JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING
HIGHWAY ENGINEERING STREAM

Life Cycle Cost Analysis of Flexible Pavement with Geosynthetic Materials and Conventional Flexible Pavement

Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Civil Engineering (Highway Engineering)

By: Zinabu Hailu Bayisa

August, 2020
Jimma, Ethiopia

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DEDICATION

You know how it is. You search a document, flip to the dedication, and find that, once again, the author has dedicated a work to someone else and not you.

Not this time.

Because we haven't yet met/have only a glancing acquaintance/haven't seen each other in much too long/are in some related/will never meet, but will, I trust, despite that, always think fondly of each other…

This one's for you.

With you know what, and you probably know why.

ACKNOWLEDGEMENT

Say, "Indeed, my prayer, my rites of sacrifice, my living and my dying are for God, Lord of the world." Lord, you never fail to amaze me with your plans to prosper me and not to harm me, plans to give me hope and a future.

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ABSTRACT

By the time the need for minimizing the costs of a road infrastructure became a necessity, LCCA had grown to be an accepted practice in the world. It was not a piece of cake for the National Cooperative Highway Research and Intermodal Surface Transportation Efficiency Act to perform a comprehensive and reliable LCCA at the time when the available information was not sufficient. Researches conducted in this area consistently confirmed that developed countries have a published Policy statement on LCCA, instructional LCCA workshop and resultant noteworthy technical bulletin outlining the best practice of LCCA methodology and related parameters. The revers is true in Ethiopia eventhough the country is about to be emerged out of road infrastructure problem, except from the challenges posed by new commitments to the economical consideration. This is because decisions have been based on a comparison of initial construction costs concept setting lowest initial construction cost option as the lowest total cost option.

As such, it was aimed to determine the overall cost of flexible pavement with and without geosynthetic material and evaluating its cost effectiveness. The true cost (LCCA) was adopted as it has the means to fulfill these requirements. This was achieved by determining the agency, user and environmental costs for the road segment under study. In this regard information like traffic data and pavement data was collected from concerned agencies. Design documents were taken from ACRA. Travel speed on the road segment, discount rate, design period, analysis period and base year were selected based on the experience of ACRA. An Indian department of transportation vehicle class were adopted and Percentages of Truck distribution were determined by conducting a sample of field survey. Accordingly, observation of sample field survey revealed that out of 100 vehicles on the road segment under study 65% were passenger cars, 20% were single unit trucks and 15% were combination trucks. Estimation of costs was done specific to each construction, maintenance and rehabilitation treatment. Two alternative methodologies were provided: one was using a per-lane length approach which incorporates updated market prices and contract data from design document and this was adopted in determining agency cost associated with maintenance and rehabilitation. The other approach was one that builds the costs from a developed model. This approach was adopted to determine the initial construction cost of both alternatives.

Accordingly, Agency cost was determined to be 3,182,653,893 and 1,580,443,895 ETB for Conventional and Geosynthesized pavement respectively. This conveys a message that using geosynthetic material in flexible pavement can reduce an Agency cost by 50.34 %. But using initial construction cost as a decision-making tool can eliminate this fact and leads to wrong direction. This is because of the fact that avoiding this fabric can reduce initial construction cost by 1.5%.

On behave of user costs, only work zone user costs were given prominent coverage in this paper and costs associated with noise, and pollution should not be a formidable concern as they are not expected to vary significantly by LCCA alternative. The seven user cost components associated to work zone operation (Travel Delay Costs & Vehicle Operating Costs) were determined. Accordingly, Inspection of analysis part in this paper reveals that, user cost was determined to be 14,178,855,923 & 4,120,182,985 ETB respectively putting the former one conventional FP. This implies that about 70.9% of user cost can be avoided when using a geosynthetic materials.

Finally, Economic evaluation of the two alternatives was carried out using the NPV as economic indicator. As such incorporating geosynthetic material in pavement was found more economical and most effective alternative pavement option.

Key words: *Agency Costs, Economic Evaluation, Net Present Value, User Cost*

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LIST OF ACRONYMS AND INITIALISM

AADT	Average Annual Daily Traffic
ACPA	American Concrete Pavement Association
BOQ	Bill of Quantity
CBR	California Bearing Ratio
CPI	Consumer Price Index
ERA	Ethiopian Roads Authority
ESA	Equivalent Standard Axle
ETB	Ethiopian Birr
FHWA	Federal Highway Administration
FP	Flexible Pavement
HDM	High way Development Management
HCM	Highway Capacity Manual
HMA	Hot Mix Asphalt
LCCA	Life Cycle Cost Analysis
LLP	Long Life Pavement
LOS	Level of Service
NBE	National Bank of Ethiopia
NCHRP	National Cooperative Highway Research Program
NPV	Net Present value
RSDP	Road Sector Development Program
SC	Subgrade strength class
TC	Traffic class
TDC	Travel Delay Cost
VOC	Vehicle Operating Cost
VPH	Vehicle Per Hour
WZ	Work Zone

CHAPTER I

INTRODUCTION

1.1. Background of the study

Budget tightening, escalating costs for maintaining public services, functioning at an acceptable level, and increased public scrutiny of government-related expenditures have focused the attention of all segments of our socioeconomic system on the importance of effective management of resources and assets. Transportation agencies are especially concerned in this pursuit due to many factors. To mention a few, they rank among the top sectors in public spending, and the impacts of their investment decisions touch upon every member of the society, which makes public scrutiny rather intense. Furthermore, an asset base of 3 trillion dollars (i.e. the value of the transportation system in the US as estimated by the FHWA) is under the influence of numerous natural and man-made dynamics, many of which are uncontrollable and/or uncertain [1].

Decision-making and management in the transportation sector must be based on informed and conversant support. One of the most recognized techniques that provide such informed support, when applied properly, is “Life Cycle Cost Analysis” (LCCA). It is an economic evaluation technique that has been particularly valuable when there is a need to compare competing alternatives for projects with entailing costs and benefits that stretch over long spans of time [1].Among different alternatives competing for economic worthiness in pavements, flexible pavement incorporating geosynthetic material and conventional one is consistently confirmed by many researchers as the high ranker.

It was determined that about 20% by weight of the subgrade soil when mixed into the aggregate will significantly reduce the bearing capacity of the base layer [2, 3, 4]. Geosynthetics have been used in pavements to either extend the service life of the pavement by avoiding intermixture of aggregate and subgrade soil or to reduce the total thickness of the pavement system. Based on the cost of the geosynthetic materials relative to additional thickness of the base layer, the use of the reinforcement geosynthetics attributed to cost savings up to 55% [5]. However, the complete life cycle cost of these materials is still not clear because most studies overlooked it. This document proposes a comprehensive life-cycle cost analysis of flexible pavement with and without geosynthetic materials. This study discussed the economic aspects of geosynthetic materials in flexible pavement.

Although the concept of life cycle costing was introduced in the early nineteenth century, it was not until the current day that life cycle cost analysis began to be used properly in determining which investment will allow for the most economical allocation of limited resources. The infrastructural sector performed different attempts to create Life Cycle Cost Analysis (LCCA) frameworks [6, 7, 8], since there is increasing emphasis on service life design [8]. LCCA is an economic assessment of an item, system, or facility to compare design alternatives considering all significant costs over the design life, expressed in terms of equivalent currency units [7]. LCCA should be performed during early design phases of the project to be beneficial, even though there is little knowledge concerning the system [6]. LCCA is used to objectively underpin decisions concerning methods and materials that influence the service life of the asset, and therefore the life cycle costs [8]. Life cycle cost analysis allows state agencies to evaluate different alternatives concerning proposed highway projects. The selection of different pavement types, the initial quality and strength of design, maintenance and rehabilitation strategies, and the financial impact on the agency are all concerns that are evaluated when performing a life cycle cost analysis. LCCA has become increasingly common amongst state transportation agencies, and it is a focus of this study to analyze an LCC for flexible pavement with geosynthetic materials and conventional pavement. Net Present Value (NPV) calculations are used to compare alternatives as the final comparison indicator [9].

