suitable to seal gravel roads with existing traffic volume in study area?
3. What are the quantitative benefits that can be derived from the life cycle cost?

1.4 Objectives

1.4.1 General objective

The general objective of this study was to determine the economical surfacing type for low volume gravel roads by making life cycle cost comparisons and economic analysis of Thin Bituminous Surfacing with gravel roads in selected representative roads section.

1.4.2 Specific Objectives

1. To identify gravel roads those need repeated maintenance in Ethiopian Roads Authority.
2. To identify the appropriate surfacing type for low volume gravel roads in the study area.
3. To analyze the life cycle cost and economic analysis of the selected segments and to identify which surfacing type is more economical.

1.5 Scope and Limitation of the Study

The scope of the study focuses on three road sections of Ethiopian Roads Authority. Moreover, the focus of research has been limited to the identification of more economical sealing type over life cycle cost comparison and economic analysis.

1.6 Significance of the Study

The primary objectives of road construction are to increase quality with the aim of reducing costs and increasing the economical effectiveness of the provision of road access for communities. This research work focuses on one of the basic requirements i.e. cost. Therefore, to make an accurate project planning in the selection of economical surfacing types for the construction of roads for allocation of justifiable budgets. The study will also be helpful:

- For construction stakeholders in the town specially to take remedial measures to reduce the impacts of the problem.
- The implementing authorities (ERA and AACRA)

CHAPTER TWO

LITERATURE REVIEW

2.1 General

As we know there are growing pressures for long life road infrastructures that require minimal maintenance. Surfacing are the critical elements of an efficient highway transportation system for moving people and goods. Without well-performing surfacing, the transportation infrastructure cannot effectively function, road users suffer (in terms of increased costs, travel time, and unsafe roads) and the overall economy suffers (in terms of higher costs for goods and commodities) [11].

When the roadway surfacing is gravel, the annual routine maintenance activities include re-grading and shaping to assure a uniform roadway cross-section and proper drainage on a scheduled basis. The cost of these activities would remain fairly constant until parameters start to change. Many agencies have conducted research to address the decision as to whether a road should be paved or gravel [2].

Gravel and paved roads differ in many aspects, including construction and maintenance costs, smoothness and types of vehicle that can be accommodated. Gravel roads have lower construction costs, but also have more dust problems, lower operational speeds, and higher user costs. On the other hand, paved roads are smoother, provide greater protection of the base and sub grade material, and may be able to accommodate a wider range of vehicle types. Cost of construction, maintenance cost of surfacing and road user costs play major role for deciding which surfacing will be more economical [8].

The economic impacts of transportation improvements have been measured alternatively at different scale. The development of methodological approaches to economic impact measurement has since evolved to fit more practical applications, and these have mostly been carried out at smaller scales, taking the form of benefit-cost analyses for particular projects regional or corridor investment analyses, or studies of the impact of specific projects on local property values. This section reviews several strands of relevant literature that aim to assess the basic issue of the economic impact of highways [7].

Economic analysis begins with a discussion of traditional, project-based economic analysis methods, based on microeconomic foundations and benefit-cost analysis methods. Some attention is paid to the specific topic of induced demand, since this issue presents unique difficulties for microeconomic analysis methods [5].

2.2 Definition

Thin bituminous surfacing is used throughout the world for surfacing newly built roads with light to medium traffic. They are also used as a maintenance treatment for roads with heavy traffic. Thin bituminous surfacing are waterproof the road surface and prevent the ingress of moisture by sealing hairline cracks. Thin bituminous surfacing also provides a durable, skid-resistant and dust-free wearing surface for the road [9].

The most common form of thin bituminous surfacing is a surface dressing, consisting of a thin film of bitumen applied to the surface followed by a layer of stone chippings. Additional layer of bitumen and chippings can be applied to form a double surface dressing, giving vastly improved durability and protection to the lower pavement layers [29].

Single and double surface dressings are the most common type of thin bituminous surfacing used for sealing road pavements especially in Ethiopia and the other one not familiar surfacing type is otta seal. Otta seal also classified in to three groups single, double and sand seal. A single surface dressing consists of a layer of bitumen protected by a layer of single sized aggregate. An additional layer of bitumen can be applied with a further layer of smaller aggregate to form a double surface dressing. However, in the case of otta seal the difference is aggregate size well graded. Other types of thin bituminous surfacing include sand seals, slurry seals and Cape seals [9].

2.3 Road Network in Ethiopia

70% to 75% of the land area in Ethiopia is more than 5 km away from an all-weather road. The first part of a ten year Road Sector Development Plan, carried out by the Ethiopian government from 1997 to 2002 resulted in considerable improvements to Ethiopia’s network of federal and regional roads, both paved and unpaved. The second part of the program, completed in 2007, involved the upgrading or construction of over 7,500 km of road, with the aim of improving access to all weather roads. By 2009, 89% of federally managed roads were in good condition. Ethiopia has a total of 101,359 km of federal and regional roads, of asphaltic or gravel construction [9].

2.4 Traffic in Ethiopia

Traffic levels across Ethiopia vary considerably from region to region. In 2015 traffic survey carried out by the Ethiopian Road Authority (ERA) on a 16,516 km sample of federal roads, AADT (Annual Average Daily Traffic) counts were taken for cars, small buses, large buses, land rovers, light trucks, medium trucks, heavy trucks and trailer trucks. Across all districts, heavier vehicles tended to account for a large proportion of the total traffic, with buses and trucks being the most common type of vehicle[29].

2.5 Life-cycle Cost Analysis as an Asset Management Tool

Life-cycle cost analysis (LCCA) has become a common practice in road construction in many countries. LCCA provides an analytical framework that goes beyond the upcoming construction event. It evaluates not only the initial construction costs of pavement, but also all the associated maintenance costs over the course of the pavement service life. By conducting a comprehensive assessment of long-term costs, it enables pavement engineers to select the pavement alternative that has the lowest life-cycle costs. Hence, agency highway funding can be allocated more optimally in the long run[23].

In practice, most applications of LCCA focused primarily on assessing the direct economic costs incurred by the government agency on road construction, and sometimes the social costs to the road user [14].

More importantly, the full contribution of LCCA to the asset management process is based upon accurate estimation of the initial and future pavement costs and performance. This is a challenging task to pavement engineers as there are often uncertainties over future pavement performance and maintenance needs [15].

2.6 Development of Life Cycle Cost Analysis (LCCA)

Many Countries have been actively promoting life-cycle cost analysis (LCCA) as an asset management tool to explore the possibility for more efficient investment in road infrastructure.

Life-cycle cost, by definition, means “the total cost of the initial project plus all anticipated costs for subsequent maintenance, repair, or resurfacing over the life of the pavement. As a result, when used in the pavement selection process, pavement engineers are able to choose the pavement type and design with the lowest cost in the long run [23].

Life-cycle cost of pavement is categorized as the following major components: agency cost and user cost. The cost directly paid by the construction owner for the project is agency cost, which includes the initial construction cost, rehabilitation cost and maintenance costs [26].

2.7 Experiences of different countries about Life Cycle Cost Analysis

Life-cycle cost analysis (LCCA) will assist in determining the best, the lowest-cost way to accomplish the project. It is an evaluation technique applicable for the consideration of certain transportation investment decisions. Specifically, when it has been decided that a project will be implemented [13].

Life cycle cost analysis approach enables the total cost comparison of competing design alternatives, each of which is appropriate for implementation of a transportation project. All of the relevant costs that occur throughout the life of an alternative, not simply the original expenditures, are included. Also, the effects of the owner’s construction and maintenance activities on users, as well as the direct costs to the owner, are accounted for [26].

LCCA is reasonably straightforward to understand and perform. It incorporates both the transportation agency’s institutional knowledge and the application of sound economic analysis techniques. In brief, the LCCA process begins with the development of alternatives to accomplish the structural and performance objectives for a project.

The analyst defines the schedule of initial and future activities involved in implementing each project design alternative. The predicted schedule of activities and their associated agency and user costs form the projected life-cycle cost (LCC) stream for each design alternative. Using an economic technique known as “discounting,” these costs are converted into present money and summed for each alternative. The analyst can then determine which alternative is the most cost-effective. It is important to note that the lowest LCC option may not necessarily be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. LCCA provides critical information, experience and Practices to the overall decision-making process [13].

Michigan DOT has a long history of using life-cycle cost analysis (LCCA) in its daily operations. MDOT first utilized LCCA as part of its pavement selection in a highway project in 1985. In the late 1980s and early 1990s, LCCA was used in selecting pavement type for more highway projects [24].

The California Department of Transportation published a Life-Cycle Cost Analysis (LCCA) Procedures Manual in November 2007. LCCA begins with the selection of alternative pavement designs to accomplish the same performance objectives. When comparing a different type of pavement alternate, the same design life should be used. The intention is to determine during the project initiation document phase which alternate pavement design life is the most cost effective. [12].

The Federal Highway Administration (FHWA) published an Interim Technical Bulletin with recommended procedures for conducting life-cycle cost analysis (LCCA) of pavements. The bulletin discusses how to address alternative pavement design strategies, length of performance periods and activity timing, agency costs (initial cost, maintenance and rehabilitation cost, residual value), and user costs (delay costs, vehicle operating, and crash cost) in LCCA. The Net Present Value is proposed as the economic indicator for comparing alternatives. A sensitivity analysis is recommended as a minimum to study the impact of the individual outputs on LCCA results. The discount rate is one of the major factors considered in the sensitivity analysis. [13].

The office of Asset Management at the FHWA published a Life-Cycle Cost Analysis introduction. The briefing was intended to provide background information to evaluate infrastructure investment alternatives. The LCCA approach considers total user and agency costs when comparing alternatives. A description of the LCCA process steps is included with a discussion on how to establish design alternatives, determine activity timing, estimate costs (agency and user), compute life-cycle costs, and analyze the results. The use of the equivalent uniform annual cost or the present value is recommended as economic indicators to compare alternatives [17].

2.8 Selection of Appropriate Road Surfacing

However gravel road play an important role in the transport infrastructure in connecting rural and remote areas into a single transport system**,** but, it requires high maintenance budget and resources, poor ride quality, vehicle delay costs, fuel consumption, and has a negative environmental impact. Therefore to avoid the above problems for low traffic volume a more economical and reasonable method is to apply the surface dressing to the gravel road. Bituminous surfacing is an integral component of paved roads. It performs a number of functions that offer many advantages over unsealed roads. These include [17]:

- ✓ Provision of a durable, impervious surfacing which seals and protects the pavement layers from moisture ingress and consequent loss of pavement strength and degradation;
- ✓ Provision of a skid-resistance surface which can resist the abrasive and disruptive forces of traffic and the environment;
- ✓ Prevention of gravel loss, resulting in elimination of costs of replacing gravel, a finite non-renewable resource;

One type of surfacing that can provide an economic and practical alternative to traditional surfacings is the Otta seal. This type of surfacing allows the use of relatively inferior, naturally occurring, unscreened gravels in circumstances where the use of traditional bituminous sprayed surfacing using relatively expensive crushed rock would generally be unaffordable or simply not possible due to the unavailability of such materials [18].

The main advantages of the Otta seal over other types of bituminous surfacing include:

- ➢ an ability to tolerate the use of relatively inferior aggregates, such as screened gravel, rather than crushed rock, without impairment of the performance of the surfacing;
- ➢ an enhanced durability that is better able to combat high solar radiation that causes rapid ageing and hardening of the binder and consequent degradation of the surfacing;
- ➢ Scope for utilizing labour-based methods in many aspects of its construction;

The Otta seal design solution does not add strength to the existing gravel surface, but this type of the surface dressing improves the gravel road operational characteristics [30].

2.9 Thin Bituminous Surfacing

A bituminous surface treatment is a simple, highly effective and inexpensive road surfacing if adequate care is taken in the planning and execution of the work. The process is used for surfacing both medium and lightly trafficked roads, and also as maintenance treatment for roads of all kinds. A surface treatment comprises a thin film of binder, generally bitumen or tar, which is sprayed onto the road surface and then covered with a layer of stone chippings. The thin film of binder acts as a waterproofing seal preventing the entry of surface water into the road structure. The stone chippings protect this film of binder from damage by vehicle tires, and form a durable, skid-resistant and dust-free wearing surface. In some circumstances the process may be repeated to provide double or triple layers of chippings [9].

2.9.1 Types of Thin Bituminous Surfacing

Surface treatments can be constructed in a number of ways to suit site conditions. The common types of surface treatments are illustrated in below.

2.9.1.1 Single Surface Dressings

In the construction of a single surface dressing a thin layer of bitumen is sprayed onto the road surface and a layer of single sized chippings is then spread onto the bitumen. Normally the chippings should be applied immediately after the bitumen is sprayed [29].

This type of thin bituminous surfacing should be used in maintenance operations on an existing road because it does not provide the durability required for surfacing newly constructed road bases. When applied as a maintenance operation to an existing bituminous road surface a single surface dressing can fulfill the functions required of maintenance re-seal, namely waterproofing the road surface, arresting deterioration, and restoring skid resistance [9].

2.9.1.2 Double Surface Dressings

Double surface dressings are more durable than single surface dressings and are used for surfacing newly constructed roads and used in the maintenance of existing roads, at locations where the surface is slightly cracked or patched. To form a double surface dressing, an additional layer of bitumen and smaller chippings is applied. The second layer of chippings generally fills the voids in the first layer and helps to lock the aggregate in place. A surface dressing can be used on roads carrying up to 1000 - 2000 vehicles per lane per day. A fog spray is sometimes added to a single or double surface dressing to reduce the possibility that chippings can be whipped off by traffic. A fog spray is also recommended if using bitumen emulsion in the tack coat [29].

2.9.1.3 Racked-In Surface Dressing

This type of surface dressing is recommended only in special conditions, when traffic is particularly heavy or fast. To construct a racked-in surface dressing a heavy layer of binder is applied, with prime if required, and given 90% coverage with a layer of large chippings. A layer of small chippings is then immediately applied and should ‘lock-in’ the larger chippings, forming a stable mosaic [9].

More bitumen is used in racked-in surface dressings than in a single surface dressing, but less than is used in a double surface dressing. The appropriate binder design will depend on the aggregate rate of spread and racked-in surface dressings can be prone to bleeding [29].

2.9.1.4 Sandwich Surface Dressing

A sandwich surface dressing is mainly used on existing road surfaces that are rich in bitumen; they may sometimes be used on gradients to reduce the tendency of the binder to flow down the slope. Asthe existing surface is rich in bitumen, no prime coat or tack coat is applied in the construction of sandwich surface dressings [9].

A layer of chippings is placed directly onto the road surface; the first layer of bitumen is then applied, followed by a layer of smaller chippings. Thus there is one layer of bitumen ‘sandwiched’ between the two layers of chippings [29].

2.9.1.5 Pad Coats

This type of surface dressing is used where the hardness of the existing road surface allows very little embedment of the first layer of chippings. Road bases constructed from cement stabilized materials and dense crushed rock can fall into this category. The hardness of the existing surface should be determined using a mexe Cone Penetro meter [9].

A layer of bitumen is applied to the road surface followed by a layer of small chippings; an additional layer of bitumen and a layer of larger chippings are then applied where required. The smaller chips in the lower layer help the larger chippings in the upper layer to key into the lower layer, providing a good bond. On heavily traffic roads, a fog spray can be used to reduce whip-off of the chippings in the upper layer [29]

2.9.1.6 Slurry Seals

These seals are usually mixed on site before being applied to the road surface. They consist of a mixture of fine aggregate, Portland cement filler, bitumen emulsion and water, giving a smooth finish to the road surface. A stable grade anionic emulsion is normally used for slurry seals. Cationic emulsions are normally used in slurries with acidic aggregates, and they can useful where there is a risk of rain during construction due to their early breaking characteristics [9].

Slurry seals are not normally used for surfacing newly constructed roads as they can be less cost effective than surface dressings, depending on the thickness of slurry used. Slurry seals also are not as durable as surface dressings. They do not provide the same skid resistance as a surface dressing which has a better surface texture [29].

2.9.1.7 Cape Seals

A Cape seal consists of a single surface dressing with a slurry seal worked into the voids in the single surface dressing. Cape seals are relatively stiff and durable with the chippings locked in place by the slurry. This type of thin surfacing can carry up to 2000 commercial vehicles per lane per day [9].