1.2. Statement of the problem

Studies indicate that pavement construction in Addis Ababa consumes too large budget to complete. This is because appropriate economic analysis not performed during investment decision making. One of the most practical economic analysis tools is life cycle cost analysis and most of the time agencies overlooked it so that they try to manage asset cost reactively adopting the minimum construction cost as standard. While they try to eliminate costs via design, unless cost management follows suit, it will be two paradigms fighting each other. Thus, the most established paradigm will usually prevail unless the challenger can present a convincing case. Regardless to the policy of avoiding future economic surprise, decisions made in any area of construction industry has been failed to avoid it. This is why failures occurred far before the intended service life, inflated future costs, being the major source and immediate cause of widespread public grievances have becoming the defining features of pavement structure. To do right from the beginning, a study considering the comprehensive LCCA of pavements with geosynthetic materials, including initial construction, future maintenance, rehabilitation, environmental, and user costs, is urgently needed.

If life cycle costs are not considered, then the myopic strategy is adopted to accept the lower up-front price despite higher present value. As a result, minimum construction-cost solutions will always be chosen. Design standards in common use have often been derived from considerations of custom and practice, and usually provide only a minimum level of safety and engineering functionally. Such an approach fails to recognize that the only reason for constructing a highway is to provide a service over a period of time into the future. An appraisal philosophy which fails to recognize this is clearly flawed.

The fact that Life-Cycle Cost Analysis (LCCA) is used to evaluate the cost-efficiency of alternatives and a good approach to avoid future economic surprise makes their study an important. Geosynthetic materials have been used in road infrastructure either to extend the service life of the pavement or to make it more economical by reducing the total thickness of the pavement structures. Even though the usefulness of these materials in pavements have been recognized, their economic benefits were not well considered and documented. Therefore, a comprehensive Life Cycle Cost Analysis (LCCA) is needed to know whether they are cost effective or not.

Generally overlooking life cycle costs makes investment decisions become subjective and dependent on the application of standards that are often themselves based on historical precedent rather than objective analysis. Surprisingly, avoiding life cycle cost was presented in some research papers as a better option than analyzing it which leads to wrong direction.

1.3. Research questions

This study was seeking to answer the following three research questions.

1. How to estimate agency, user and environmental costs for flexible pavement with and without geosynthetic materials?
2. How to carry out the economic evaluation and determine the more economical and sustainable option from pavement with geosynthetic materials and conventional pavement?
3. What is the best and most effective alternative of pavement option from economic point of view?

1.4. Objective of the study

1.4.1 General objective

The general objective of this study was to identify economical pavement option by making life cycle cost comparisons and economic analysis of flexible pavement with and without geosynthetic materials in Addis Ababa.

1.4.2 Specific objectives

- To estimate agency, user and environmental costs for both flexible pavement with geosynthetic materials and without geosynthetic materials.
- To carry out economic evaluation of flexible pavement with geosynthetic materials and without geosynthetic materials on selected segments of roads in Addis Ababa and to determine which

pavement option is more economical.

- To draw conclusions and recommend the best and most effective alternative pavement option from economic point of view.

1.5. Scope of the study

In order to accomplish these objectives, a thorough review of the literature was completed first to identify the debates and gaps of previous studies on LCCA on flexible pavement with geosynthetic. In this study, parameters associated with cost components were identified. This study was also covering a procedure for using LCCA techniques to evaluate flexible pavement with and without geosynthetic materials. The practice also accommodated the remaining residual or salvage value. Economic indicator was limited to NPV as the concern of the study was comparison that relied on differential costs only.

1.6. Significance of the study

Performing LCCA to develop more economical strategies is becoming more important for transportation agencies as traffic volumes increase, highway infrastructure deteriorates, and their budgets tightens. In the face of scarce funds and limited budgets, transportation officials must constantly choose the most cost-effective project alternatives as they consistently rank among the top sectors in public spending, choosing the most cost-effective type and design of pavement. To be able to do this, the magnitude of different costs and their variations must be identified and investigated. Even though it is aimed to avoid future economic surprises, to “think first” and to make wise decisions; unfortunately, economic surprises arise in almost all road infrastructure projects. One of the main reasons for this is that when a new project is to be launched, it is common to treat only the cost construction true cost must be considered to evaluate the economical aspect of the projects. All factors must be considered in the analysis such as user-delay costs and salvage value.

With these limitations and concepts in mind, this study is significant in that it incorporates all cost components such as; the agency, environmental and user costs associated with flexible pavement to make a wise decision and avoid future economic surprise.

CHAPTER II

LITERATURE REVIEW

2.1. Introduction

Transportation is essential for economic and social development. Because of this, countries advanced in development have devoted considerable resources to the development of high-quality transport networks which need to be adequately maintained. Current road construction methods lead to significant maintenance requirements, which can only be met at a very high cost. The continued growth in road traffic and axle loads and the pressure to restrain government spending put growing pressures on road authorities to come up with new solutions. Besides, the cost to economies due to congestion and disruption during road works on high volume roads has become unacceptably high [11].

This study focuses on the comprehensive LCCA of flexible pavement with and without geosynthetic materials and their impact on the decision-making process. To achieve this objective, the literature was compiled from the following sources:

- Textbooks covering area of interest
- journal articles, articles in periodicals, conference proceedings, reports, and document from websites
- FHWA and USDOT publications
- Searches of internet-based National Transportation library systems (example, transportation research information services, national technical information services)
- Published proceedings of ASCE, TRB, and other agencies.
- Works that have been done previously in the area concerned with this issue and need to be supplemented by this study.

2.2. Flexible Pavement

Flexible pavements are those, which are surfaced with bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments or, HMA surface courses. These types of pavements are called "flexible" since the total pavement structure "bends" or "deflects" due to traffic loads. A flexible pavement structure is generally composed of several layers of materials, which can accommodate this "flexing". A flexible pavement is a structure that maintains intimate contact with and distributes loads to the sub grade and depends on aggregate interlock, particle friction, and cohesion for stability [4].

2.3. Geosynthetics

Geosynthetics are used in any application area to have technical benefits and/or the overall cost savings.

Their use may result in lower initial cost and/or greater durability and longer life, thus reducing maintenance costs. The cost analysis of a geosynthetic-related project needs careful handling when taking decisions for the acceptance or the rejection of the option of using geosynthetics in the project just only on the basis of its cost [12]. Geosynthetic materials are "fabric-like materials made from polymers such as polyvinyl chloride (PVC), polyethylene, polypropylene, and polyester". The term geosynthetics represents many types of construction materials that serve several purposes, but the two forms of geosynthetics that are most widely used in pavement systems are geogrids and geotextiles [13]. Although both of these reinforcements may contribute to pavement performance, it was found that the mechanisms by which the two types reinforced the pavement are different. The major product uses in this area are geotextiles, geogrids, geosynthetic clay liners, geo-composites, geomembrane, geofoam, geocells, and geonets. The main purpose of using geosynthetic materials is to have better performance and to save money [14].

There are four fundamental functions of geosynthetic materials in pavements; Separation (Inserting an adaptable permeable geosynthetic will keep layers of various measured particles isolated from each other), Drainage (Geosynthetics permit the entry of water either descending through the geosynthetic into the subsoil or laterally within the engineered material), Reinforcement (The geosynthetic can really fortify the earth or it can expand clear soil support. For instance, when put on sand, it disseminates the heap equitably to lessen rutting), Filtration (The texture enables water to travel through the soil while limiting the movement of soil particles) [15].

According to [16] Separation function was perceived as the primary function of geosynthetics in pavements, particularly when they are utilized to upgrade the road with low bearing capacity subgrade. At the point when a lean layer is set between two different materials to anticipate the intermixing of the two materials, each material can completely play out their unique function. In this situation, there are fundamentally two mechanisms occurring with the geosynthetics as a separator in the wet, soft, weak subgrade road. One is avoiding the intrusion of subgrade soil up into the base coarse aggregate. The other is that the base coarse aggregate tends to penetrate the subgrade soil, which influences the quality of the base layer [13].

Putting a proper geosynthetic layer at the subgrade base interface can decrease the upward plastic flow of subgrade soil since the geosynthetic layer can offer assistance to dissipate the excess pore water pressure [17].

However, in spite of the fact that the geosynthetic layer can offer assistance to dissipate pore water pressure, there are a few limitations for geosynthetic selection. They found that in spite of the fact that higher permeability geosynthetics can dissipate pore water pressure faster, this will moreover cause the erosion of the subgrade surface and upward movement of the eroded material.

Thicker geosynthetic material can decrease critical hydraulic gradient at the boundary of the contact area between a subbase particle and subgrade soil and so can diminish pumping. Also, compressible geosynthetics cause higher cyclic pore pressure and thus cause higher pumping. In addition, the base course particles enter the subgrade soil. This comes about within the reduction of base course thickness. When mixes with subgrade soil; the base aggregate loses its original quality [18].

There are prerequisites which must be taken after when utilizing geosynthetic as a separator [15].

Burst resistance: The geosynthetic must stand up to the underneath soil entering the upper base layer. Traffic loads cause force which energizes this movement. These loads are transmitted to the stone, through the geotextile, and into the basic soil. The focused soil at that point tries to push the geosynthetic fabric up. **Tensile strength**: The geosynthetic fabric must stand up to horizontal or in-plane tensile stress which is mobilized when an upper piece of aggregate is constrained between two lower pieces that lies against the fabric.

Puncture resistance: The geosynthetic fabric must be solid sufficient to stand up puncture. During utilize, sharp stones, tree stumps, roots, and base course load seem puncture through the geotextile.

Impact resistance: The geosynthetic fabric must stand up to numerous impacts of different objects. Impacts as a rule come from free falling objects such as falling rock, construction equipment, or materials. **Water permeability**: On the off chance that the water level rises, it should not be conceivable for water pressure to construct up beneath a separation layer to such a degree that the structure steadiness is imperiled. Water within the base layer should deplete out through the geotextile. On the off chance that not, the base may get to be unsteady. For that reason, the water permeability of the geotextile should be more noteworthy, or at least equal to, that of the subgrade.

There's a boundary between the separation and the geosynthetics function. There's unmistakable relationship between the opening estimate of geosynthetics and weight of soil mass. Abundance pore water pressure expanded as the number of loadings increased. Separation was found to be the essential function when the proportion of vertical stress on the top of subgrade (σz) to the undrain shear strength of the subgrade(cu) less than eight and reinforcement was the essential function when it is more than eight [19].

The geosynthetic materials can placed between the subgrade and the base, between the base and the hot-mix asphalt (HMA) layer or between the HMA layers and overlays. All the applications pertained to soft clay subgrades. Strain gages within the subgrade, moisture sensors and falling weight deflectometer (FWD) measurements were used to monitor the performance of constructed roadways. FWD results from his studies showed an increase in pavement stiffness in sections where geotextiles were placed as a separator. The inclusion of fabric provided an increase in pavement strength by improving load distribution and acting as a separating membrane. No analytical modeling was performed to predict the observed behavior [20].

2.4. General Life cycle cost analysis (LCCA)

Before Life Cycle Cost Analysis (LCCA), a very basic concept must be clarified, namely the life cycle. The interpretation of the term life cycle differs from decision-maker to decision-maker, as is evident from the literature. According to Jan Emblemsvag (2003), a marketing executive will most likely think in terms of the marketing perspective, which consists of at least four stages [21]:Introduction, Growth, Maturity and Decline. A manufacturer, on the other hand, will think in terms of the production perspective, which can be described using five main stages or processes: Product conception, Design, Product and process development, Production, and Logistics. When the product has reached the customer (user or consumer), a different perspective occurs: the customer perspective. This perspective often includes five stages or processes: Purchase, Operating, Support, Maintenance and Disposal.

In Highway engineering; the concept of economics in line with life cycle was introduced as early as the end of the nineteenth century, when Gillespie issued his “Manual of the Principles and Practices of Road Making” in 1847. Gillespie characterized the most cost-effective highway project as the one that has the highest returns as to the expenses associated with its construction and maintenance [1].

Life-cycle cost analysis is a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future cost, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project [22, 23]. In simple terms, LCCA is an analysis technique that supports more informed and better investment decisions. It builds on well-founded principles of economic analysis that have been used to evaluate highway and other public works investment for years. It incorporates discounted long-term agency, user, and other relevant costs over the life of a highway or bridge to identify the best value for investment expenditures (i.e., the lowest long-term cost that satisfies the performance objective sought). LCCA can be applied to a wide variety of investment-related decision levels to evaluate the economic worth of various designs, projects, alternatives, or system strategies to get the best return on the funds. A usable project segment is defined as a portion of a highway that, when completed, could be opened to traffic independent of some larger overall project (Highway engineering economics was introduced as early as the end of the nineteenth century, when Gillespie issued his Manual of “the Principles and Practices of Road Making” in 1847. According to Gillespie, the most cost-effective highway project is the one that has the highest returns as to the expenses associated with its construction and maintenance [24].

Though seemingly, LCCA was present in the works of Gillespie, it was articulated especially in the 1930s as part of the federal legislation in relation to flood control. By the time the need for minimizing the costs of a transportation facility became a necessity, LCCA had grown to be an accepted practice in various disciplines of our society [1].

However, researches conducted in this area consistently confirmed that, this concept was not used in highway projects until the 1950s. The works of the economist Winfrey in the 60s and the American Association of State Highway Officials (AASHO'S) "Red Book" of 1960 ushered in the concept of Life Cycle Cost Analysis to the transportation domain [25]. At the time, the available information was not sufficient to perform a comprehensive and reliable LCCA that truly encapsulates all components. Extensive research started as a result. The research focused on issues like information gathering and integration and quantifying the user cost and vehicle operating cost [26].

In 1984, the National Cooperative Highway Research (NCHRP) commenced project number 20-5 FY 1983 with the aim of promoting LCCA [27]. The aim of the project was to investigate the practice of LCCA in transport agencies of that time and examine important aspects and parameters of the life cycle process. The AASHTO, in their "Pavement Design Guides of 1983 and 1993", endorsed the use of LCCA as a means for economic evaluation and as a tool to support decision making process.