A Cape seal is more expensive than a double surface dressing. The first layer is identical to a single surface dressing, but the slurry has much higher binder content than that used for a single slurry seal [29].

2.9.1.8 Sand Seals

Sand seals should only be used where chippings for a surface dressing are not obtainable or are prohibitively expensive. Sand seals are less durable than surface dressings and abrade away under traffic when natural, rounded sand is used. Better performance can be obtained if the sand seal is given an additional layer within a year [9].

Sand seals should only be used on very lightly trafficked roads where there are less than 100 vehicles per lane per day and are more often used in combination with other seals , such as an Otta seal. The life of a sand seal depends very much on the quality of the sand. [29].

2.9.1.9 Otta Seals

Otta seal is a particular type of bituminous surface treatment which was originally developed by the Norwegian Road Research Laboratory (NRRL) in the early 1960sas one type of surfacing that can provide economical and practical alternatives to traditional surfacing [18]. Since 1960; 12,000 km of Norwegian roads had been surfaced using Otta Seal. Such seals have subsequently been constructed successfully in a number of countries including Sweden, Iceland, Kenya, Botswana, Zimbabwe, South Africa, Bangladesh and Australia. Otta Seal has relatively simple design. The use of the Otta seal extends to a number of developing countries, particularly in eastern and southern Africa, where its use is becoming more wide-spread as more experience is gained in its design, construction and maintenance [19].

Otta seal was tried in Norway, Sweden, Finland, Island, Minnesota, Bangladesh, and Australia and in a number of eastern and southern Africa countries as an alternative to paving gravel roads. The main advantages of an Otta seal are the flexibility it offers in terms of the variety of materials that can be used for producing the graded aggregate [20].

The chief characteristic of an Otta seal is that it uses graded aggregate with a range of sizes, including filler material, instead of a single sized aggregate. This type of seal can be constructed in single or double layers; the latter is usually recommended. A single sand seal can also be applied to the Otta seal to give it further durability. This type of seal can provide a highly cost-effective solution [9].

Figure 1: Matrix of Otta seal

Otta seals are appropriate for secondary and tertiary roads with low to medium volumes of traffic, with Average Annual Daily Traffic (AADT) of less than 1000. They should not be used on roads carrying higher volumes of traffic. Otta Seals are most appropriate for secondary, tertiary and access roads [9].

When we see the construction of an Otta seal, it is similar in principle to that of a conventional bituminous surface treatment. However, many of its construction activities can be undertaken using labour-based methods - a major advantage in terms of employment provision [18].

Otta seals are constructed over an aggregate base course. Since Otta seals do not add structural capacity to the roadway, the base/subbase must be designed to support the anticipated traffic loading. Subgrade and base materials should be compacted and graded to provide a stable working surface prior to Otta seal placement. A prime coat is usually not used above the aggregate base prior to Otta seal application [21].

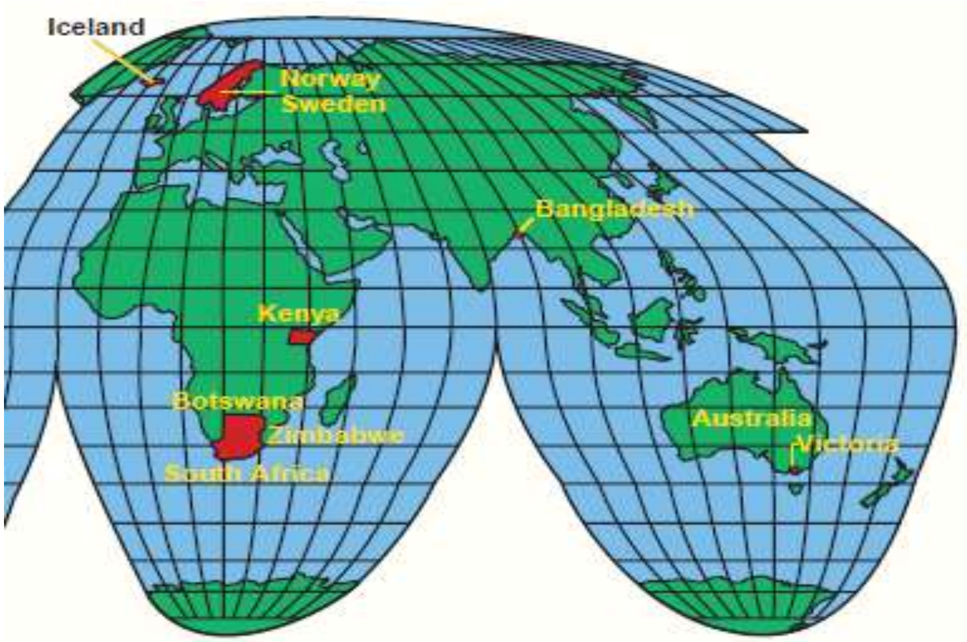

Figure 2: The Global use of Otta Seals

Otta Sael has the following advantages:

- Cheap and easy to carry out anywhere in the country
- Utilize locally available screened natural aggregates
- impervious to prevent water into the water susceptible base material
- very flexible, durable and easy to man power

Table 1: Recommended type of Otta seal in relation to traffic levels

Traffic levels and type of work	Type Otta Seal
Temporary seal (diversions, haul roads, temporary accesses, etc.).	Single Otta Seal
Maintenance resealing (all traffic classes to which sprayed surfacing are applicable.	Double Otta Seal
AADT less than 500 Single	Otta Seal + sand cover seal
AADT more than 500	Double Otta Seal

Therefore, from the above all types of thin bituminous surface dressing double otta seal is selected by the researcher due to the following reasons:

- ✓ Otta Seal has relatively simple design
- ✓ flexibility it offers in terms of the variety of materials that can be used for producing the graded aggregate
- ✓ chief characteristic of an Otta seal is that it uses graded aggregate with a range of sizes, including filler material, instead of a single sized aggregate
- ✓ its construction activities can be undertaken using labour-based methods - a major advantage in terms of employment provision
- ✓ Utilize all types of locally available screened natural aggregates
- ✓ Cheap and easy to carry out anywhere in the country

2.10 Description and Types of Otta seal

Otta seals differ in many respects from traditional bituminous surface treatments. These differences include such factors as aggregate quality, binder type, design, construction, and durability. By virtue of these differences, Otta seals offer a number of important advantages over traditional surface treatments, including [18]:

- an ability to tolerate the use of relatively inferior aggregates, such as screened gravel, rather than crushed rock, without impairment of the performance of the surfacing;
- an enhanced durability that is better able to fighting high solar radiation that causes rapid ageing and hardening of the binder and consequent degradation of the surfacing;
- scope for utilizing labour-based methods in many aspects of its construction;
- a favorable life-cycle cost-benefit ratio of the order of 50% to 60% of the more Commonly used seals, such as the Chip seal.

Otta seal is constructed of a graded aggregate on top of a thick application of relatively soft bituminous binding agent. The bituminous binding is typically emulsified asphalt. Bituminous binder application rates vary from about 1.9 liter/m2 to 2.4 liter/m2 for emulsified asphalt, depending on aggregate gradation and type. In comparison to other surface treatments, material and construction specifications are not as strict. Local aggregates that would not meet the requirements for high quality paving aggregate are often used in Otta seals. Natural gravels are acceptable. The maximum aggregate size in the graded aggregate is generally 13 to 25 mm (0.50 to 1 in.). The graded aggregate can be crushed or uncrushed and contain up to 10% fines. Otta seal design is empirical in nature and trial sections are recommended to determine the appropriate material application rates [21].

Otta seal consists essentially of a 16-32 mm thick bituminous surfacing constituted of an admixture of graded aggregates ranging from natural gravel to crushed in combination with relatively or low viscosity binders, with or without a sand seal cover [31].

2.11 Material for Otta Seal

Prime:

Is used to avoid dust on the existing road & it reduce high amount of binder absorbed by base course or Existing Road [32].

Types of Prime

Cut buck bitumen with viscosity in the range of MC 30 or MC 70 is normally used for priming. Due to environmental protection Tar primes are not recommended for use as priming [19].

Application rate

Application rate of prime depend on material used as base course normal used between 0.8-1.2 l/m^2 [32].

Binders

The type of binder used in an Otta seal can significantly affect its constructability, durability and ultimate performance. It is therefore critically important that a correct choice of binder is made to ensure that the critical function of a complete coating of the mineral aggregate particles, even the fines, is achieved during construction. The range of binders and related viscosities that have been found to be most appropriate for this purpose are as follows [18]:

- MC 800 cut back bitumen (softest).
- MC 3000 cut back bitumen (medium).
- 150/200 penetration grade bitumen (hardest).

The above types of binders are generally manufactured at refineries from where they can be readily supplied. However, one may also cut back the penetration grade bitumen with power paraffin to the required viscosity range.

To choice a right types of binder's application rate on otta seal type of surfacing depend on the property of aggregate.

Binders must full fill the following properties

- ✓ Be Viscose enough to provide sufficient stability after the initial curing of the seal.
- ✓ Be durable enough to use with available equipment and skills
- ✓ Be environmentally friendly to the grater possible extent.
- ✓ Be economical in use.

Types of binder

A general description of selected binder types and their potential use in otta seals is given below.

Penetration grade bitumen

- ✓ 80/100 penetration grade bitumen is conventionally used chip seals ,However does not full fill the requirement of otta seals and should never be used as otta seal surfacing.
- ✓ 150/200penetration grade bitumen is hardest type of bitumen that can be used for otta seal surfacing.

Cutback bitumen

- ✓ MC 3000 and MC 800 Viscosity range has also been used

Tar

- ✓ Has not been used in otta seal because it tends to harden mach more rapidly than bitumen, thus compromising the service Life of the seal.
- ✓ Have serious environmental disadvantage and their use in road surfacing is not recommended.

Aggregate

One of the main advantages of an Otta seal is the flexibility it offers in terms of the variety of materials that can be used for producing the graded aggregate. Accordingly, the approach to producing the graded aggregate should be to devise the best way of using whatever source of materials is available in combination with a judicious choice of binder [20].

Both crushed or uncrushed material and a mixture of both can be used for producing graded aggregate for Otta seals. The following are typical examples of the types of gravels/aggregate that have been successfully used [17].

- ✓ Screened natural gravel from weathered granitic rocks
- ✓ Crushed and screened gravel from sand stone an lake deposits
- ✓ Screened river or lake gravel and sand
- ✓ Crushed, screened rock from a Varity of rock types such as

The grading of the aggregate is relatively wide, the preferred maximum size is 16mm (19mm can be tolerated for the double Otta seal) and the maximum amount of fines (material passing the 0.075 mm sieve) should preferably not exceed 10%, although fines in excess of 20 % have performed well. The grading of naturally occurring gravel generally falls within the specified envelope, but where there is oversize material it has to be removed by screening [18].

Screened natural gravel

Naturally produced or collected gravel should screen to remove over size and excessive fine particle. Low moisture content in the material to desirable to avoid clogging/blockage of the finer mesh of the sieve. But it must contain well graded particle size according to the grading envelop [17].

Crushed gravel

The wide grading envelope requirement of otta seals allows a relatively higher production of the crushed product to be used compared to chip seals. Crushing allows a better utilization of the gravel sources and generally improves the quality of the aggregate [19].

The bulk of the crushed gravel production is normally utilized in otta seal resulting in little or zero wastage. High establishment cost may prohibit crushing of gravel on smaller projects [17].

Crushed rock

The most widely used type of aggregate for any surfacing in Ethiopia. Any crushed material acceptable in the base course layer can be used to produce aggregate for an otta seal surfacing [9].

Table 2: Otta seal aggregate grading requirements

Material Properties	Requirements	AASHTO Test designation
Plasticity index	**Max 10**	**T 90 – 61**
Flakiness index	**Max 30 (Applies only for crushed material)**	
Sieve sizes, mm	**Overall grading requirements, % passing**	T 146- 49
19	100	
16	80 – 100	
13.2	52 – 100	
9.5	36 – 98	
6.7	20 – 80	
4.75	10 – 70	
2.00	0 – 48	
1.18	0 – 38	T 146- 49
0.425	0 – 25	
0.075	0 – 10	

The strength requirements of aggregate are higher if the traffic is greater than 100 vehicles per day.

A sand seal can be placed on top of the Otta seal if required. MC 800 or 150/200 pen, cut back with kerosene, is used. The sand is then spread on the top and rolled [17].

2.12 Design of Otta Seal

Otta Seal has empirical approach to design. Relies to some extent on guideline and trial on site. Design may change during construction. From its early beginning the Otta Seal was either applied as a single or double seal using the same grading and binder application for the first and second seals. Today, this is still the practice with only minor adjustments. However, in African country, namely Botswana a variety of combination using the Otta Seal approach has been constructed successfully [22].

Apart from the normal single and double seals' Botswana has split the grading into two fractions, more "open" and "dense" graded aggregate, respectively. Very fine graded Kalahari sand (100% passing the 1, 00 mm sieve) which is easily available over a large part of the country, is in many cases, and in particular for single Otta seals, used as Sand seal cover in order to ensure proper aggregate retainment and to delay the ageing of the Otta Seal binder [18].

Compared to other types of surfacing the design of an Otta Seal is simple, but requires an empirical approach-based experience in the formulation of selecting appropriate binder-aggregate combination and application rates [19]. The factors that influence this formulation are:

- Aggregate type and grading
- Traffic intensity and proportion of heavy vehicles
- Porosity of base or condition of old surfacing
- Rolling equipment and procedure
- Weather conditions during construction

Table 3: guide for spray rates

AADT	spray rates
AADT < 100	1,8 - 2,2 l/m2
AADT 100 -500	1,8 - 2,0 l/m2
AADT > 500	1,6 - 1,8 l/m2

In Africa it has been common practice reducing the binder application rate for the second seal with 10% compared to the first seal. While in Scandinavia the application rate for the second seal is similar to the first seal or slightly above [20].

In Scandinavia adhesion additives/wetting agents are normally used at a quantity of 0,8% by weight of bitumen. Reported from elsewhere, Kenya and Bangladesh Otta Seals have preformed excellently without any adhesion additives [18].

The design used for Otta seals is empirical and trial sections should be constructed to check that the design selected is satisfactory. The binders normally suitable for Otta seals in Africa are MC 3000 or 150/200 penetration grade bitumen but they are dependent on the quality of the aggregate used. The hot rate of spray usually lies within the range from 1.6 to 2.1 l/m2 but detailed adjustments should be made in accordance with the recommendations made in the (1999) Guide to the use of Otta Seals [31].

The following tables illustrate the design procedure for Otta seals. Traffic is expressed in these tables as Annual average daily traffic (AADT).

Table 4: Preferred aggregate grading for Otta seals [31].

AADT	Best suited grading
Less than 100	Open
100-1000	Medium
More than 1000	Dense

Table 5: Choice of bitumen in relation to traffic and grading

AADT at the time of construction	**Type of bitumen**		
	Open grading	**Medium grading**	**Dense grading**
More than 1000	Not applicable	150/200 pen grade	MC 3000, MC 800 in cold weather
100 to 1000	150/200 pen grade	150/200 pen grade in cold weather	MC 3000, MC 800 in cold weather
Less than 100	150/200 pen grade	MC 3000	MC 800

Table 6: Making cut back bitumen on site

The cut back bitumen grades can be made by blending 80/100 pen grade on site using the following proportions	
To make 150/200 pen. grade:	3 - 5% softener mixed with 95 - 97 % 80/100 pen grade. Softener can be a purpose-made petroleum distillate, alternatively engine oil, old or new. In addition 3% points of power paraffin shall be used.
The cut back bitumen grades can be made by blending 150 /200 pen grade on site using the following proportions:	
To make MC 3000:	5 - 8% power paraffin mixed with 92 - 95% 150/200 pen grade
To make MC 800:	15-18 power paraffin mixed with 82 - 85% 150/200 pen grade.

Table 7: Aggregate application rates

	Aggregate spread rates (m3/m2)		
	Open grading	Medium grading	Dense grading
Otta seal	0.013 – 0.016	0.013 – 0.020	0.013 – 0.020
cover seal	0.010 – 0.012		

In practice, the aggregate application rates will very often be increased in order to reduce the risk of bleeding.