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 called for "the use of life cycle costs in the design and engineering of bridges, tunnels, or pavement. Subsequently, the National Highway System (NHS) Designation Act of 1995 mandated the States to perform LCCA on NHS projects. In 1996, the Federal Highway Agency released its Final Policy statement on LCCA.

The Transportation Equity Act for the 21st Century (TEA-21) of 1998, which replaced the ISTEA 1991, had removed the requirement for State Highway Agencies to perform LCCA on NHS projects. However, the same act continues the endorsement of LCCA by requiring the Secretary of Transportation to authorize research and development for LCCA enhanced implementation. Demonstration Project 115 "Life-Cycle Cost Analysis in Pavement Design", carried out by FHWA in 1998, developed an instructional LCCA workshop that has since been presented in various states many times. In addition, a resultant noteworthy technical bulletin outlining the best practice of LCCA methodology and related parameters was published [1].

In the year 2000, within FHWA, LCCA came under the charge of the Office of Asset Management. Its most recent product (late 2002) is the development of an LCCA instructional software package for pavement. Research commissioned by the State Highway Agencies and other interested partners continues to be conducted on a broader scale. It covers LCCA in the context of planning and management for transportation projects, as well as other aspects, such as data collection and integration, the element of uncertainty, and the boundless topic of related user costs [1].

In the current day, **Life-cycle cost analysis (LCCA)** is defined as an analysis technique, based on well-founded economic principles, used to evaluate the overall long-term economic efficiency between competing alternate investment options. LCCA is typically used as a means to evaluate and then compare the cost to the agency of any number of alternate pavement alternatives, including variations of concrete and asphalt pavement solutions. When done correctly, a life-cycle cost analysis of pavement design or rehabilitation alternatives identifies the strategy that will yield the best value by providing the expected performance at the lowest cost over the analysis period.

2.4.1. Economic Indicator

In the economic evaluation of projects, there are several formats of economic indicators for the analysis results. The most common are Net Present Value (NPV), Cost-Benefit Ratio (B/C), Equivalent Uniform Annual Costs (EUAC), and Internal Rate of Return (IRR). The choice of the appropriate indicator depends largely on the level and context of the analysis. It may also depend on the degree of uncertainty in some parameters [1]

In principle, the choice of the economic indicator should cater to the following questions [28, 29]:

1. Are benefits included in the analysis?
2. What is the level of decision-making and/or analysis involved?
3. What methods suit the requirements of the particular agency involved?
4. How important is the initial capital investment in comparison to future expenditure?
5. What method of analysis is the most understandable to the decisionmaker?

Since the LCCA project-level secondary analysis aims at evaluating project alternatives that result in equal categorical benefits but entail unequal costs, the Net Present Value (NPV) is considered the appropriate (and the prevalent) indicator for comparing the differential economic worth of projects. The Net Present Value indicator, with its additive function, allows the analyst to account only for the differential costs (or benefits) and, at the same time, maintain consistency in the evaluation process. This characteristic reduces the computations needed in the analysis tremendously. The Uniform Equivalent Annual Cost (UEAC) indicator is also acceptable, but should be derived from NPV. Computation of Benefit/Cost (B/C) ratios are generally not recommended because of the difficulty in sorting out cost and benefits for use in the B/C ratios [29].

Net Present Value NPV is the discounted monetary value of expected net benefits (i.e., benefits minus costs). NPV is computed by assigning monetary values to benefits and costs, discounting future benefits

(PVbenefits) and costs (PVcosts)using an appropriate discount rate, and subtracting the sum of discounted costs from the sum of discounted benefits. Discounting benefits and costs transforms gains and losses occurring in different time periods to common unit of measurement. Programs with positive NPV value increase social resources and are generally preferred. Programs with negative NPV should generally be avoided. The basic formula for computing NPV is [29]:

NPV = PVbenefits – PVcosts

Because the benefits of keeping the roadway above some pre-established terminal level are the same for all design alternatives, the benefits component drops out and the formula reduces to:

$$NPV = IC + \sum_{k}^{N} MC \left[\frac{1}{1+d_r}\right]^{nk} + \sum_{k}^{N} RC \left[\frac{1}{1+d_r}\right]^{nk} + \sum_{k}^{N} UC \left[\frac{1}{1+d_r}\right]^{nk} - SV \left[\frac{1}{1+d_r}\right]^{n} \quad \text{Equation 1}$$

Where;

IC = initial construction cost; MC= maintenance cost; RC= rehabilitation cost; UC= user cost; SV = salvage value; n= analysis period/lifetime of the project, years; nk = number of years from the initial construction to the *k*th expenditure; N= number of future costs incurred over the analysis period; dr = discount rate.

2.4.2. Selection of base year

The base year is the year to which all "future costs and benefits" are to be discounted. Future benefits and costs will be discounted back to the base year's price level to give an indication of the present value of these factors. The selection of the base year should be consistent with the price year used to value benefits and costs. The base year is generally the 'current year'.

2.4.3. LCCA Procedures

The LCCA structured approach can be outlined in the following steps [23]:

1. Define projects alternative

This is the first step in the LCCA procedure. Experts and experienced professionals suggest potential life cycle strategies for the project. Each pavement design strategy specifies initial design and performance, time-dependent rehabilitation/treatment activities, and the timings of these rehabilitation activities and respective performances. At this stage, common costs between different strategies can be identified. For example, in evaluating new pavement projects, right-of-way costs are common to all alternatives. Marginal costs, especially those occurring in the future, can be insignificant with respect to the total value of the project; thus, it is helpful to identify such costs beforehand [1, 23].

2. Decide on the approach that would be followed (Probabilistic vs. Deterministic)

Deciding on the approach to be followed at this time should be accomplished based on information and data available for the LCCA model parameters. In all cases, “most of the LCCA parameters” are uncertain, and it is generally recommended that the probabilistic approach be adopted. The deterministic approach uses point estimates for all input variables for the model, whereas the probabilistic approach uses probability distributions for all unsure variables and therefore treats the inherent uncertainty in the model [23, 1].

3. Choose general economic parameters

General economic parameters are the discount rate and the analysis periods. Both parameters should be equal for all options.

4. Establish expenditure stream for each alternative

Expenditure stream diagrams can be constructed as shown in (Figure2). The expenditure stream diagram (Figure2) helps to visualize the quantity and timing of expenditures over the life of the analysis period. Three kinds of elements would be presented in the expenditure stream diagram: initial and future activities, agency, environmental and user costs related to these activities, and the timing and costs of these activities. The upward arrows on the diagram are expenditures whereas the horizontal arrow and segments show the timing of work zone activities and the period of time between them. The “remaining service life (RSL) value (salvage value)” is presented as a downward arrow and reflects a negative cost at the end of the “analysis period” [1].

5. Compute Net Present Value for each alternative

After constructing the expenditure stream, computing the “Net Present Value” of each alternative becomes a straightforward calculation using Equation. It is advisable to compute the agency, user, and societal costs separately before computing the total value of a project, in order to better understand the exact contribution of each cost category to the total final worth [23].

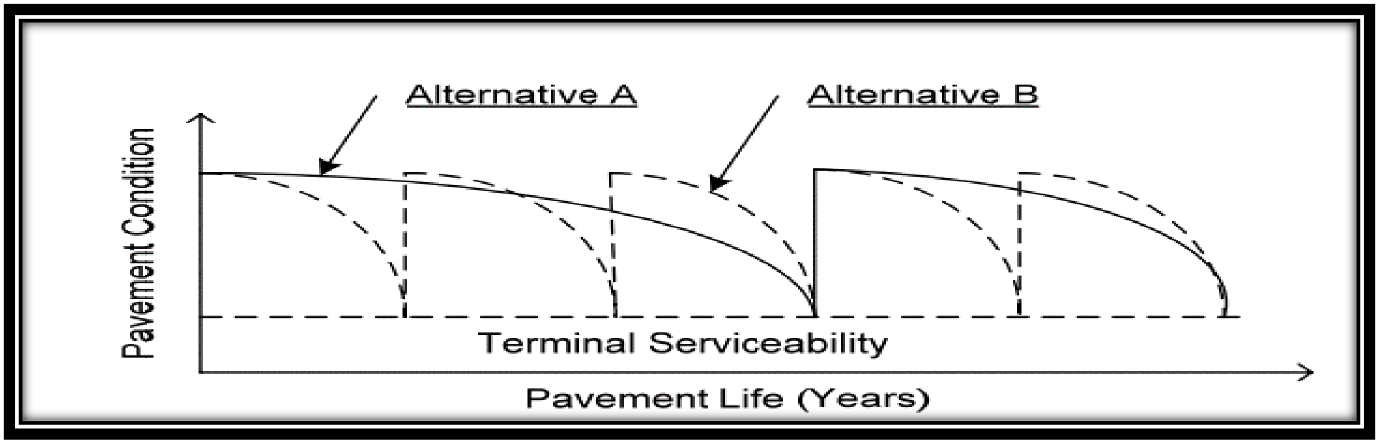


Figure 1: Performance Curve for Different Rehabilitation or Maintenance Strategies

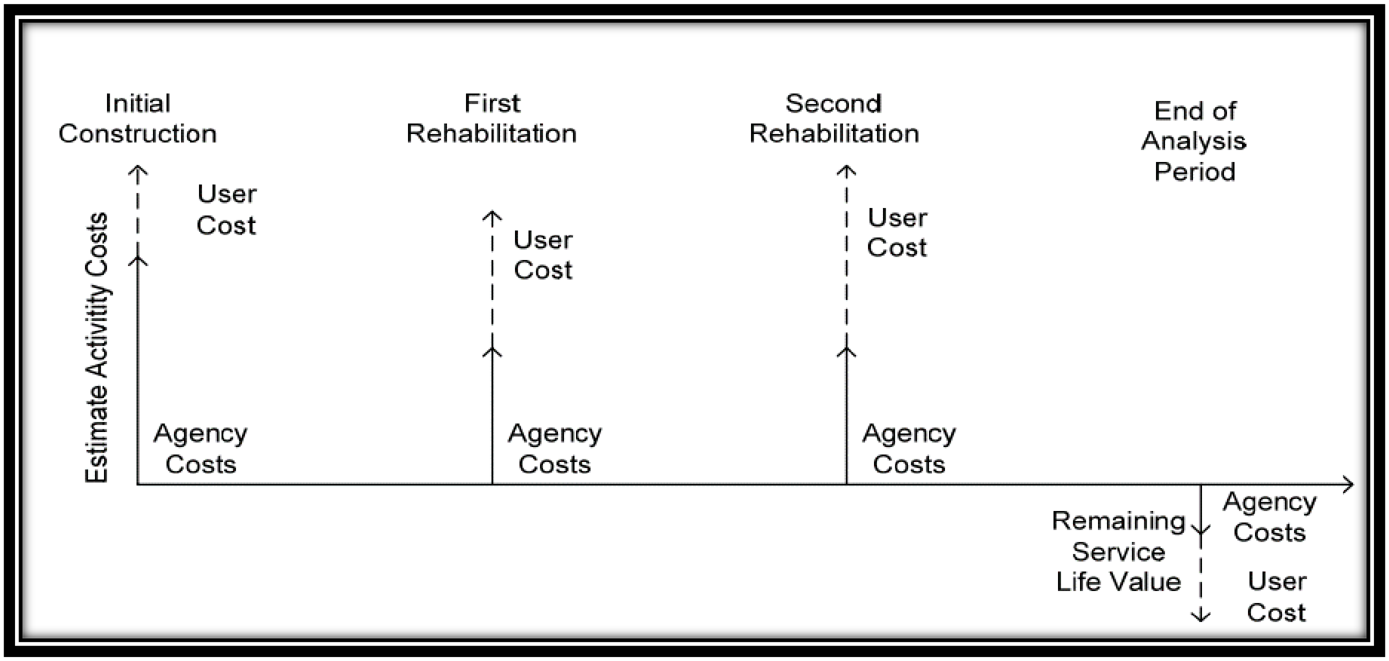


Figure 2: Expenditure Diagram/Cash Flow Diagram

6. Compare and interpret results/Sensitivity Analysis

Once NPV for each alternative is computed, with agency, user, and environmental costs presented distinctively, interpretation of these results can be made. Generally, an alternative is preferred if its NPV is a minimum of 10 percent less than the NPV of other competing alternatives. If the difference in NPV of alternatives is smaller than 10 percent, then such alternatives are considered similar or equivalent. A detailed discussion of the interpretation of results and the treatment of uncertainty is given in the next chapter, which presents the recommended probabilistic approach. On the contrary, if the deterministic approach is adopted in the analysis, SA should be conducted as a minimum. The sensitivity analysis should check the effect of variability in the main input parameters for the analysis of the overall results. This is done by performing the analysis over a range of possible values of a particular parameter under testing while holding all other parameters constant. This analysis can give the decision-maker a better representation of the comparison, and it can rule out bias toward certain alternatives to some extent [23, 1].

According to [1], the most significant parameters that should be tested for sensitivity in the analysis are:

- The discount rates
- Timing of future rehabilitation activities
- Traffic growth rate
- Unit costs of the major construction components and
- Analysis period

7. Re-evaluate design strategies if needed, report and give comments on the result.

Presenting results and analyzing them help the process of re-assessing the design strategies, whether in regards to scope, timing, or other factors. Sometimes minor alterations of the design strategies can lead to a better choice for the project [1].Figure 3 illustrates the LCCA structured approach

2.5. LCCA parameters

2.5.1. Discount rate

Choosing the appropriate discount rate for LCCA of a project under simulated environments remains the subject of international debates. Among the key features in the LCCA process, the most important is accounting for the future costs. The treatment of future costs is based on a well-established principle in economics according to which money has time value. That is to say, a dollar in the future year is worth less than the value of the dollar today. Therefore, to be able to make decisions regarding investments with different long-term time-lines, all future costs and benefits must be converted to a common time dimension. This procedure is referred to as discounting. Discounting is performed by employing a discount rate that represents the percent change in the value of the dollar per period of time. Similar to costs, LCCA can use discount rates. In the concept of the LCCA, the discount rate either real or nominal discount rate can be defined as a value in percent used as a mean for comparing the alternative uses of funds and costs over a period of time by reducing the future amounts to present worth. In that manner the economics of the different alternatives can be compared on a common basis [30, 1]. Real discount rates reflect the true-time value of money with no inflation premium and should be used in conjunction with non-inflated dollar cost estimates of future investments. Nominal discounts rates include an inflation component and should only be used in conjunction with inflated future dollar cost estimates of future investments. Data on the historical trends over a very long period indicate that the real value of money is approximately 4%. In 1995 and 1996, the FHWA Office of Engineering, Pavement Division, conducted a national pavement design review and found that the discount rates showed a distribution of values clustering in the 3-5% range. Good practice suggests using a real discount rate, one that does not reflect an inflation premium, of 3–5% in conjunction with real/constant dollar cost estimates. The following basic equation can represent the relationship of the future cost and its present value:

$$\mathrm{P} = F\left[\frac{1}{1+\mathrm{d}r}\right]^{n} \qquad \text{Equation 2}$$

where P is the present worth of a future cost, F is the future cost occurring after n time period from the present, n is the number of time periods at which F is incurred, and dr is the discount rate in decimal.