2.13 Construction of Otta Seal

2.13.1 Stages in Construction of Otta Seal

The first stage in constructing an Otta seal is to apply the fluid binder to the existing surface, which is usually a new road base. A prime coat may or may not be applied beforehand, and the existing surface may or may not be bituminous [9].

All-in crushed stone or natural gravel is then spread at a rate in accordance with the applicable design, depending on the grading of the material and the traffic level at the time of construction. This layer must then be rolled for a minimum of fifteen passes on the first day of construction. For the following two days the entire area of the Otta seal must be rolled for a minimum of fifteen passes per day. Two roller compacters with a minimum weight of 12 ton should be used for the rolling operations. Other alternative rolling methods, such as trucks loaded with heavy sandbags, are acceptable [19].

The road may be opened to traffic after the first three days but the traffic speed must be limited to a maximum of 50 km/h for three weeks. It is beneficial if the traffic is channeled so that an even distribution of rolling is maintained across the road width. During the first three weeks, any material that is dislodged by traffic should be broomed back onto the exposed areas. After three weeks, all excess material should be broomed off the surfacing and speed restrictions can be lifted [20].

If natural gravel with a high percentage of fines has been used, it may be necessary to continue rolling the gravel for up to six weeks before removing excess material and speed restrictions. A team must be available to deal with areas of bleeding when required, and during the normal construction period as well as during the first hot season following the completion of sealing operations [9].

Additional layers of Otta seal or a sand seal should not be constructed for at least three months after the initial layer is placed, and the surface should be swept clean of excess material or dirt before any additional layers are constructed [18].

It is a good indication that the bitumen application rate is correct when droplets of bitumen appear in the wheel tracks of the tipper trucks delivering the aggregates [18].

Bleeding is corrected by application of fine or coarse sand until a satisfactory surface has been achieved. Application of a sand cover seal would give a more uniform appearance [19].

Construction of Otta seal is not sensitive to standards of workman- ship. Labour intensive methods can easily apply. The construction operations for an Otta Seal are similar to those of a conventional bituminous surface treatment by spraying binder followed by the spreading of aggregate. Different from these more conventional surface treatments is that the binder for the first layer of an Otta Seal very often is sprayed on a non-primed base. In order to bind the dust on the top of the base, and also open the top base upper pores, hence, it is absolutely necessary to water the base prior to spraying the binder. After watering ample time should be given to allow the base to dry into a dampened stage with open pores allowing the binder to penetrate and ensure a good bond to the base. On a dry and dusty base contraction behavior of the binder will take place, resulting in uncovered spots in the sprayed layer of bitumen, and eventually resulting in potholing [17].

The aggregates are normally applied by self-propelled or truck mounted chip spreaders. However, spreading the aggregate by hand, both from a reversing truck or from staggered aggregate stockpiles along the road have successfully been used [20].

In constructing an Otta Seal emphasis should be concentrated, but not limited, to the following:

- ❖ Pneumatic rollers are essential as their ability to knead the binder upwards the many particles- thick- aggregate- layer is superior to the steel rollers. At the time the initial rolling with the pneumatic equipment is completed commercial traffic should be allowed on the surfaced area as this will assist further in the kneading process of the binder/aggregate mix. A maximum speed limit should not exceed 40 - 50 km/hour the following first weeks. (In the absence of pneumatic rollers, compaction has been successfully carried out by the use of loaded trucks following a set rolling pattern covering the entire surfaced area. Pneumatic rollers are essential as their ability to knead the binder upwards the many particles- thick- aggregate- layer is superior to the steel rollers. At the time the initial rolling with the pneumatic equipment is completed commercial traffic should be allowed on the surfaced area as this will assist further in the kneading process of the binder/aggregate mix. A maximum speed limit should not exceed 40 - 50 km/hour the following first weeks. (In the absence of pneumatic rollers, compaction has been successfully carried out by the use of loaded trucks following a set rolling pattern covering the entire surfaced area.

- ❖ The following two days excessive rolling by pneumatic roller(s) shall take place in order to ensure that all particles embedded in the binder are properly coated. It should be noted that it is not possible to over-roll an Otta Seal for the first two-three days after construction. The more rolling, the better the quality of the seal that is formed.
- ❖ The initial occurrence of signs of bleeding and isolated fatty spots should not be any cause of concern, and can be blinded off with finer aggregate and preferably rolled into the surfacing. Signs of slight bleeding confirm that the ratio aggregate/binder has been optimal.
- ❖ A minimum period of three months should normally elapse between the construction of the first and second layers. This is to allow as much traffic as possible before evaporation of the cutters is completed. During this period the surfacing becomes more settled and the exposed wheel paths (aggregate blown out by traffic) show a “premix” like appearance. A newly constructed Otta Seal may be dusty and liable to flying stones at least for the first weeks after construction.
- ❖ Excess cover material is always needed in the case when constructing an Otta Seal, and it is important to ensure that the aggregates are excessively applied (ref. point 4). After the elapse period is over excessive material should be broomed off and collected. This surplus material should be added to the second seal or be added to the material forming the future first seal. In the case of a second seal bitumen from the first layer shall by then be visible over the entire surface width.

- The Otta Seal concept makes allowances for a variety of aggregate grading and cannot be directly designed by a general rational method (as for a chip seal). Its design must therefore be tailored to the local environment in terms of the aggregate and binder available, type of traffic and climate. Local experience and sound judgment by the engineer and not at least the work foreman at the start of the sealing work (adjustment may often be required) will be essential to achieve a satisfactory result. However, saying so it is experienced that with only 75-80% successful construction achievements for an Otta Seal, one can still obtain close to maximum performance of the seal. Contrary, for a chip seal under equal construction conditions the performance of the chip seal would have been far from satisfactory, probably being described as completely ruined.

2.14 Sustainability of Otta Seal

2.14.1 Performance of Otta Seal

The dense textures of the Otta Seal as formed by many particles thick layer of aggregates where the interstices are filled with comparatively soft bitumen has been found to be fairly resistant to wear and tear from the studded tires. Also, in Scandinavia, on roads with inferior bearing capacity during the thaw period the Otta Seal is often preferred. This is mainly because of its flexible behavior and easiness to both construct and maintain. In hotter climates such as Africa where binder oxidation and following brittleness are caused by solar radiation, timely and appropriate maintenance/resealing frequency has to be adopted to prevent disintegration of the bituminous seal. It seems that the close-textured grading as formed by the Otta Seal concept is less susceptible to binder ageing, and hence may be described as more durable than the more open-textured chip-seal surfacing[18].

From the behavioral mechanism of the Otta Seal, and from visual evidence of performance under different climatic conditions (ranging from freezing cold -40OC, to mild and wet, from temperate hot and wet to very hot and dry), varying levels of traffic, different type of aggregates (varies from weak natural occurring material to crushed hard rock) and different construction approaches (labour intensively to very mechanized plant operations) it seems that the Otta Seals have no other limitation regarding traffic volumes than one would apply to any other sprayed bituminous surfacing types [20]**.**

a

b

C

Figure: 3a). During spraying and spreading, b) during compaction and c) physical appearance of double otta seal after 2 year.

2.14.2 Economic Benefits

The Otta Seal has proved to be a very cost-effective surfacing and its use has in many circumstances made allowances to construct roads under very unfavorable prevailing conditions, where conventional surfacing approaches would have been too expensive or not possible at all. It is therefore recommended when it comes to appropriate surfacing for roads (low volume roads) carrying traffic volumes of less than 1000 vpd to make cost comparisons to other sprayed bituminous surfacing, assessing the availability of local materials and their use in an Otta Seal. This exercise would in many cases derive to the conclusion that an Otta Seal would be the most economical and appropriate surfacing type [20].

The cost of construction will vary considerably depending on a variety of factors such as availability of materials (crushing or only screening required), remoteness of construction site, haulage distance and cost of plant and labours among others. Such costs will vary from country to country, but the interesting point is the relative cost of constructing and maintaining an Otta Seal versus a conventional bituminous seal (Chip seal) under similar conditions. The following factors are predominant with regard to cost savings [18].

- Reduced cost in aggregate production (only screening may be required and if crushing is necessary most of what is crushed is used, including the fines).
- Hauling cost is reduced because of the utilization of local gravels.
- In most cases' prime is omitted.
- In many cases surfacing operations cost is reduced.

2.14.2.1 Otta Seal Lasts Longer

Otta Seal lasts longer and requires less or no maintenance over its lifetime than gravel roads and other bituminous surfacing. Also minimizes the appearance of potholes. This translates into safe highways that require less maintenance, with less disruption for the traveling public and other commercial truckers [32].

Life Expectancy: Life expectancy varies depending on construction materials used, environmental conditions, and traffic volumes. Service lives for double Otta seals range from 12 to 16 years [18].

2.14.3 Environmental Benefits of Otta Seal

2.14.3.1 Ability to Recycle/Reuse

Otta seals can be pulverized and reused as an unbound or stabilized material [21].

2.14.4 Users Benefit from Otta Seal

2.14.4.1 Ride Quality

Otta seals can provide minor improvements to ride quality. On a proper prepared application surface, a good ride quality can be achieved after construction. Ride quality deteriorates over the serviceable life [20].

2.14.4.2 Appearance of Otta Seal

Immediately after placement, the Otta seal's appearance is similar to a gravel road and is influenced by the aggregate color. With time and traffic, the black bituminous binding agent works its way up through the aggregate, creating a surface appearance similar to cold mix asphalt concrete [19].

2.15 Economic Analysis

2.15.1 Components of a Life Cycle Cost Analysis

Several economic analysis techniques can be used to assess pavement type options. The two most popular are the Net Present worth (NPW) method and the Internal Rate of Return method (IRR).The IRR method simply asks what rate of return makes the Net Present Worth equal to zero[24].

The economic evaluation has the following principal inputs:

- Base year traffic
- Existing road condition data
- Vehicle fleet and operating cost data
- Economic and traffic growth forecasts
- Project works and maintenance costs

The principal outputs of the evaluation are indicators of economic viability:

- Net Present Value (NPV): discounted project benefits – discounted project costs
- Economic Internal Rate of Return (EIRR): the discount rate at which NPV = 0

Net present value method (present worth) method is based on the discounted cash flow technique. In this method, the stream of Cost/benefits associated with the project over an extended period of time is calculated and discounted at a selected discount rate to give the present value. Benefits are related as positive and costs are as negative and the net present value is found. Any project with a positive net present value is treated as acceptable. In comparing more than one project, a project with the highest net present value should be accepted. The internal rate of return is the discount rate which makes the discounted future benefits equal to the initial outlay. In other words, it is the discount rate which makes the stream of cash flows to zero. The minimum requirement of a project in terms of economic viability is to produce a positive NPV and an EIRR greater than the discount rate. In general, however, it is necessary to achieve more convincing results than the minimum requirements because of competing projects and limited funds [26].

LCCA is used to compare the relative long term costs of different pavement alternatives. LCCA allows the Engineer to objectively evaluate costs of two or more rehabilitation and/or new/reconstruction alternatives that may have significantly different initial costs and require very different levels of future preventive maintenance expenditures [6].

Life-cycle cost analysis procedure is desired when developing alternates, especially during the Preliminary design stage. Life-cycle cost analyses are used for the prediction of future costs of proposed pavements over a given period of time, using the best available information as to total costs and predicted performance. Pavement designs will consider similar traffic and comparable age for the alternatives. Factors considered in the economic analysis for comparison of the pavement type included initial construction cost, the expected maintenance costs, road-user delay costs, and the expected salvage value at the end of the analysis period [26].

Several components make up the framework of a comprehensive life cycle cost analysis methodology. Inherent in the definition of life cycle cost analysis is the idea that all costs involved in a pavement’s construction, maintenance, rehabilitation, social and economic impacts, and any other costs that can be attributed to the use, care and maintenance of a pavement and highway section are captured and considered in the design decision process. Each component of a life cycle cost methodology is reduced and combined with other components in some way to produce a cost that is borne by some entity. The major costsincluded in the life cycle cost process are divided into two major categories: agency costs and user costs [6].

Different pavement types have different cost profiles over their lives. Initial constructions costs of a pavement are often go above by the costs of operation. Whole-life costing analysis is used to identify the extent and timing of the costs involved and to help choose the most cost-effective pavement type. It uses net present worth (NPW) or net present value (NPV) for the assessment of future costs to provide a common basis of comparison of those costs [27].

2.15.1.1 Initial Cost

The initial costs have a major impact on the total PW. The initial costs are determined at year zero of the analysis period. Although numerous activities are performed during the construction, reconstruction or major rehabilitation of a pavement, only those activities that are specific to a pavement alternative should be included in the initial costs [26].

Comparing the initial cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplication by their unit prices. Material quantitiesare generally direct functions of their thicknesses in the structure. They are also functions of thicknesses of other layers and width of pavement and shoulders. The cost of in-place material in a pavement structure is not directly proportional to the volume required. Unit material price is dependent on material quantity to be provided, construction procedure employed, length of project, etc. Therefore, care should be taken to estimate quantities and true expected costs carefully [5].

2.15.1.2 Types of Maintenance

Periodic, routine or corrective maintenances are types of maintenance, which are need for all pavement types during their life time.

The estimates of all costs which are essential to maintaining pavement investment at a desirable specified level of service, or at a specified rate of deteriorating service, is essential to a proper economic analysis. The level of maintenance, i.e., the type and extent of maintenance operations, determines the rate of loss of riding quality or serviceability index [3].

As a result of the enhanced durability characteristics of otta seal, maintenance intervention is not required to the extent necessary with conventional seals. Thus, such interventions as fog spraying are unnecessary with the otta seals. Further, the resealing frequency for the otta sealvaries between 9- 15 years. The repair and resealing of any localized surface defects are similar for the otta seal as for any other sprayed type of surfacing [31].

Repairing of any localized surface defects of an Otta seal surfacing are similar to that undertakenfor any other sprayed type of surfacing.

The use of Otta seals as reseals does not differ from other sprayed types of bituminous reseals that are commonly used. However, in contrast to traditional Chip seals where aggregate size requirements are an important factor depending on the existing seal aggregate, this meshing aggregate requirement does not apply for Otta seals. Any aggregate size within the general grading envelope can be used.

Due to the relatively flexible nature of the Otta seal, it is also well suited as a reseal for roads that are extensively cracked or patched, but are still structurally sound [18].

2.15.1.3 Salvage Value

Salvage or residual value is used by some agencies in economic evaluation. It can be significant in the case of pavements because it involves the value of reusable materials at the end of the design period. With the depletion of resources, such material can become increasingly important in the future, especially when used in a new pavement by reworking or reprocessing [3].

2.15.1.4 Road User Costs

User costs are associated with a number of indirect or non-agency costs which accrue to the road user and must be considered for a rational economic analysis. Such costs cannot be ignored because, similar to pavement costs, user costs are related to the roughness or serviceability history of the pavement [3].

The main areas of user costs are:

- Vehicle Operating costs: Fuel consumption, Tier wear, Vehicle maintenance, Oil consumption, Vehicle depreciation and Parts replacement.
- User Travel Time cost or delay cost
- Accident or crash costs: Fatal Accidents, Non-fatal accidents and Property damage.

All costs given above are a function of roughness level as well as vehicle speed resulting from such roughness level.

Delay of user costs are intended to cover the user cost associated with delays when the capacity of a roadway is reduced due to roadway construction and rehabilitation lane closures. These costs include things such as idling costs and delay of time costs as the vehicles slow down through the work zone or wait at construction zones and take longer route due to detour [28].

Travel time delay is normally the greatest component of user costs, since the value of time and the number of hours spent in work zone queues are multiplied to determine the total cost of travelers sitting in traffic. When motorists sit idle in vehicles longer than they would have under normal traffic conditions, the time lost is a cost borne by each individual passenger. However, this is a cost that must be considered when a decision is made as to the proper design for a highway project. Minimizing the disruption of traffic flow during each construction (and therefore, work zone) period throughout the analysis period is an important aspect of any highway project's design. The user costs associated with highway construction usually exceed the agency's construction costs by a substantial amount, particularly in urban areas [3].