The discount rate used in roadway LCCA is a function of both the interest rate and the inflation rate. In general, the interest rate (often referred to as the market interest rate) is associated with the cost of borrowing money and represents the earning power of money. Low interest rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high interest rates favor reverse combinations. The inflation rate is the rate of increase in the prices of goods and services (construction and upkeep of highways) and represents changes in the purchasing power of money. The discount rate used in roadway LCCA is approximately the difference of the interest rate minus inflation rates. Discount rate represents the real value of money over time. The exact mathematical relationship between the discount rate, the interest rate, and the inflation rate is as follows [31]:

$$d_r = \left[\frac{1+i}{1+f}\right] - 1 \quad \text{Equation 3}$$

Where: dr = discount rate, decimal

f = inflation rate, decimal

I = interest rate, decimal

Selection of an appropriate discount rate is highly debatable. The FHWA Office of Engineering, Pavement Division, conducted a pavement design review and found that the discount rates currently used by State Highway Agency to have a distribution of values clustering in the 3 to 5 percent range [31].

There are many factors that affect the time value of the money or the discount rate; the most significant of these are the earning capacity of the money and the inflation.

2.5.2. Interest rate

This represents the annual yield of the principal if invested in some form, such as bonds, treasury bills, or a bank savings account. When interest paid over a specific time unit is expressed as a percentage of the principal, the result is called the **interest rate** [32]**.**

2.5.3. Inflation

Besides the above discussion of the effects of inflation on the discount rate in LCCA, inflation can be utilized for another purpose in LCCA. It is not uncommon to find that the available documented prices of construction, material, labor, or any LCCA-related components are dated. When this is the case, these unit prices must be converted to today’s value by “inflating” them. This can be done by multiplying the dated price by the relative increase in the price index between the date of the price and the present. Price indexes can be a broad-based price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index when the dated prices concern general items such as the value of time. Alternatively, a specific price index such as the Highway Construction price index can be considered a better indicator for prices related to construction activities [1].

2.5.4. Analysis period

Like all transportation assets, highway pavements are aimed to be designed and constructed so that they can provide service for a longer period of time. The service life of a facility may generally be defined as the time (or cumulative value of some usage parameter such as loading) that elapses between initial construction and the next construction, and typically exceeds one decade for highway pavements. The facility service life depends on the minimum level of service and the rate of facility deterioration. The overall service life of a facility may be considered an aggregation (sometimes overlapping) of the service life of the pavement design (assuming zero maintenance) and the individual service lives of various rehabilitation and maintenance treatments that comprise the preservation strategy. Competing pavement design alternatives may vary in service life. As such, in order to make an impartial comparison between alternatives, it is useful to either express all costs and benefits in their equivalent annual value, or utilize a fixed time frame for all alternatives. In the latter case, such fixed time frame is referred to as the analysis period or time horizon [33].

The analysis period is the period chosen over which the facility performance will be analyzed in Life Cycle Cost Analysis [1]. Conceptually, this period should represent the useful life of the associated facilities/assets affected by the decision, or in other words, the period over which the project will be in operation [1]. In the ideal case, the analysis period is equal to the overall facility service life, but in many cases, is less or more than the service life [33].

Many of the public projects are expected to be in operation for as long as it is needed or for an indefinite period. When planning an interstate highway, we do not plan the project to be operational for some specific period after which the highway will be demolished and its right-of-way will be transferred to other uses. In such cases, the analysis period chosen when conducting LCCA has to be estimated by the service life of the most durable component of the facility, which is typically the component that carries the higher portion of the initial cost [1].

This period should be sufficiently long enough to reflect long-term differences between different design and rehabilitation strategies, and it may contain several maintenance and rehabilitation activities, as conceptualized in Figure 3 [1, 29].

When options involving facilities with different economic lives are being compared based on their life cycle cost, it is recommended that the analysis period is set the same for all options, and this period should be equal to the useful life of the most durable option. Also, the FHWA cautions that the analysis period should not drive the decision, and asserts that a robust decision can be made only if the analysis period is of sufficient length. In other words, if a sufficiently long analysis period is used for the analysis, incremental changes in the analysis period are not likely to change the decision supported by the LCCA [33]. For assets having useful life remaining at the end of this timeframe, a residual value/salvage value should be estimated [1].

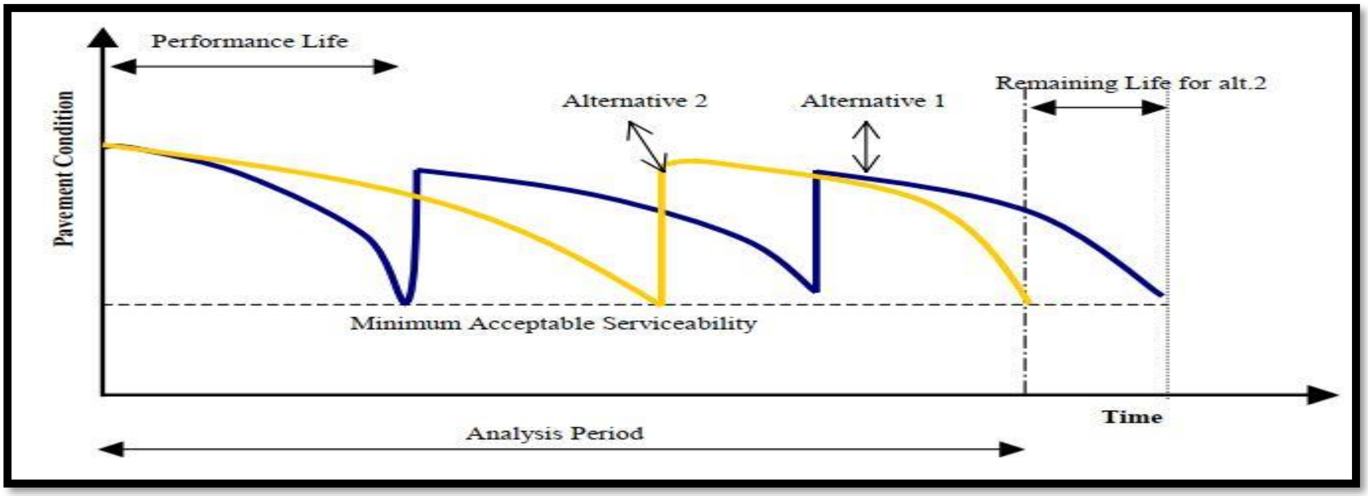


Figure 3: Conceptual Graph Representing the Serviceability of a Facility over Time/analysis period

Analysis period, or the time horizon over which alternatives are evaluated, should be enough to reflect long-term cost differences associated with reasonable design strategies. While FHWA's LCCA Policy Statement recommends an analysis period should not be less than 75 years for major bridge, tunnel, or hydraulic system investment and 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects. an analysis period range of 30 to 40 years is not unreasonable. The following graphical representations of expenditures over time was developed to help visualize the extent and timing of expenditures [29].