Vehicle operating costs: Mostly as a result of increased fuel usage, wear on tires and other parts.

Vehicle operating costs increase during maintenance periods. In service vehicle operating costs are a function of pavement serviceability level, which is often difficult to estimate. User delay costs: User delay costs are connected with road users' time. Usually timesaving is mentioned as one of the key benefits in transportation projects [26].

User costs mostly increase during maintenance and rehabilitation periods, when traffic is completely shut down or diverted into other lanes. Time delay cost is mostly due to changes in speed. Speed changes are the additional cost of slowing from one speed to another and returning to the original speed. Time value depends on the vehicle type and the purpose of the trip.

However, user delay costs are one of the most difficult and most controversial life-cycle cost analysis parameters: they are extremely difficult to calculate because it is necessary to put amonetary value on individuals' delay time [28].

2.15.1.5 Design life

The first step in Surfacing design is to determine an appropriate design period. Those factors may influence on this decision including budget constraints. However, the designer should follow certain guidelines in choosing an appropriate design period, taking into account the conditions governing the project. Some of the points to consider include [23]:

- Financial constraints
- Functional importance of the road
- Location and terrain of the project
- Traffic volume

The durability of otta seal is good and they can be designed for periods of up to 16 years. If properly constructed, the otta seal will last long with a good level of serviceability and no or low maintenance requirements. The possibility to design otta seal is more than three times the maximum design life of gravel road and also the lower maintenance costs make them generally more economical in the long term [20].

Construct roads with longer design period is economical for important roads and for roads with all traffic volume. Where rehabilitation would cause major inconvenience to road users, a longer period may be used. For roads in difficult locations and terrain where regular maintenance proves to be costly and time consuming because of poor access and non-availability of nearby construction material sources, a longer design period is also appropriate [23].

2.15.1.6 Analysis Period

The analysis period refers to the time for which the economic analysis is to be conducted. The analysis period can include provision for periodic surface renewal or rehabilitation strategies which will extend the overall service life of a Surfacing to 15to16 years without maintenance or with minor maintenance [18]. For this research an analysis period of 15 years was chosen.

2.15.1.7 Discount Rate

Discount rate is used to convert the future benefits and costs of projects to present value. The higher the discount rate, the lower the net present worth of future costs will be. Thus, higher rates make initially expensive projects less profitable, while lower rates give them more so. A discount rate of 10.23% was used in this study as recommended by Ministry of Finance for evaluation of project feasibilities in Ethiopia.

2.15.1.8 Present Worth Method

The Present worth **(**PW) method involves conversion of all future costs to the present using an appropriate discount rate. All costs are predicted and are reduced to an equivalent single cost. Present-worth costs of the strategies provide a fair comparison basis, all other things being equal [3].

2.15.1.9 Traffic Analysis

The composition and volume of traffic has always been a major focus of pavement design due to the impact it has on determining the thickness of the pavement. Traffic has been traditionally described as the number of vehicles using the road in terms of the Average Annual Daily Traffic (AADT). In the 1993 AASHTO Design Guide, the traffic was described in terms of Equivalent Single Axle Loads (ESALs), which described the total damage caused by different vehicles [3].

To design a paved highway, it is necessary to consider not only the traffic volume or the total number of vehicles that will use the road but also to predict the number of repetitions of each axle load group (or wheel load group) during the design period.To convert the traffic volumes into cumulative equivalent standard axle loads (CESAL which is one design parameter in pavement design) equivalency factors are used [25].

2.15.2 Axle load surveys

When we see axle load surveys, axle load surveys carried out to determine the axle load distribution of a sample of the heavy vehicles using the road. Data collected from these surveys are used to calculate the mean number of ESA for a typical vehicle in each class. These values are then used in conjunction with traffic forecasts to determine the predicted cumulative equivalent standard axles that the road will carry over its design life [10].

Once the axle load data has been gathered, it remains to be used to determine the mean equivalency factor for each class of vehicle. The thickness of pavement is governed by the number of repetition of a standard vehicles or axle load. A summation of the equivalent effect of all axle loads during the design period results in an equivalent single axle loads (ESAL) which is the single traffic parameter for the design purposes. This method is widely used in most countries for highway pavement design; ERA follows the producer of fixed vehicle for highway pavement design. The axle loads can be converted and compared using standard factors to determine the damaging power of different vehicle types. A vehicle's damaging power, or equivalency factor (EF), can be expressed as the number of equivalent standard axles (ESAs).The design lives of pavements are expressed in terms of the ESA [10].

The cumulative ESAs over the design period (N) are calculated as the products of the cumulative one-directional traffic volume (T) for each class of vehicle by the mean equivalency factor for that class and added together for each direction. The higher of the two directional values should be used for design.

2.16 Elasticity of Transport Demand

In the method of long-term traffic forecasting incorporates analyses of some of the key socio-economic characteristics in the road influence area and their anticipated rates of change during the study period, these characteristics being taken as indicators for the future growth of traffic [16].The growth rates for normal traffic obtained from this approach take account of the following factors, which affect future traffic levels:

- The prospective growth in the economy,
- The estimated elasticity of demand for transport, and

The growth in agriculture and manufacturing sectors affect the growth of freight vehicles, but the growth in population and income level affects growth of passenger vehicles [16].

Considering medium growth scenario with some modifications in comparison to Consultants' recent feasibility studies, the following traffic growth rates are adopted for traffic forecasting as table below.

Table 8: Average Annual Traffic Growth for Medium Scenario

Vehicle	Type Period in years	Growth rate (%)
Passenger vehicles (Car,4WD, Buses)	2018 – 2025	6.5
	2026 – 2032	5.9
Freight vehicles (ST, MT, HT,TT)	2018 – 2025	6.12
	2026 – 2032	5.50

CHAPTER THREE

METHODOLOGY

The aim of the research was to identify the economical type of road surfacing for low volume gravel roads in Ethiopia by making life cycle cost comparisons and economic analysis of Double Otta Seal with Gravel Roads in selected segments.

3.1 Study Area

Selected Road sections from three districts of Ethiopian Roads Authority namely; Woito – Turmi form Turmi section, Agbe – Sekota from Maychew section and Metu – Alge from Metu section.

Woito – Turmi: the proposed project road connects Woito and Turmi towns which are locatedin the southern part of Ethiopia under the administration of Southern Nations, Nationalities & People's Region (SNNPR).

Agbe – Sekota: the proposed project road connects Agbe and Sekotatowns which are located in the northern part of Ethiopia under the administration of two regional States viz. Tigray and Amhara.

Metu – Alge: the proposed project road connects Metu and Alge towns which are located in the south-western part of Ethiopia under the administration of Oromia.

The study has been conducted on projects with low traffic volume (100 veh/lane/day to 200 veh/lane/day) of Federal Roads of Ethiopia.

Figure: 4 Map of projects

3.2 Study Design

For the three road section a 1 km length representative road section was taken for the Life Cycle Cost Analysis of Gravel Roads and Double Otta Seal by using HDM-4 model software. The LCCA applied here includes all costs that are involved in the manufacture and use of the product during its life time; it was compared alternatives by using the Present Worth method.

3.2.1 Traffic Analysis

Traffic analysis and forecast were conducted using the applicable trend of traffic projection practices of the country as the following.

- ✓ **Traffic Projection**

The annual average daily traffic anticipated within the design period i.e. 2018 – 2032 is projected by using the following relation

AADTb= AADTo (1+r) n-- (Eq. 3.1)

Where:

AADTb= Baseline AADT (AADT2018)

AADTo= Normal AADT (AADT2015)

r = growth rate (fraction)

n = number of years elapsed from the time of counting to the period of opening of the road opened to traffic.

- ✓ **Cumulative traffic Volume**

Cumulative traffic loading of each of the motorized vehicle classes over the design life is calculated by the following equation (Eq. 3.2):

T (m) = 0.5 x 365 x AADT (x) b $[(1+i/100)^N – 1]/(i/100)$--------------------------- (Eq. 3.2)

Where

T (m) = the cumulative traffic of traffic class x

AADT (x)b = The AADT of traffic class x in the first year

N = the design period in years

i = the annual growth rate of traffic in percent

The cumulative design traffics of each class is converted to equivalent axle load by using the following Eq. 3.3.

$$CESA=0.5*365*\sum_{i=2018}^{2032} AADTi *EF \text{--} \text{(Eq. 3.3)}$$

Where:

CESA = cumulative equivalent standard axles

EF = Equivalence Factor which is taken from the consultants' feasibility studies under ERA road projects.

AADTi = Annual average daily traffic on the ith year

3.2.2 HDM-4 Software Input

Basic input data modules of HDM-4 software with values for various input parameters are described in the following sections.

- ✓ **Vehicle Fleet Details and Operating Costs**
- ✓ **Traffic Data**

According to ERA practices for vehicle classification, traffic data has been established and projected into 8 vehicles types.

- ✓ **Road Network Characteristics**
    - speed-flow pattern,
    - climatic zone,
    - Existing geometry and condition of the project road, i.e. the length, width, curvature, rise and fall, existing pavement type and thickness, roughness and the traffic levels were used as input data.

3.2.3 Life-Cycle Cost (Economic Evaluation)

For otta seal surfacing ranges from10 to 15 years is reasonable for analysis period. Therefore for this research 15 years was taken. Using the PW method and salvage value (S) at the end of analysis period is assumed to be 10%.

3.3 Study Population and sample size

The study population used in this research was the road section of three segments has been taken from Turmi Section, May-chew Section and Metu Section of Ethiopian Roads Authority.

3.4 Sampling

The sampling technique used for this research was a non-probability Sampling technique which is the purposive method. Because of these sections need frequent maintenance according to ERA maintenance history and this was proposed based on the information that the researcher have and the aim or goal of the researcher to be achieved.

3.5 Study Variables

3.5.1 Independent Variables

- Life Cycle Cost Analysis
- Vehicle Fleet Details and Operating Costs
- Traffic Data
- Design life
- Existing road condition data
- Economic and traffic growth forecasts

3.5.2 Dependent Variables

- Thin Bituminous Surfacing as an alternative Surfacing type for low volume Gravel Roads

3.6 Data Collection

All traffic and design data were collected from ERA's historic data from annual inventories. The researcher took initial traffic data (AADT) from those inventories for each specific road segment. All unit costs for material were taken from current market values during the time of data collection, July, 2016.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Appropriate Surfacing Type for Low Volume Gravel Roads

The road sections for the evaluation have been identified, on the basis of traffic, and are summarized in Table 9 below which indicates that 1km ideal section is chosen from each road. Each has its own uniform traffic data (homogeneous section).

Table 9: rural roads taken from ERA Roads (representative homogeneous sections)

Description	Length(Km)	Carriage Way width	No of Lanes	Shoulder Width	IRI (m/km)	AADT 2015
Woito-Turmi	1	7m	2	0	25	93
Agbe-Sekota	1	7m	2	0	20	177
Metu-Alge	1	7m	2	0	23	197

Source: Budget Report of ERA Road Maintenance, 2008 E.C.

The construction period for each representative road section is set to be one year (start of 2017 – end of 2017) and the analysis period is 15 years (2018 – 2032) with the discount rate of 10.23% as shown in Table 10.

Table 10: Summary of Assumed time horizon and Discount rate

Construction period	1year (start of 2017- end of 2017)
Analysis period 15 years	(start of 2018- end of 2032)
Discount rate	10.23% (annually)

4.1.1 Traffic Projection Based on Historic Data

The future traffic demand was estimated based on the secondary data of Average Annual Traffic Growth rate.

Table 11: Average Annual Traffic Growth for Medium Scenario

Vehicle	Type Period in years	Growth rate (%)
Passenger vehicles (Car,4WD, Buses)	2018 – 2025	6.5
	2026 – 2032	5.9
Freight vehicles (ST, MT, HT,TT)	2018 – 2025	6.12
	2026 – 2032	5.50

4.1.1.1 Base line Traffic

The construction of the road was completed and opened for traffic by the year 2018; the baseline traffic was taken as the projected traffic volume of 2018. Thus, the baseline traffic volumes on each road were computed bellow from ERA's historic traffic data and presented in the Tables (from Table 19 to Table 21) below.

Table 12: Baseline traffic on Woito-turmi

	Car	LR	MB	LB	ST	MT	HT	TT	Total
AADT2015	2	32	2	2	20	12	10	13	93
AADT2018	2	39	2	2	25	14	12	16	112

Table 13: Baseline traffic on Agbe-Sekota

	Car	LR	MB	LB	ST	MT	HT	TT	Total
AADT2015	0	29	38	1	36	34	24	15	177
AADT2018	0	35	46	1	46	41	29	18	215

Table 14: Baseline traffic on Metu - Alge

	Car	LR	MB	LB	ST	MT	HT	TT	Total
AADT2015	0	26	54	2	31	50	33	1	197
AADT2018	0	31	65	2	37	60	39	1	235

4.1.1.2 Cumulative traffic Volume

The projected AADTs over the design period were presented in the Tables in Appendix B. But the cumulative designs traffics of each class and computed with equivalent axle load factor are shown in Table 22 and Table 23. The equivalent factor in Table 22 was taken from the consultants' feasibility studies under ERA road projects.

Table 15: Cumulative Traffic each road (10^6) with 10% generated traffic

Route Name	Car	LR	MB	LB	ST	MT	HT	TT	Total
Woito-Turmi	0.01	0.19	0.01	0.01	0.12	0.07	0.06	0.08	0.550
Agbe-Sekota	0	0.17	0.22	0.01	0.21	0.19	0.13	0.08	1.01
Metu-Alge	0	0.15	0.31	0.01	0.17	0.28	0.18	0.01	1.11
EF	0.001	0.01	0.07	0.77	0.12	0.96	4.5	8.5	

The total cumulative traffic volume of the three road section were 0.550, 1.01 and 1.11which was used for the next step as input data.

Table 16: Cumulative equivalent standard axles on the design lane of each road

Route Name	Car	LR	MB	LB	ST	MT	HT	TT	Total
Woito-Turmi	--	--	0.00	0.01	0.01	0.07	0.27	0.68	1.04
Agbe-Sekota	--	--	0.02	0.00	0.03	0.18	0.60	0.71	1.45
Metu-Alge	--	--	0.02	0.01	0.02	0.27	0.81	0.09	1.22

From this table the Cumulative equivalent standard axles on the design lane were 1.04, 1.45 and 1.22 for Woito-Turmi, Agbe-Sekota and Metu-Alge respectively. This was used for identification of their traffic class.

4.1.2 Traffic Classes for Flexible Pavement Design

From cumulative equivalent standard axles calculated above we had the following traffic classes for flexible pavement design.

Table 17: Traffic classes for Flexible Pavement Design

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

Depending on the traffic analysis results shown above, in table 16 the Cumulative equivalent standard axles on the design lane of the road section lies on traffic class of $0.7*10^6(T_2)$ and $1.5*10^6(T_3)$.This indicates that the traffic volume for the traffic class of T2 and T3 were categorized under low traffic, therefore for gravel road double otta seal surfacing was appropriate for the selected road sections and the existing road conditions were adequate to seal with double otta seal.

4.1.3 Otta Seal Design

Depending on the above traffic classes and from different countries practice was recommend to used Otta Seal thickness of 10 mm as Base Coarse before applying otta seal, 19 mm thickness for first lay er and 16 mm for second layer. The results are shown in table below.

Table 18: Pavement Layer Thicknesses

Layer	Otta seal Pavement Thickness (mm)
2nd coat Otta seal	16mm
1st coat Otta seal	19mm
Base Coarse	100mm

4.2 HDM-4 Model software Input

Basic input data modules of HDM-4 with values for various input parameters were described in the following sections.

4.2.1 Vehicle Fleet Details and Operating Costs

All the input data of Vehicle Fleets were attached as Appendix A.

4.2.2 Traffic Data

The traffic volume and its composition in terms AADT by vehicle type and annual traffic growth rates were key inputs for economic analysis. The derivation of base year AADTs (2015) and traffic growth rates have been discussed earlier. Following ERA practices for vehicle classification, traffic data has been established and projected into 8 vehicles types.