One approach, favored by some economists, for deciding on the analysis period in long term public projects is to use a "floating" time period. A floating time period is determined as that point in the future where the costs and benefits, discounted to present-day terms, become negligible (i.e. they fall below some selected threshold). The discount rate used is then the prime factor in determining the extent of the floating time period [1].

The FHWA LCCA Interim Technical Bulletin published in 1998 [29], states that it might be appropriate to deviate from the recommended minimum 35-years analysis period for pavement projects when slightly shorter periods could simplify salvage value computations. It further recommends a shorter analysis period (i.e. ten years) when analyzing pavement rehabilitation/reconstruction projects. The recommended analysis period for new pavements is between 25 and 40 years and between 5 and 15 for rehabilitation alternatives.

However, factors such as geometry and traffic capacity may have a bearing on the analysis period. Walls and Smith [1998] argue that regardless of the analysis period selected, the analysis period used should be the same for all alternatives. However, this issue may be further investigated, because it seems that different analysis periods could be used in cases where EUAC is used as a measure of economic efficiency.

2.5.5. Rehabilitation Timings

This parameter is one of the highly uncertain and sensitive parameters in the LCCA model. Future activities can be classified as Cyclic activities and future activities that do not recur on a cyclical basis. The former one covers the activities that take place on a cyclical basis like annual maintenance and user costs/activities during normal operations. Generally, the timing of these activities corresponds to the time cycles, which is taken as incremental number of years in LCCA. The later covers all rehabilitation, restoration, and resurfacing activities. The main factor that should affect the timing of these activities is the pavement condition. Nevertheless, in practice, there are other exogenous factors that affect the actual timings of these activities such as resources constraints within the agency. For those reasons, the timings of these activities are among the most important yet uncertain parameters in LCCA [1].

2.5.6. Remaining service life (RSL)

In many cases, LCCA pavement design and preservation scenarios are such that there is some residual pavement level of service at the end of the analysis period. In other words, the pavement can still serve for some more years beyond the analysis period. Some literature refers to such extra service life as remaining service life. The FHWA cautions that failing to account for such remaining service lives can result in a biased LCCA output. Figure 4 shows how remaining service life is calculated [23].

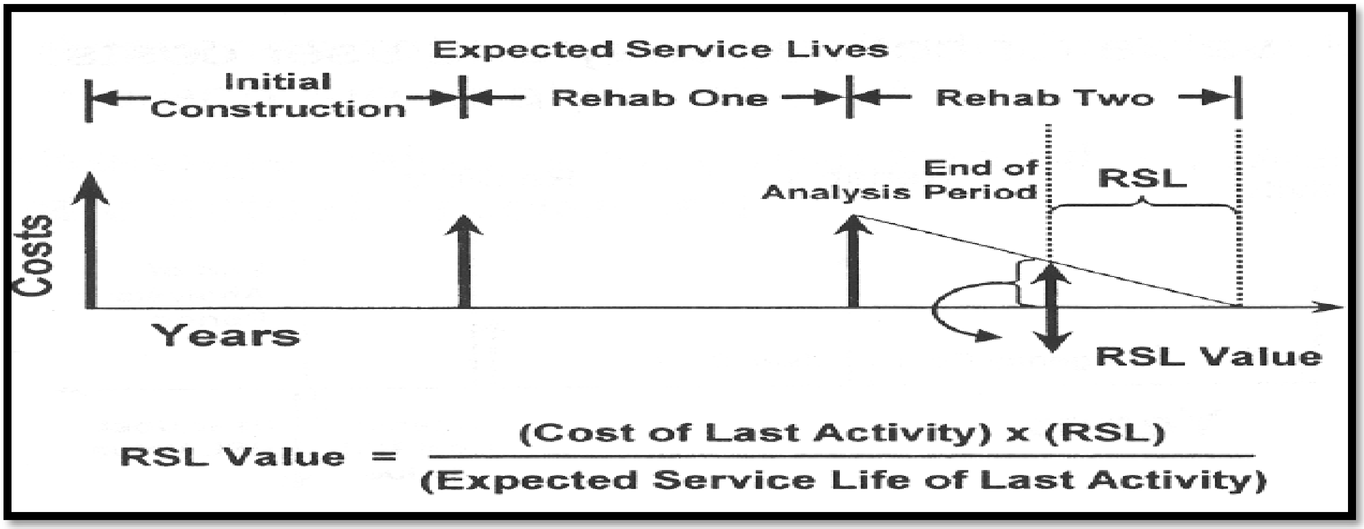


Figure 4: Calculation of Remaining Service Life

The figure shows that at the end of the analysis period, there may be some remaining service life from rehabilitation number 2. The RSL is calculated by performing a straight-line depreciation of the cost of the last rehabilitation activity over the course of its expected service life. The RSL is considered as a benefit, or a negative cost that occurs at the end of the analysis period and is therefore discounted to present value and added to the present value of other cost streams. The application of the RSL concept to agency costs of pavement preservation treatments is generally straightforward and accepted. However, the user costs associated with such activities is not as intuitively obvious [FHWA, 1998]. User costs are less definitive than agency costs, but like agency costs, there is some “benefit” or “avoidance” of user cost due to an RSL: the remaining service life of a preservation activity has the effect of deferring the next expenditure of user costs. Without RSL for user costs, the decision supported by user costs can change as the analysis period changes unless very long analysis periods are used. The FHWA states that using RSL or user costs removes bias from the analysis. The FHWA argues that the user “pain and suffering” was fully experienced and cannot be assuaged at the end of the analysis period. The subsequent imposition of user costs due to the next work zone operations is simply being delayed and some LCCA “benefit” should be recognized and taken for such deferment. Also, the FHWA cautions that User Cost RSL is not User cost salvage value as the latter does not really exist in the true sense of the word.

2.6. Costs in LCCA for pavement projects

based on the bearing entity of the costs, costs in LCCA for pavement projects are classified into Agency, user, and social costs. Even though the theory behind LCCA does not implicate any differential treatment for these types of costs, LCCA practices have calculated them separately, since the provision that the decision-makers may weigh them differently.