4.2.3 Road Network Characteristics

The input data for the Model were obtained from site investigation and project surveys. The economic evaluation exercise has been done for the selected route during the route selection procedure. The input data of the road characteristics were attached as Appendix C for all selected road projects.

4.3 Life-Cycle Cost (Economic Evaluation)

4.3.1 Costs of Initial Construction

Initial costs of otta seal were determined using the following material price.

Table 19: Materials Price for Cost Analysis (June 2016)

Unit price includes transport costs up to site			
Item	**Material Description**	**Unit**	**Unit Price (ETB)**
1	Aggregate (natural well graded)	m3	251.00
2	Bitumen grade 150/200(NOC)	Lts.	45
3	Kerosene/paraffin(NOC)	Lts.	14.20
4	Prime Coat	Lts.	40

For Otta Seal Construction by applying 10mm base layer on existing road surface, we can calculate initial costs of otta seal. The other thicknesses are the same for both gravel road and otta seal and not necessary to calculate for cost comparison,(i.e both have the same sub-grade and sub-base thickness). As we discussed above the aim of this work is to seal gravel roads with Otta Seal on the existing road condition. Therefore the initial costs for both gravel roads and otta seal are the same up to sub-base.

By considering the above component (unit rates and cost breakdown) inputs, initial costs of otta seal are computed. All construction costs of otta seal and maintenance cost for both are calculated by HDM-4 software .Table below shows the computed results.

Table 20: Initial Pavement cost of Otta seal

Description	**Surface Type**	**Amount**	**Unit**	**Quantity /km**	**Unit rate**	**Cost(ETB)**
Binder	2nd coat Otta seal MC 3000	1.6	Lt	11200	45	504,000.00
	1st coat Otta seal MC 3000	2.0	Lt	14000	45	630,000.00
Prime Coat	MC 30	1.1	Lt	7700	40	308,000.00
Aggregate	Screened Natural (well graded)2ndotta seal	0.019	m^3	147	251	36,897.00
	Screened Natural (well graded)1stotta seal	0.019	m^3	147	251	36,897.00
Base course	Screened Natural Gravel	0.10	m^3	700	225	157,500.00
Total Initial cost per km For Otta Seal Surfacing						**1,673,294.00**

4.3.2 Maintenance Type and costs

Details of the latest unit costs of gravel roads and double otta seal road maintenance operations in Ethiopia as relevant to the current project are given in table 28 below. It is concluded from the countries considerable experience of road maintenance and improvement projects in Ethiopia cross-referenced with recent relevant consultants studies. The recommended types of maintenance for each section varying slightly depending upon the types of surfacing.

Table 21: Maintenance Schedules & Estimated costs for Gravel Road

Maintenance Operation		Economic (ETB)	Financial (ETB)	Unit	Intervention Criteria	Effect
GWC	**Routine Maintenance**					
	Light Grading	1953.3	2441.62	Km/year	Every year	IRI=12
	Ditch clearing, tree cutting, etc	5860.65	7325.81	Km/year	Every year	
	Recurrent Maintenance					
	Spot Re – gravelling (with Selected Material)	146.64	183.30	Per m^3	≤ 50 mm thickness	IRI=12
	Periodic Maintenance					
	Re-gravelling	201.16	251.45	Per m^3	Every 4 years	IRI=10

Source: ERA and Consultants Estimate

Table 22: Maintenance Schedules &Estimated costs for Double Otta Seal

Maintenance Operation		Economic (ETB)	Financial (ETB)	Unit	Intervention Criteria	Effect
Otta Seal	**Routine Maintenance**					
	Ditch clearing, tree cutting, etc	5860.65	7325.81	Km/year	Every year	
	Recurrent Maintenance					

Maintenance Operation		**Economic (ETB)**	**Financial (ETB)**	**Unit**	**Intervention Criteria**	**Effect**
	Pothole Patching	67	84	Per m^2	≥10 No/Km	100% potholes removed
	Crack Sealing	67	84	Per m^2	≥20% per Km	100% potholes removed
	Periodic Maintenance					
	Re-surfacing	62.5	78	Per m^2	Every 9 years	IRI=5

Source: ERA and Consultants Estimate

On the above tables we used Economic and Financial cost. The market prices used as inputs for project road improvement costing reflect the prices in financial terms, whereas economic costs represent the true cost of resource consumption of those inputs. For the purpose of economic analysis, the financial costs have been converted into the economic costs using standard conversion factors. For example, taxes paid on goods and services are costs to the domestic consumers. However, from the national economic view point, taxes are transfer payments from the consumers to the government and not economic costs.

The Ministry of Finance and Economic Development *(*MoFED*)* have established a set of conversion factors to convert the market prices into the economic costs for Ethiopian projects. This conversion factor has been used in the economic evaluation for the project road. The financial costs are shown excluding VAT components and converted to economic costs using a conversion factor of 0.8 obtained from a document issued by MoFED 'National Economic Parameters and Conversion Factors for Ethiopia.

4.3.3 Life Cycle costs Analysis for both Alternatives

The output of the HDM-4 software result for the selected road sections were shown below.

4.3.3.1 The output of Agbe – Sekota Road Section.

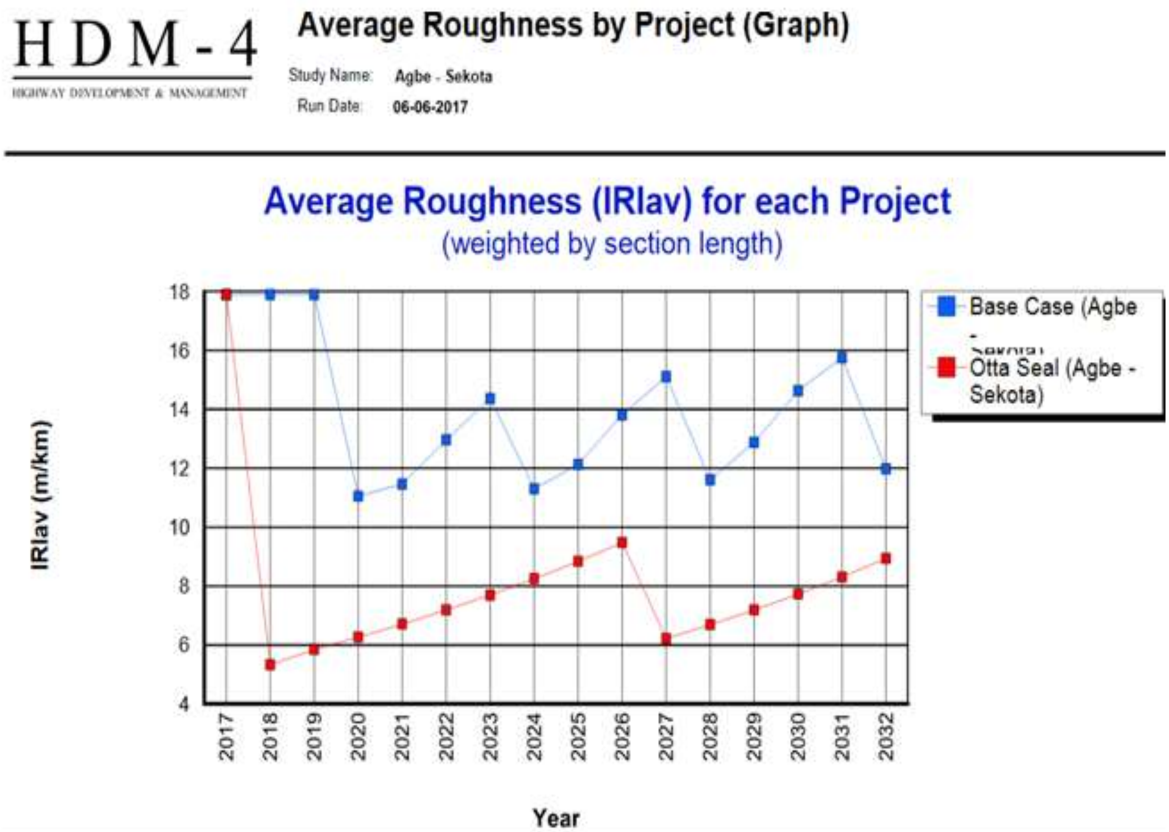

Figure 5: Average Roughness for each projects of Agbe - Sekota

From the above graph the roughness of the road section shows that as the gravel road sealed with otta seal immediately the average roughness was dropped from 18 to 5 IRIav.

Road User Cost of Agbe – Sekota Road Section

The Road User Costs of the Project for Gravel Road and for Double Otta Seal Were 17,405,000.00 birr and13, 566,000.00 birr respectively. Therefore Raod User Cost of Gravel Road was greater than that of Double Otta Seal. The detailed were presented in Appendix D.

Table 23: Life Cycle Costs of Gravel Road for Agbe - Sekota

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Agbe - Sekota**
Run Date: **25-06-2017**
Currency: **Ethiopian Birr (millions)**

Alternative: Base Case (Agbe - Sekota)
Section: Agbe - Sekota Road Project **Road Class:** Secondary or main
Surface Class: Unsealed
Length: 1.00 km **Width:** 7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	1.458	0.064	0.000	1.522
2018	0.000	0.000	0.000	1.559	0.069	0.000	1.628
2019	0.160	0.019	0.000	1.667	0.074	0.000	1.920
2020	0.000	0.008	0.000	1.445	0.055	0.000	1.508
2021	0.000	0.008	0.000	1.565	0.060	0.000	1.632
2022	0.000	0.008	0.000	1.752	0.069	0.000	1.829
2023	0.126	0.019	0.000	1.957	0.080	0.000	2.182
2024	0.000	0.008	0.000	1.904	0.073	0.000	1.985
2025	0.000	0.008	0.000	2.088	0.081	0.000	2.177
2026	0.000	0.008	0.000	2.352	0.095	0.000	2.455
2027	0.135	0.019	0.000	2.618	0.110	0.000	2.882
2028	0.000	0.008	0.000	2.512	0.097	0.000	2.617
2029	0.000	0.008	0.000	2.793	0.111	0.000	2.912
2030	0.000	0.008	0.000	3.154	0.131	0.000	3.293
2031	0.147	0.019	0.000	3.491	0.150	0.000	3.807
2032	0.000	0.008	0.000	3.322	0.130	0.000	3.460
Total cost for the section:	0.567	0.155	0.000	35.638	1.450	0.000	37.810

Table 23, Above shows that the total cost of gravel road of Agbe- Sekota road section for 1 km and at the end of their analysis period the cost per km would be 37,810,000.00 birr.

Table 24: Life Cycle Costs of Double Otta Seal for Agbe - Sekota

HDM-4 Cost Streams by Road Section

Alternative:	Otta Seal (Agbe - Sekota)		
Section:	Agbe - Sekota Road Project	Road Class:	Secondary or main
Surface Class:	Unsealed		
Length:	1.00 km	Width:	7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.339	0.000	0.000	1.458	0.064	0.000	2.861
2018	0.000	0.003	0.000	0.908	0.029	0.000	0.941
2019	0.000	0.003	0.000	1.085	0.035	0.000	1.123
2020	0.000	0.003	0.000	1.174	0.038	0.000	1.215
2021	0.000	0.003	0.000	1.271	0.041	0.000	1.316
2022	0.000	0.003	0.000	1.378	0.045	0.000	1.427
2023	0.000	0.003	0.000	1.494	0.050	0.000	1.548
2024	0.000	0.003	0.000	1.622	0.056	0.000	1.682
2025	0.000	0.003	0.000	1.767	0.063	0.000	1.833
2026	0.438	0.003	0.000	1.928	0.071	0.000	2.440
2027	0.000	0.003	0.000	1.874	0.061	0.000	1.939
2028	0.000	0.003	0.000	2.031	0.067	0.000	2.101
2029	0.000	0.003	0.000	2.202	0.074	0.000	2.279
2030	0.000	0.003	0.000	2.390	0.082	0.000	2.475
2031	0.000	0.003	0.000	2.598	0.091	0.000	2.693
2032	-0.134	0.003	0.000	2.833	0.103	0.000	2.806
Total cost for the section:	1.642	0.050	0.000	28.013	0.972	0.000	30.678

From table 23 and table24: The total cost of gravel road and otta seal of Agbe – Sekota road section for 1 km and at the end of their analysis period the cost per km would be 37,810,000.00 birr and 30,678, 000.00 respectively. Therefore the total cost of the gravel road is greater than the total cost of double otta seal surfacing.

Table 25: Economic feasibility of Double Otta Seal Vs Gravel Road

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Agbe - Sekota**
Run Date: **26-06-2017**

Alternative: Otta Seal (Agbe - Sekota) vs Alternative: Base Case (Agbe - Sekota)

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	1.08	-0.10	0.00	10.42	0.58	0.00	0.00	0.00	10.03
Discounted	1.20	-0.05	0.00	4.80	0.27	0.00	0.00	0.00	3.92

Economic Internal Rate of Return (EIRR) = 49.9% (No. of solutions = 1)

The minimum requirement of a project in terms of economic viability is to produce a positive NPV and an EIRR greater than the discount rate. From the table 26 above the net benefit of double otta seal was 3,920,000.00 birr, which is a positive net present value (NPV). Therefore the double –otta seal was satisfied the minimum requirement of NPV. And the discount rate used for the determination of future cost analysis was 10.23% as per recommendation of MoFED but in this case find out that EIRRav value of 49.9% which was greater than the discount rate, therefore it would be feasible to be used double otta seal surfacing rather than gravel road.

4.3.3.2 The output of Metu–Alge Road Section.

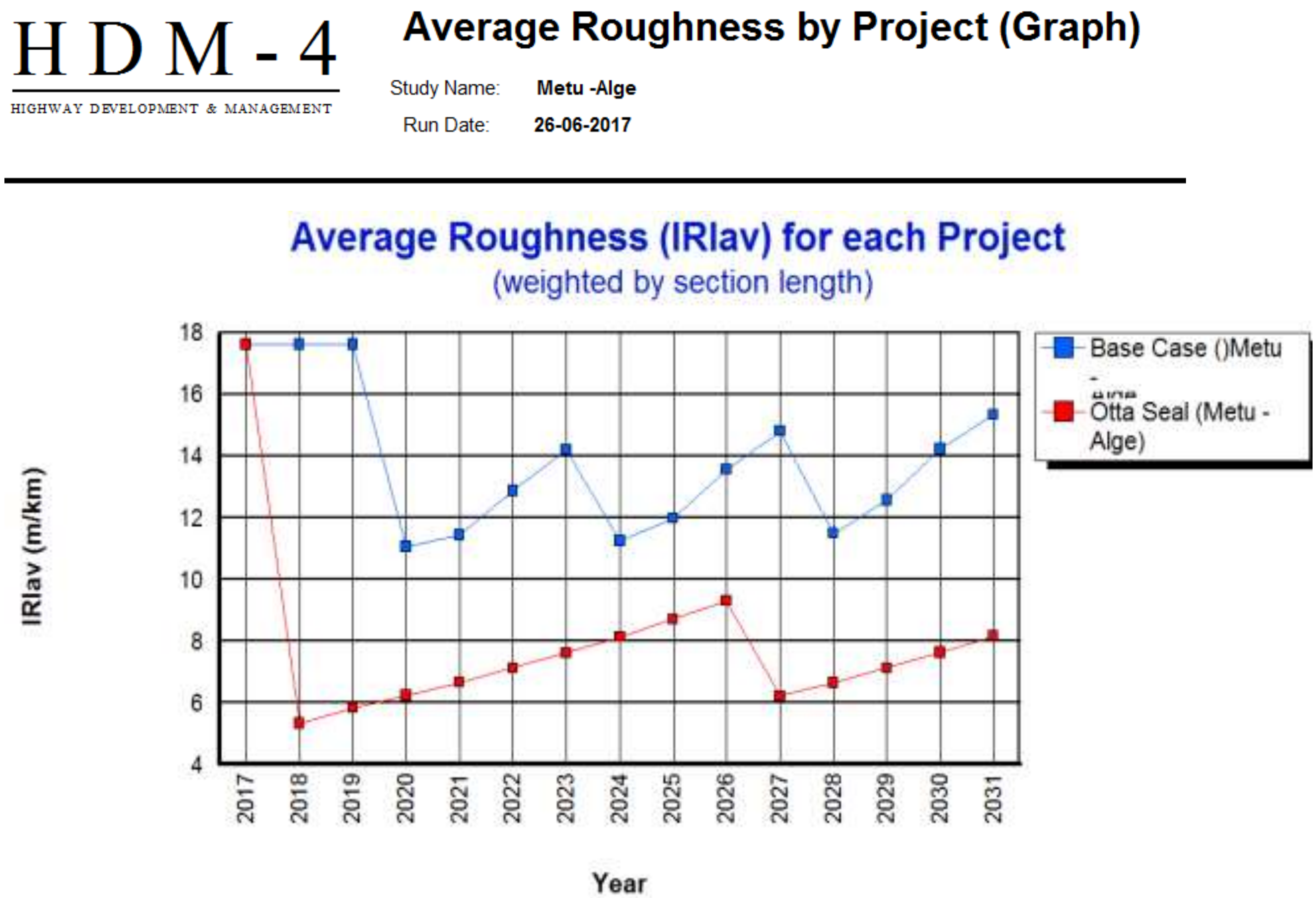

Figure 6: Average Roughness for each projectof Metu–AlgeRoad Section

From the above graph the roughness of the road section shows that as the gravel road sealed with otta seal immediately the average roughness was drops from 17.5 to 5 IRIav.

Road User Cost of Metu–Alge Road Section

The Road User Costsof the Project for Gravel Road and for Double Otta Seal Were 15,512,000.00 birr and 12, 047,000.00 birr respectively. Therefore Raod User Cost of Gravel Road was greater than that of Double Otta Seal. The detailed were presented in Appendix D.

Table 26: Life Cycle Costs of Gravel Road of Metu- Alge

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Metu -Alge**
Run Date: **26-06-2017**
Currency: **Ethiopian Birr (millions)**

Alternative:	**Base Case ()Metu - Alge**		
Section:	**Metu - Alge Road Project**	**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**		
Length:	**1.00 km**	**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	1.448	0.084	0.000	1.532
2018	0.000	0.000	0.000	1.529	0.089	0.000	1.618
2019	0.198	0.019	0.000	1.615	0.094	0.000	1.927
2020	0.000	0.008	0.000	1.398	0.070	0.000	1.476
2021	0.000	0.008	0.000	1.493	0.076	0.000	1.576
2022	0.000	0.008	0.000	1.647	0.086	0.000	1.740
2023	0.129	0.019	0.000	1.812	0.098	0.000	2.058
2024	0.000	0.008	0.000	1.749	0.089	0.000	1.846
2025	0.000	0.008	0.000	1.888	0.097	0.000	1.993
2026	0.000	0.008	0.000	2.092	0.112	0.000	2.212
2027	0.137	0.019	0.000	2.296	0.127	0.000	2.579
2028	0.000	0.008	0.000	2.191	0.113	0.000	2.312
2029	0.000	0.008	0.000	2.391	0.126	0.000	2.524
2030	0.000	0.008	0.000	2.657	0.146	0.000	2.810
2031	0.146	0.019	0.000	2.903	0.164	0.000	3.233
Total cost for the section:	0.610	0.147	0.000	29.106	1.571	0.000	31.435

Table 26: Above shows that the total cost of gravel road of Metu- Alge road section for 1 km and at the end of their analysis period the cost per km would be 31,435,000.00 birr.

Table 27: Life Cycle Costs of Double Otta Seal of Metu - Alge

HDM-4 Cost Streams by Road Section

Alternative:	**Otta Seal (Metu - Alge)**		
Section:	**Metu - Alge Road Project**	**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**		
Length:	**1.00 km**	**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.339	0.000	0.000	1.448	0.084	0.000	2.871
2018	0.000	0.006	0.000	0.899	0.039	0.000	0.944
2019	0.000	0.006	0.000	1.060	0.045	0.000	1.111
2020	0.000	0.006	0.000	1.132	0.049	0.000	1.186
2021	0.000	0.006	0.000	1.209	0.052	0.000	1.267
2022	0.000	0.006	0.000	1.293	0.057	0.000	1.355
2023	0.000	0.006	0.000	1.384	0.062	0.000	1.452
2024	0.000	0.006	0.000	1.485	0.068	0.000	1.558
2025	0.000	0.006	0.000	1.594	0.075	0.000	1.676
2026	0.438	0.006	0.000	1.716	0.084	0.000	2.243
2027	0.000	0.006	0.000	1.658	0.073	0.000	1.736
2028	0.000	0.006	0.000	1.771	0.078	0.000	1.855
2029	0.000	0.006	0.000	1.894	0.085	0.000	1.985
2030	0.000	0.006	0.000	2.030	0.092	0.000	2.128
2031	-0.134	0.006	0.000	2.178	0.102	0.000	2.152
Total cost for the section:	1.642	0.082	0.000	22.751	1.045	0.000	25.520

From table 26 and table27: The total cost of gravel road and otta seal of Metu - Algeroad section for 1 km and at the end of their analysis period the cost per km would be 31,435,000.00 birr and 25, 520, 000.00 birr respectively. Therefore the total cost of the gravel road is greater than the total cost of double otta seal surfacing.

Table 28: Economic feasibility of Otta Seal Vs Gravel Road

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Metu -Alge**

Run Date: **26-06-2017**

Alternative: Otta Seal (Metu - Alge) vs Alternative: Base Case ()Metu - Alge

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	1.03	-0.07	0.00	8.59	0.64	0.00	0.00	0.00	8.26
Discounted	1.16	-0.03	0.00	4.22	0.32	0.00	0.00	0.00	3.40

Economic Internal Rate of Return (EIRR) = 48.9% (No. of solutions = 1)

The minimum requirement of a project in terms of economic viability is to produce a positive NPV and an EIRR greater than the discount rate. From the table 26 above the net benefit of double otta seal was 3,400,000.00 birr, which is a positive net present value (NPV). Therefore the double –otta seal was satisfied the minimum requirement of NPV. And the discount rate used for the determination of future cost analysis was 10.23% as per recommendation of MoFED but in this case find out that EIRR a value of 48.9% which was greater than the discount rate, therefore it would be feasible to be used double otta seal surfacing rather than gravel road.

4.3.3.3 The output of Woito - Turmi Road Section.

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Average Roughness by Project (Graph)

Study Name: **Woito - Turmi**
Run Date: **26-06-2017**

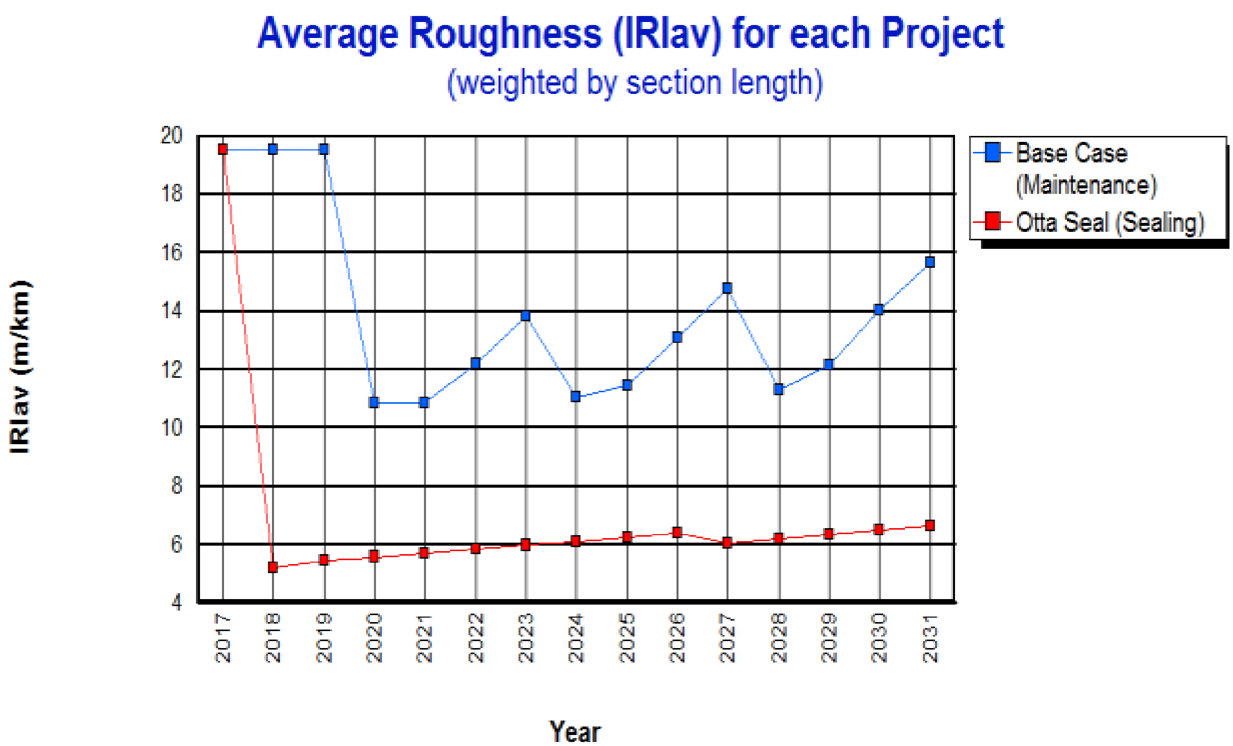

Figure 7: Average Roughness for each projectof Woito - Turmi

From the above graph the roughness of the road section shows that as the gravel road sealed with otta seal immediately the average roughness was drops from 19.5 to 5 IRIav.

Road User Cost of Woito - TurmiRoad Section

The Road User Costs of the Project for Gravel Road and for Double Otta Seal Were 9,231,000.00 birr and 6, 797,000.00 birr respectively. Therefore Raod User Cost of Gravel Road was greater than that of Double Otta Seal. The detailed were presented in Appendix D.

Table 29: Life Cycle Costs of Gravel Road of Woito - Turmi

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: Woito - Turmi
Run Date: 26-06-2017
Currency: Ethiopian Birr (millions)

Alternative:	Base Case (Maintenance)		
Section:	Woito - Turmi Road Project	Road Class:	Secondary or main
Surface Class:	Unsealed		
Length:	1.00 km	Width:	7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	0.852	0.021	0.000	0.873
2018	0.000	0.000	0.000	0.911	0.023	0.000	0.934
2019	0.352	0.019	0.000	0.974	0.024	0.000	1.370
2020	0.000	0.008	0.000	0.820	0.016	0.000	0.844
2021	0.000	0.008	0.000	0.877	0.017	0.000	0.902
2022	0.000	0.008	0.000	0.974	0.020	0.000	1.002
2023	0.129	0.019	0.000	1.090	0.023	0.000	1.262
2024	0.000	0.008	0.000	1.077	0.021	0.000	1.107
2025	0.000	0.008	0.000	1.166	0.023	0.000	1.197
2026	0.000	0.008	0.000	1.306	0.027	0.000	1.341
2027	0.142	0.019	0.000	1.464	0.032	0.000	1.658
2028	0.000	0.008	0.000	1.418	0.028	0.000	1.454
2029	0.000	0.008	0.000	1.554	0.032	0.000	1.594
2030	0.000	0.008	0.000	1.753	0.038	0.000	1.799
2031	0.160	0.019	0.000	1.963	0.045	0.000	2.187
Total cost for the section:	0.783	0.147	0.000	18.200	0.392	0.000	19.522

Table 29: Above shows that the total cost of gravel road of Woito- Turmi road section for 1 km and at the end of their analysis period the cost per km would be 19,522,000.00 birr.

Table 30: Life Cycle Costs of Double Otta Seal of Woito - Turmi

HDM-4 Cost Streams by Road Section

Alternative:	Otta Seal (Sealing)		
Section:	Woito - Turmi Road Project	Road Class:	Secondary or main
Surface Class:	Unsealed		
Length:	1.00 km	Width:	7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.339	0.000	0.000	0.852	0.021	0.000	2.212
2018	0.000	0.006	0.000	0.496	0.009	0.000	0.510
2019	0.000	0.006	0.000	0.587	0.010	0.000	0.603
2020	0.000	0.006	0.000	0.631	0.011	0.000	0.647
2021	0.000	0.006	0.000	0.677	0.012	0.000	0.695
2022	0.000	0.006	0.000	0.727	0.013	0.000	0.746
2023	0.000	0.006	0.000	0.781	0.014	0.000	0.800
2024	0.000	0.006	0.000	0.839	0.015	0.000	0.859
2025	0.000	0.006	0.000	0.901	0.016	0.000	0.923
2026	0.438	0.006	0.000	0.969	0.017	0.000	1.429
2027	0.000	0.006	0.000	1.024	0.018	0.000	1.048
2028	0.000	0.006	0.000	1.100	0.019	0.000	1.125
2029	0.000	0.006	0.000	1.181	0.021	0.000	1.208
2030	0.000	0.006	0.000	1.269	0.022	0.000	1.297
2031	-0.134	0.006	0.000	1.364	0.024	0.000	1.260
Total cost for the section:	1.642	0.082	0.000	13.398	0.240	0.000	15.362

From table 29 and table 30: The total cost of gravel road and otta seal of Woito – Turmi road section for 1 km and at the end of their analysis period the cost per km would be 19,522,000.00 birr and 15, 362, 000.00 birr respectively. Therefore the total cost of the gravel road is greater than the total cost of double otta seal surfacing.

Table 31: Economic feasibility of Otta Seal Vs Gravel Road

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Woito - Turmi**
Run Date: **26-06-2017**

Alternative: Otta Seal (Sealing) vs Alternative: Base Case (Maintenance)

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	0.86	-0.07	0.00	6.17	0.18	0.00	0.00	0.00	5.56
Discounted	1.03	-0.03	0.00	2.97	0.09	0.00	0.00	0.00	2.06

Economic Internal Rate of Return (EIRR) = 34.2% (No. of solutions = 1)

The minimum requirement of a project in terms of economic viability is to produce a positive NPV and an EIRR greater than the discount rate. From the table 26 above the net benefit of double otta seal was 2,060,000.00 birr, which is a positive net present value (NPV). Therefore the double –otta seal was satisfied the minimum requirement of NPV. And the discount rate used for the determination of future cost analysis was 10.23% as per recommendation of MoFED but in this case find out that EIRR a value of 34.2% which was greater than the discount rate, therefore it would be feasible to be used double otta seal surfacing rather than gravel road.

4.4 Sensitivity Analysis

Sensitivity analysis has been tested by changing the main inputs of the projects i.e cost and benefit. In this case there were three scenarios to examine the effects on the project's main cost component indicators. The effects of changes of add or subtract 25%, 40% and 45% in the main input values are considered in this study. The detailed were presented in Appendix E.

Table 32: Sensitivity Analysis for the selected road section by adding or subtracting 25%

Road section	Sensitivity test	NPV/ M Birr	EIRR	Cost /M Birr	
				GWC	OS
Woito–Turmi	Case 1, AADT decreased by 25%	1.18	25.1%	14.62	11.98
	Case 2, Initial cost increased by 25%	1.73	26.6%	19.52	15.66
	Case 3, Initial cost increased by 25% and benefit was decreased by 25%)	0.85	19.0%	14.62	12.28
Agbe–Sekota	Case 1, AADT decreased by 25%	2.46	36.5%	28.07	23.43
	Case 2, Initial cost increased by 25%	3.57	39.3%	37.81	31.12
	Case 3, Initial cost increased by 25% and benefit was decreased by 25%)	2.11	28.5%	28.1	23.77
Metu–Alge	Case 1, AADT decreased by 25%	2.01	34.6%	22.87	19.21
	Case 2, Initial cost increased by 25%	3.01	37.7%	31.27	25.79
	Case 3, Initial cost increased by 25% and benefit was decreased by 25%)	1.62	26.1%	22.72	19.48

Therefore, for all scenarios considered for sensitivity test of double otta seal was feasible which means still the EIRR and NPVwere positive.

Table 33: Sensitivity Analysis for the selected road section by adding or subtracting 40%

Road section	Sensitivity test	NPV/ M Birr	EIRR	Cost /M Birr	
				GWC	**OS**
Woito–Turmi	Case 1, AADT decreased by 40%	0.67	19.3%	11.70	9.93
	Case 2, Initial cost increased by 40%	1.73	26.6%	19.52	15.66
	Case 3, Initial cost increased by 40% and benefit was decreased by 40%)	0.35	14.0%	11.70	10.23
Agbe–Sekota	Case 1, AADT decreased by 40%	1.59	28.2%	22.18	18.99
	Case 2, Initial cost increased by 40%	1.57	29.5%	27.81	21.12
	Case 3, Initial cost increased by 40% and benefit was decreased by 40%)	1.25	21.6%	22.18	19.33
Metu–Alge	Case 1, AADT decreased by 40%	1.12	23%	1427	10.8
	Case 2, Initial cost increased by 40%	1.05	27.7%	21.27	25.79
	Case 3, Initial cost increased by 40% and benefit was decreased by 40%)	0.74	17%	18.35	16.4

In this case also for all scenarios considered for sensitivity test of double otta seal was feasible which means still the EIRR and NPV were positive. But at 50% of the sensitivity test double otta seal was not feasible for the selected road section.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

There were many gravel road sections in our country which needs maintenance according to the researcher's observation and secondary data from ERA maintenance history. Based on ERA data the three road section were needs repeatedly maintenance, these road sections were Woito–Turmi, Agbe–Sekota and Metu–Alge section.

There are different types of thin bituminous surfacing. The double otta seal is a type of bituminous surface treatment that can provide a practical and economic alternative to the other type of seals and it was more preferable than the other types of thin bituminous surfacing because of:-

- An ability to tolerate the use of relatively inferior aggregates, such as screened gravel, rather than crushed rock, without impairment of the performance of the surfacing.
- It used locally available materials that have all size aggregate from finer to coarser.
- Needs un-skilled man power

Double otta seal as an alternative surfacing type over low volume gravel roads in ERA by making life cycle cost comparison and economic analysis were studied in this research and found the following conclusions;

- Double Otta seal is the main example of a well-graded aggregate seal constructed by spray and spread. It can be constructed using normal labour-based practices. It was primarily of merit because of its efficient material usage and construction method.
- The traffic class of the selected road section lied between T2 and T3 this indicates that double otta seal was appropriate surfacing type for the selected road sections.
- The life cycle cost of the double otta seal of the three selected road section of metu- alge, Agbe - Sekota and Woito – Turmifor the analysis period per km was 25,520,000.00 birr/km, 30,678,000.00 birr/kmand 15,362,000.00 birr/km respectively. Whereasthe gravel road of the three road section was 31,435,000.00 birr/km, 37,810,000.00 birr/km

and 19,522,000.00 birr/km respectively. Therefore the double otta seal was more feasible than the gravel road.

- The user cost of double otta seal of the three selected road section were 12,047,000.00 birr,13,566,000.00 birr and 6,797,000.00 birr respectively as above. Whereas for the gravel roads, 15,512,000.00 birr, 17,405,000.00 and 9,23,000.00 respectively. Therefore double otta seal was cost effective than the gravel road.
- The selected three projects in terms of economic viability (NPV) were 3,400,000.00 birr, 3,920,000.00 birr and 2,060,000.00 respectively. the NPV is positive which means the project is satisfied the minimum requirement and feasible.
- The values of EIRR found out for the selected project was greater than the discount rate recommended by MoFED and it was possible to be used the double otta seal.
- The Roughness of double otta seal of the three road section was better than gravel roads.
- The cost and benefit of the road section was tested by sensitivity analysis for three scenarios and the double otta seal was satisfied feasible.
- From the results of the study it was found that the double otta seal was more economical and feasible surfacing type than gravel road surfacing due to its improved long life, used locally available material and recyclability lead reduce demand on non-renewable resources.

5.2 RECOMMENDATION

Based on the research outcomes; the following recommendations are included to be considered by beneficiaries' of this research.

- ✓ It is recommended that ERA should use double otta seal rather than to be used gravel roads.
- ✓ Implementing Authorities should consider to use of the Otta seal as an alternative surfacing rather than continuous gravelling/re-gravelling.
- ✓ The Research should be extended to other road section /towns those not covered in the study.

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APPENDIX–A Summary of Vehicle Fleet Characteristic and Costs from Consultants Estimates Based on VOT Computed

Characteristics	**Vehicle Fleet Type**							
	Car	**4WD**	**S/Bus**	**L/Bus**	**S. Truck**	**M. Truck**	**H. Truck**	**T & T**
Physical Characteristics								
Operating Weight (ton)	1.1	2.3	2.2	12	5.1	13	22	35
Axle per vehicle (No)	2	2	2	2	2	2	3	5
Tires per vehicles (No)	4	4	4	6	4	6	10	18
Tire Type	Radial	Radial	Radial	Radial	Radial	Radial	Radial	Radial
Passenger occupancy (no)	3	3	28	50	-	-	-	-
PCSE	1.0	1.0	1.4	1.6	1.4	1.6	1.8	2.2
ESAL (ton)			0.35	0.75	0.2	1.98	4.75	7.5
Utilization								
Annual Run (km)	20,000	30,000	40,000	60,000	30,000	60,000	60,000	86,000
Annual Hours	600	1300	1200	2000	1200	1500	1500	2050
Average service life (yrs)	13	13	15	15	10	15	15	15
Private Use (%)	60	20	15	-	-	-	-	-
Work Related (%)	40	80	85	100	100	100	100	100
Economic Unit Cost								
New vehicle price (‘000Birr)	305.12	1,094.13	682.86	1,480.41	599.03	997.15	1,103.68	3,514.02
Tire price (Birr)	1,759	5,078	5,078	5,078	8,877	8,877	16,867	16,867

Characteristics	Vehicle Fleet Type							
	Car	**4WD**	**S/Bus**	**L/Bus**	**S. Truck**	**M. Truck**	**H. Truck**	**T & T**
Retread cost (%)	15	15	15	15	15	15	15	15
Economic Vehicle Resource Costs								
Fuel (Birr/Liter)	13.18	13.18	17.42	17.42	17.42	17.42	17.42	17.42
Lub. Oil (Birr/Liter)	66.29	66.29	66.29	66.29	66.29	66.29	66.29	66.29
Crew hour (Birr)	27.50	22.60	15.40	14.00	17.30	14.60	18.10	19.00
Maintenance labor (Birr/Hr)	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60
Passenger working time cost (Birr/Hr)	9.74	9.74	4.87	4.87	4.87	4.87	4.87	4.87
Passenger non-working time cost (Birr/Hr)	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
Cargo time value (Birr/Hr)	-	-	-	-	0.13	0.30	0.36	0.77
Annual Interest Rate (%)	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23

APPENDIX–B Traffic Data from Era and Traffic Analysis Results

Woito – Turmi									
Year	**Car**	**4WD**	**MB**	**LB**	**ST**	**MT**	**HT**	**TT**	**Total**
1018	2	39	2	2	25	14	12	16	112
2019	2	42	2	2	27	15	13	17	
2020	2	44	2	2	28	16	14	18	
2021	2	47	2	2	30	17	14	19	
2022	3	50	3	3	32	18	15	20	
2023	3	53	3	3	34	19	16	22	
2024	3	57	3	3	36	20	17	23	
2025	3	61	3	3	38	21	18	24	
2026	3	64	3	3	40	22	19	26	
2027	3	68	3	3	42	24	20	27	
2028	4	72	4	4	44	25	21	28	
2029	4	76	4	4	47	26	23	30	
2030	4	81	4	4	50	28	24	32	
2031	4	85	4	4	52	29	25	33	
2032	5	91	5	5	55	31	26	35	252
Total	48	930	48	48	579	324	278	371	
	52	1023	52	52	637	357	306	408	
EF	--	--	0.07	0.77	0.12	0.96	4.5	8.5	
10^6 ESA	--	--	0.00	0.01	0.01	0.07	0.27	0.68	1.04

Agbe- -Sekota									
Year	**Car**	**4WD**	**MB**	**LB**	**ST**	**MT**	**HT**	**TT**	**Total**
1018	0	35	46	1	46	41	29	18	215
2019	0	37	49	1	49	43	30	19	
2020	0	40	52	1	52	46	32	20	
2021	0	42	55	1	55	49	34	21	
2022	0	45	59	2	58	52	36	23	
2023	0	48	63	2	62	55	39	24	
2024	0	51	67	2	65	58	41	26	
2025	0	54	71	2	69	62	43	27	
2026	0	58	76	2	73	65	46	29	
2027	0	61	80	2	77	69	48	30	
2028	0	65	85	2	81	72	51	32	
2029	0	68	90	2	86	76	54	34	
2030	0	73	95	3	91	80	57	36	
2031	0	77	101	3	96	85	60	37	
2032	0	81	107	3	101	90	63	40	484
Total	0	835	1095	29	1060	941	664	415	
	0	919	1204	32	1166	1035	731	457	
EF	--	--	0.07	0.77	0.12	0.96	4.5	8.5	
106 ESA	--	--	0.02	0.00	0.03	0.18	0.60	0.71	1.54

Metu-Alge									
Year	**Car**	**4WD**	**MB**	**LB**	**ST**	**MT**	**HT**	**TT**	**Total**
1018	0	31	65	2	37	60	39	1	235
2019	0	33	69	3	39	63	42	1	
2020	0	36	74	3	42	67	44	1	
2021	0	38	79	3	44	71	47	1	
2022	0	40	84	3	47	76	50	2	
2023	0	43	89	3	50	80	53	2	
2024	0	46	95	4	53	85	56	2	
2025	0	49	101	4	56	91	60	2	
2026	0	52	107	4	59	96	63	2	
2027	0	55	114	4	62	101	67	2	
2028	0	58	120	4	66	106	70	2	
2029	0	61	127	5	70	112	74	2	
2030	0	65	135	5	73	118	78	2	
2031	0	69	143	5	77	125	82	2	
2032	0	73	151	6	82	132	87	3	533
Total		749	1556	58	858	1384	913	28	
		824	1711	63	944	1522	1005	30	
EF	--	--	0.07	0.77	0.12	0.96	4.5	8.5	
10^6 ESA	--	--	0.02	0.01	0.02	0.27	0.81	0.09	1.22

APPENDIX–CExistingRoadCharacteristics of the Selected Road Section from ERA Recorded data

Description	**Unit**	**GWC Woito - Turmi**	**Otta Seal Woito–Turmi**
Geometries			
Length	km	1	1
Carriageway Width	m	7	7
Rise & Fall	m/km	60.5	40.33
No. of Rise & Fall	No./km	5	3.33
Horizontal Curve	deg/km	48.85	33.8
Avg Super-elevation	%	5.78	3.83
Material Property			
Type of pavement	-	Gravel	Otta Seal
Pavement Surface Thickness	mm	50	35
Surfacing Compaction	%	97	97
International Roughness Index (IRI)	m/km	18	7
Climate	-	Tropical Sub-humid	Tropical Sub-humid

Description	**Unit**	**GWC Agbe - Sekota**	**Otta Seal Agbe - Sekota**
Geometries			
Length	km	1	1
Carriageway Width	M	7	7
Rise & Fall	m/km	60.5	40.33
No. of Rise & Fall	No./km	5	3.33
Horizontal Curve	deg/km	48.85	33.8
Avg Super-elevation	%	5.78	3.83
Material Property			
Type of pavement	-	Gravel	Otta Seal
Pavement Surface Thickness	mm	50	35
Surfacing Compaction	%	97	97
International Roughness Index (IRI)	m/km	18	7
Climate	-	Tropical Sub-humid	Tropical Sub-humid

Description	Unit	GWC Metu – Alge	Otta Seal Metu – Alge
Geometries			
Length	km	1	1
Carriageway Width	m	7	7
Rise & Fall	m/km	60.5	40.33
No. of Rise & Fall	No./km	5	3.33
Horizontal Curve	deg/km	48.85	33.8
Avg Super-elevation	%	5.78	3.83
Material Property			
Type of pavement	-	Gravel	Otta Seal
Pavement Surface Thickness	Mm	50	35
Surfacing Compaction	%	97	97
International Roughness Index (IRI)	m/km	18	7
Climate	-	Tropical Sub-humid	Tropical Sub-humid

APPENDIX–D Road User Costs of Selected Road Section

Road User Cost of Metu – Alge for Grave Road

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
1.448	0.084	0.000	0.000	1.532
1.387	0.081	0.000	0.000	1.468
1.329	0.078	0.000	0.000	1.407
1.043	0.053	0.000	0.000	1.096
1.011	0.051	0.000	0.000	1.062
1.012	0.053	0.000	0.000	1.065
1.010	0.055	0.000	0.000	1.064
0.884	0.045	0.000	0.000	0.929
0.866	0.045	0.000	0.000	0.911
0.871	0.047	0.000	0.000	0.917
0.867	0.048	0.000	0.000	0.915
0.751	0.039	0.000	0.000	0.789
0.743	0.039	0.000	0.000	0.782
0.749	0.041	0.000	0.000	0.790
0.742	0.042	0.000	0.000	0.785
14.713	0.799	0.000	0.000	15.512

Road User Cost of Metu – AlgeDoublefor Otta Seal

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
1.448	0.084	0.000	0.000	1.532
0.816	0.035	0.000	0.000	0.851
0.872	0.037	0.000	0.000	0.910
0.845	0.036	0.000	0.000	0.881
0.819	0.036	0.000	0.000	0.854
0.794	0.035	0.000	0.000	0.829
0.772	0.035	0.000	0.000	0.806
0.751	0.034	0.000	0.000	0.785
0.731	0.035	0.000	0.000	0.766
0.714	0.035	0.000	0.000	0.749
0.626	0.027	0.000	0.000	0.653
0.607	0.027	0.000	0.000	0.633
0.589	0.026	0.000	0.000	0.615
0.572	0.026	0.000	0.000	0.598
0.557	0.026	0.000	0.000	0.583
11.513	0.534	0.000	0.000	12.047

Road User Cost of Woito –Turmi for Grave Road

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
0.852	0.021	0.000	0.000	0.873
0.827	0.021	0.000	0.000	0.847
0.802	0.020	0.000	0.000	0.822
0.612	0.012	0.000	0.000	0.624
0.594	0.012	0.000	0.000	0.606
0.598	0.012	0.000	0.000	0.611
0.608	0.013	0.000	0.000	0.621
0.545	0.011	0.000	0.000	0.556
0.535	0.011	0.000	0.000	0.546
0.543	0.011	0.000	0.000	0.555
0.553	0.012	0.000	0.000	0.565
0.486	0.010	0.000	0.000	0.495
0.483	0.010	0.000	0.000	0.493
0.494	0.011	0.000	0.000	0.505
0.502	0.011	0.000	0.000	0.513
9.034	0.197	0.000	0.000	9.231

Road User Cost of Woito –Turmifor Double Otta Seal

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
0.852	0.021	0.000	0.000	0.873
0.450	0.008	0.000	0.000	0.457
0.483	0.008	0.000	0.000	0.492
0.471	0.008	0.000	0.000	0.479
0.459	0.008	0.000	0.000	0.467
0.447	0.008	0.000	0.000	0.455
0.435	0.008	0.000	0.000	0.443
0.424	0.007	0.000	0.000	0.432
0.414	0.007	0.000	0.000	0.421
0.403	0.007	0.000	0.000	0.410
0.387	0.007	0.000	0.000	0.393
0.377	0.007	0.000	0.000	0.383
0.367	0.006	0.000	0.000	0.374
0.358	0.006	0.000	0.000	0.364
0.349	0.006	0.000	0.000	0.355
6.675	0.122	0.000	0.000	6.797

Road User Cost of Agbe – Sekota for Grave Road

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
1.458	0.064	0.000	0.000	1.522
1.414	0.063	0.000	0.000	1.477
1.372	0.061	0.000	0.000	1.433
1.079	0.041	0.000	0.000	1.120
1.060	0.041	0.000	0.000	1.100
1.077	0.042	0.000	0.000	1.119
1.091	0.045	0.000	0.000	1.136
0.963	0.037	0.000	0.000	1.000
0.958	0.037	0.000	0.000	0.995
0.979	0.040	0.000	0.000	1.018
0.989	0.041	0.000	0.000	1.030
0.861	0.033	0.000	0.000	0.894
0.868	0.035	0.000	0.000	0.903
0.889	0.037	0.000	0.000	0.926
0.893	0.038	0.000	0.000	0.931
0.771	0.030	0.000	0.000	0.801
16.720	0.685	0.000	0.000	17.405

Road User Cost of Agbe –Sekotafor Double Otta Seal

Road User Costs (RUC)				
MT Vehicle Operation	MT Travel Time	NMT Travel & Operation	Accidents	Total RUC
1.458	0.064	0.000	0.000	1.522
0.824	0.027	0.000	0.000	0.850
0.893	0.029	0.000	0.000	0.922
0.877	0.028	0.000	0.000	0.905
0.861	0.028	0.000	0.000	0.889
0.847	0.028	0.000	0.000	0.875
0.833	0.028	0.000	0.000	0.861
0.820	0.028	0.000	0.000	0.849
0.810	0.029	0.000	0.000	0.839
0.803	0.030	0.000	0.000	0.832
0.708	0.023	0.000	0.000	0.731
0.696	0.023	0.000	0.000	0.718
0.684	0.023	0.000	0.000	0.707
0.674	0.023	0.000	0.000	0.697
0.664	0.023	0.000	0.000	0.688
0.657	0.024	0.000	0.000	0.681
13.108	0.458	0.000	0.000	13.566

APPENDIX–E Sensitivity analysis

Sensitivity Analysis for Metu - Alge road section,AADT decreased by 25%

Life Cycle Costs of Gravel Road of Metu- Alge with decreased AADT by 25%

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Metu -Alge**
Run Date: **26-06-2017**
Currency: **Ethiopian Birr (millions)**

Alternative:	**Base Case ()Metu - Alge**		
Section:	**Metu - Alge Road Project**	**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**		
Length:	**1.00 km**	**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	1.066	0.062	0.000	1.128
2018	0.000	0.000	0.000	1.125	0.066	0.000	1.191
2019	0.194	0.019	0.000	1.189	0.069	0.000	1.471
2020	0.000	0.008	0.000	1.022	0.051	0.000	1.081
2021	0.000	0.008	0.000	1.078	0.054	0.000	1.140
2022	0.000	0.008	0.000	1.179	0.060	0.000	1.247
2023	0.121	0.008	0.000	1.297	0.068	0.000	1.494
2024	0.000	0.008	0.000	1.277	0.065	0.000	1.350
2025	0.000	0.008	0.000	1.359	0.069	0.000	1.436
2026	0.000	0.008	0.000	1.496	0.078	0.000	1.582
2027	0.127	0.019	0.000	1.647	0.089	0.000	1.882
2028	0.000	0.008	0.000	1.597	0.082	0.000	1.687
2029	0.000	0.008	0.000	1.717	0.089	0.000	1.814
2030	0.000	0.008	0.000	1.901	0.102	0.000	2.010
2031	0.133	0.019	0.000	2.088	0.116	0.000	2.357
Total cost for the section:	0.575	0.136	0.000	21.038	1.122	0.000	22.871

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Metu -Alge**
Run Date: **26-06-2017**

Alternative: Otta Seal (Metu - Alge) vs Alternative: Base Case ()Metu - Alge

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	1.07	-0.05	0.00	5.94	0.44	0.00	0.00	0.00	5.36
Discounted	1.18	-0.02	0.00	2.94	0.22	0.00	0.00	0.00	2.01

Economic Internal Rate of Return (EIRR) = 34.6% (No. of solutions = 1)

Life Cycle Costs of Double Otta Seal of Metu- Alge Road Section with decreased AADT by 25%

HDM-4 **Cost Streams by Road Section**

Alternative:	Otta Seal (Metu - Alge)		
Section:	Metu - Alge Road Project	Road Class:	Secondary or main
Surface Class:	Unsealed		
Length:	1.00 km	Width:	7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.339	0.000	0.000	1.066	0.062	0.000	2.466
2018	0.000	0.006	0.000	0.662	0.028	0.000	0.696
2019	0.000	0.006	0.000	0.780	0.033	0.000	0.819
2020	0.000	0.006	0.000	0.833	0.036	0.000	0.874
2021	0.000	0.006	0.000	0.889	0.039	0.000	0.934
2022	0.000	0.006	0.000	0.950	0.042	0.000	0.998
2023	0.000	0.006	0.000	1.017	0.045	0.000	1.068
2024	0.000	0.006	0.000	1.090	0.050	0.000	1.146
2025	0.000	0.006	0.000	1.170	0.055	0.000	1.231
2026	0.438	0.006	0.000	1.258	0.061	0.000	1.763
2027	0.000	0.006	0.000	1.220	0.053	0.000	1.279
2028	0.000	0.006	0.000	1.303	0.057	0.000	1.366
2029	0.000	0.006	0.000	1.393	0.062	0.000	1.461
2030	0.000	0.006	0.000	1.492	0.068	0.000	1.566
2031	-0.134	0.006	0.000	1.600	0.075	0.000	1.547
Total cost for the section:	1.642	0.082	0.000	16.723	0.767	0.000	19.214

Life Cycle Costs of Gravel Road of Metu- Alge with increased of cost by 25%

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Metu -Alge**
Run Date: **26-06-2017**
Currency: **Ethiopian Birr (millions)**

Alternative:	**Base Case ()Metu - Alge**		
Section:	**Metu - Alge Road Project**	**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**		
Length:	**1.00 km**	**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	1.448	0.084	0.000	1.532
2018	0.000	0.000	0.000	1.529	0.089	0.000	1.618
2019	0.161	0.016	0.000	1.615	0.094	0.000	1.886
2020	0.000	0.004	0.000	1.398	0.070	0.000	1.472
2021	0.000	0.004	0.000	1.493	0.076	0.000	1.573
2022	0.000	0.004	0.000	1.647	0.086	0.000	1.737
2023	0.105	0.016	0.000	1.812	0.098	0.000	2.030
2024	0.000	0.004	0.000	1.749	0.089	0.000	1.842
2025	0.000	0.004	0.000	1.888	0.097	0.000	1.989
2026	0.000	0.004	0.000	2.092	0.112	0.000	2.208
2027	0.111	0.016	0.000	2.296	0.127	0.000	2.550
2028	0.000	0.004	0.000	2.191	0.113	0.000	2.308
2029	0.000	0.004	0.000	2.391	0.126	0.000	2.521
2030	0.000	0.004	0.000	2.657	0.146	0.000	2.807
2031	0.118	0.016	0.000	2.903	0.164	0.000	3.202
Total cost for the section:	0.494	0.102	0.000	29.106	1.571	0.000	31.274

Life Cycle Costs of Double Otta Seal of Metu- Alge Road Section with increased of cost by 25%

HDM-4 **Cost Streams by Road Section**

Alternative:	**Otta Seal (Metu - Alge)**		
Section:	**Metu - Alge Road Project**	**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**		
Length:	**1.00 km**	**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.673	0.000	0.000	1.448	0.084	0.000	3.205
2018	0.000	0.003	0.000	0.899	0.039	0.000	0.941
2019	0.000	0.003	0.000	1.060	0.045	0.000	1.109
2020	0.000	0.003	0.000	1.132	0.049	0.000	1.184
2021	0.000	0.003	0.000	1.209	0.052	0.000	1.265
2022	0.000	0.003	0.000	1.293	0.057	0.000	1.353
2023	0.000	0.003	0.000	1.384	0.062	0.000	1.450
2024	0.000	0.003	0.000	1.485	0.068	0.000	1.556
2025	0.000	0.003	0.000	1.594	0.075	0.000	1.673
2026	0.438	0.003	0.000	1.716	0.084	0.000	2.241
2027	0.000	0.003	0.000	1.658	0.073	0.000	1.734
2028	0.000	0.003	0.000	1.771	0.078	0.000	1.853
2029	0.000	0.003	0.000	1.894	0.085	0.000	1.982
2030	0.000	0.003	0.000	2.030	0.092	0.000	2.126
2031	-0.167	0.003	0.000	2.178	0.102	0.000	2.116
Total cost for the section:	1.943	0.047	0.000	22.751	1.045	0.000	25.786

HDM-4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Metu -Alge**

Run Date: **26-06-2017**

This report shows total economic benefits using the following:
Currency: Ethiopian Birr (millions).
Discount rate: 10.23%.
Analysis Mode: Analysis-by-Project

Alternative: Otta Seal (Metu - Alge) vs Alternative: Base Case ()Metu - Alge

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	1.45	-0.06	0.00	8.59	0.64	0.00	0.00	0.00	7.84
Discounted	1.55	-0.03	0.00	4.22	0.32	0.00	0.00	0.00	3.01

Economic Internal Rate of Return (EIRR) = 37.7% (No. of solutions = 1)

Life Cycle Costs of Gravel Road of Metu- Alge with increased of cost by 25% and with decreased AADT by 25%

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Metu -Alge**
Run Date: **26-06-2017**
Currency: **Ethiopian Birr (millions)**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	1.066	0.062	0.000	1.128
2018	0.000	0.000	0.000	1.125	0.066	0.000	1.191
2019	0.157	0.016	0.000	1.189	0.069	0.000	1.431
2020	0.000	0.004	0.000	1.022	0.051	0.000	1.078
2021	0.000	0.004	0.000	1.078	0.054	0.000	1.136
2022	0.000	0.004	0.000	1.179	0.060	0.000	1.243
2023	0.098	0.004	0.000	1.297	0.068	0.000	1.468
2024	0.000	0.004	0.000	1.277	0.065	0.000	1.346
2025	0.000	0.004	0.000	1.359	0.069	0.000	1.433
2026	0.000	0.004	0.000	1.496	0.078	0.000	1.579
2027	0.103	0.016	0.000	1.647	0.089	0.000	1.855
2028	0.000	0.004	0.000	1.597	0.082	0.000	1.684
2029	0.000	0.004	0.000	1.717	0.089	0.000	1.811
2030	0.000	0.004	0.000	1.901	0.102	0.000	2.007
2031	0.108	0.016	0.000	2.088	0.116	0.000	2.328
Total cost for the section:	0.466	0.091	0.000	21.038	1.122	0.000	22.717

Life Cycle Costs of Double Otta Seal of Metu- Alge with increased of cost by 25% and with decreased AADT by 25%

H D M - 4 **Cost Streams by Road Section**

Alternative:	**Otta Seal (Metu - Alge)**			
Section:	**Metu - Alge Road Project**		**Road Class:**	**Secondary or main**
Surface Class:	**Unsealed**			
Length:	**1.00 km**		**Width:**	**7.00 m**

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.673	0.000	0.000	1.066	0.062	0.000	2.801
2018	0.000	0.003	0.000	0.662	0.028	0.000	0.694
2019	0.000	0.003	0.000	0.780	0.033	0.000	0.817
2020	0.000	0.003	0.000	0.833	0.036	0.000	0.872
2021	0.000	0.003	0.000	0.889	0.039	0.000	0.931
2022	0.000	0.003	0.000	0.950	0.042	0.000	0.995
2023	0.000	0.003	0.000	1.017	0.045	0.000	1.066
2024	0.000	0.003	0.000	1.090	0.050	0.000	1.143
2025	0.000	0.003	0.000	1.170	0.055	0.000	1.229
2026	0.438	0.003	0.000	1.258	0.061	0.000	1.760
2027	0.000	0.003	0.000	1.220	0.053	0.000	1.277
2028	0.000	0.003	0.000	1.303	0.057	0.000	1.364
2029	0.000	0.003	0.000	1.393	0.062	0.000	1.459
2030	0.000	0.003	0.000	1.492	0.068	0.000	1.563
2031	-0.167	0.003	0.000	1.600	0.075	0.000	1.511
Total cost for the section:	1.943	0.047	0.000	16.723	0.767	0.000	19.480

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Economic Analysis Summary

Study Name: **Metu -Alge**
Run Date: **26-06-2017**

This report shows total economic benefits using the following:
Currency: Ethiopian Birr (millions).
Discount rate: 10.23%.
Analysis Mode: Analysis-by-Project

Alternative: Otta Seal (Metu - Alge) vs Alternative: Base Case ()Metu - Alge

	Increase in Road Agency Costs			Savings in MT VOC	Savings in MT Travel Time Costs	Savings in NMT Travel & Operating Costs	Reduction in Accident Costs	Net Exogenous Benefits	Net Economic Benefits (NPV)
	Capital	Recurrent	Special						
Undiscounted	1.48	-0.04	0.00	5.94	0.44	0.00	0.00	0.00	4.94
Discounted	1.56	-0.02	0.00	2.94	0.22	0.00	0.00	0.00	1.62

Economic Internal Rate of Return (EIRR) = 26.1% (No. of solutions = 1)

Sensitivity Analysis for Woito - Turmi road section, AADT decreased by 25%

Life Cycle Costs of Gravel Road of Woito - Turmiwithincreased of cost by 25% and with decreased AADT by 25%

H D M - 4
HIGHWAY DEVELOPMENT & MANAGEMENT

Cost Streams by Road Section

Study Name: **Woito - Turmi**
Run Date: **26-06-2017**
Currency: **Ethiopian Birr (millions)**

Alternative: Base Case ()Woito - Turmi)
Section: Woito - Turmi Road Project — **Road Class:** Secondary or main
Surface Class: Unsealed
Length: 1.00 km — **Width:** 7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	0.000	0.000	0.000	0.641	0.016	0.000	0.657
2018	0.000	0.000	0.000	0.686	0.017	0.000	0.703
2019	0.352	0.019	0.000	0.733	0.018	0.000	1.123
2020	0.000	0.008	0.000	0.614	0.012	0.000	0.634
2021	0.000	0.008	0.000	0.651	0.013	0.000	0.672
2022	0.000	0.008	0.000	0.716	0.014	0.000	0.738
2023	0.119	0.008	0.000	0.798	0.016	0.000	0.941
2024	0.000	0.008	0.000	0.806	0.016	0.000	0.830
2025	0.000	0.008	0.000	0.862	0.017	0.000	0.887
2026	0.000	0.008	0.000	0.957	0.020	0.000	0.984
2027	0.128	0.019	0.000	1.071	0.023	0.000	1.242
2028	0.000	0.008	0.000	1.059	0.021	0.000	1.088
2029	0.000	0.008	0.000	1.146	0.023	0.000	1.177
2030	0.000	0.008	0.000	1.283	0.027	0.000	1.317
2031	0.142	0.019	0.000	1.438	0.032	0.000	1.631
Total cost for the section:	0.741	0.136	0.000	13.463	0.285	0.000	14.624

Life Cycle Costs of Double Otta Seal of Woito – Turmi with increased of cost by 25% and with decreased AADT by 25%

HDM-4 **Cost Streams by Road Section**

Alternative:	Otta Seal (MWoito - Turmi)		
Section:	Woito - Turmi Road Project	Road Class:	Secondary or main
Surface Class:	Unsealed		
Length:	1.00 km	Width:	7.00 m

Year	Road Agency			MT VOC	MT Travel Time	Exo. Costs & Benefits	Total Costs
	Capital	Recurrent	Special				
2017	1.339	0.000	0.000	0.641	0.016	0.000	1.996
2018	0.000	0.006	0.000	0.373	0.006	0.000	0.385
2019	0.000	0.006	0.000	0.442	0.008	0.000	0.455
2020	0.000	0.006	0.000	0.474	0.008	0.000	0.488
2021	0.000	0.006	0.000	0.509	0.009	0.000	0.524
2022	0.000	0.006	0.000	0.547	0.009	0.000	0.562
2023	0.000	0.006	0.000	0.587	0.010	0.000	0.603
2024	0.000	0.006	0.000	0.631	0.011	0.000	0.647
2025	0.000	0.006	0.000	0.677	0.012	0.000	0.695
2026	0.438	0.006	0.000	0.727	0.013	0.000	1.184
2027	0.000	0.006	0.000	0.771	0.013	0.000	0.790
2028	0.000	0.006	0.000	0.828	0.014	0.000	0.848
2029	0.000	0.006	0.000	0.889	0.016	0.000	0.910
2030	0.000	0.006	0.000	0.955	0.017	0.000	0.977
2031	-0.134	0.006	0.000	1.025	0.018	0.000	0.916
Total cost for the section:	1.642	0.082	0.000	10.076	0.180	0.000	11.981