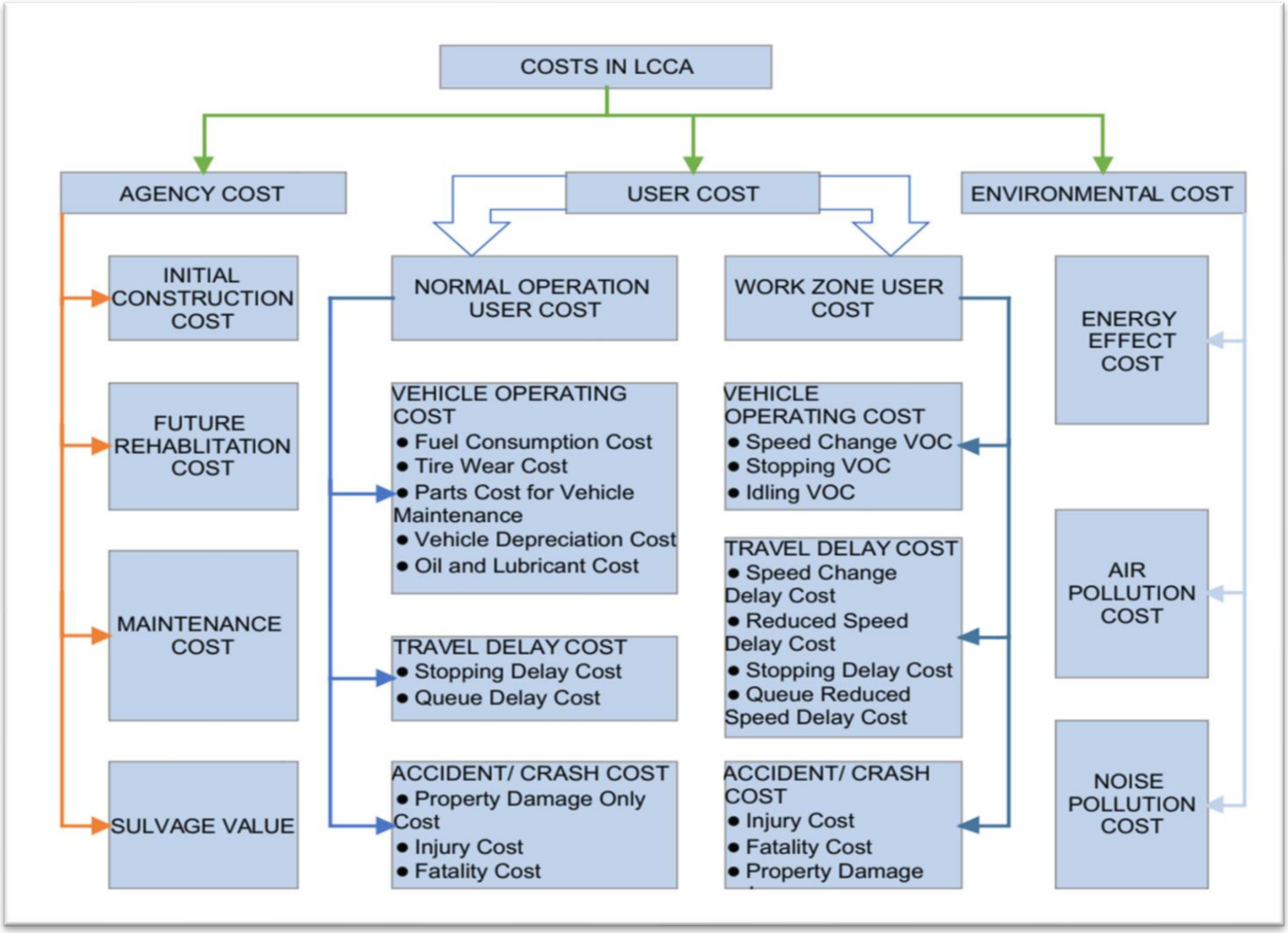


Figure 5: Cost Components Frame Work [33]

2.6.1. Agency cost

Management of any civil infrastructure is associated with costs incurred by the responsible agency including initial costs associated with feasibility studies, engineering design, construction, operation of the facility, maintenance and rehabilitation, and disposal costs. In the context of LCCA for pavement design, preliminary costs such as feasibility and engineering studies are excluded, as they are typically common among all pavement alternatives and LCCA needs only consider differential costs between alternatives. Agency costs include all costs incurred directly by the agency over the life of the project. They typically include initial preliminary engineering, contract administration, construction supervision and construction costs, as well as future routine and preventive maintenance, resurfacing and rehabilitation cost, and the associated administrative cost. Agency costs also include the maintenance of traffic cost and can include operating costs such as pump station energy costs, tunnel lighting, and ventilation. Cost analysis is a cardinal element of any

LCCA study. Initial cost is no longer considered the sole criterion in evaluation of a pavement projects or the selection of project alternatives. In the current state of pavement design and management practice, all costs incurred over the life of the pavement are considered. These include rehabilitation and maintenance costs, and salvage value. However, the changing value of money over time means that some adjustment has to be made to bring all such costs to constant dollar [31].

According to FHWA, (2003) agency Costs are the costs that are assumed by the agency as a result of putting the facility in service at the outset and maintaining its function at an acceptable level. Agency costs consist of the costs of initial construction, rehabilitation and upgrading, periodic maintenance, engineering, and agency overhead. Initial construction, maintenance, and rehabilitation costs cover the costs of material, labor, machinery, traffic control, and any other contingencies. These costs can be estimated from recent bids and historic records, provided that inflation is considered. Most highway agencies keep detailed records of such data, and generally, acquiring these costs is a straightforward matter. Engineering judgment can assist in estimating such costs when new materials or technology is used in the project [1].

2.6.1.1. Capital cost

Capital costs represent the initial outlay of expenditure required to start up a project (planning, design and construction). There are a number of inputs and activities that make up the total capital costs for a road project. Each input and activity must be estimated as accurately as possible and a project plan is often required to determine the timing and duration of each task. The timing of capital cost expenditure must also be estimated. The makeup of capital expenditure can include; design and construction costs, earthworks, pavement and seal, intersection work, value of land resumptions or voluntary acquisitions, value of any land purchased at an earlier date even if the land has been in Crown ownership for several years, costs of environmental mitigation such as noise barriers, fencing, landscaping or drainage, project construction and design contingences, project management and other professional costs.

2.6.1.2. Maintenance cost

Maintenance costs include all Laboure, machinery and materials costs for routine, periodic and rehabilitation maintenance. Estimates of annual expenditure required to maintain and preserve road infrastructure can generally be determined based on historical expenditure levels. According to [23], Changes in maintenance costs commonly arise when:

1. pavement improvement reduces the need for maintenance costs
2. the maintenance effort is reduced in line with declining traffic volumes. In this situation, the gain to a project from reduced maintenance may be offset by increases in user travel time and VOC, and decreased benefits from the lower amount of traffic using the road

3. maintenance costs may be higher in the project case due to an asset extension, e.g. the addition of an overtaking lane
4. maintenance effort is increased to improve service standards or to postpone the need for capital works.

Consistent with FHWA methodology, maintenance costs are considered part of the ‘cost’ measurement in the LCCA. This recognizes an assumption that the road agency’s objective is to efficiently utilize all resources, not only its capital budget. As such, any saving in maintenance costs as a result of a project, is considered as a reduction in costs in a whole-of-life context.

2.6.1.3. Salvage values

While many sources of literature consider the terms salvage value, residual value, and remaining service life to be synonymous, the FHWA appropriately makes a clear distinction between these terms. The FHWA attaches a physical connotation to the concept of salvage value and argues that it is strictly defined as the value of recovered, recycled or scrap materials, and can only be realized when the entire pavement structure is excavated at the end of the analysis period and the pavement materials are actually reclaimed. In that case, the value of the salvage is treated as a negative agency cost. It is the estimated remaining value of the project at the end of the analysis period. It represents the capacity of the asset to accrue benefits past the end of the evaluation period.

For example, a concrete bridge structure with a life of 100 years has a capital expenditure of $10 million. If the evaluation period is 30 years and the project life is 100 years then this represents a 70% remaining life of the bridge. Using a straight-line depreciation method, the residual value would be $7 million. The depreciated value of the new bridge after 30 years represents the minimum value that could be returned. The maximum value would be the present value of the benefits (road user cost savings) the project could produce between years 31 and 100. The residual value is treated as a negative value, reducing project capital costs When using a residual value, it is important that the method used to calculate it is appropriate and the value is justifiable. It is generally recommended that specialized economic advice be sought to calculate the residual value. The discounted salvage value is deducted from the total costs when calculating the net present value [1].

There is no general consensus on how to estimate the salvage value, primarily because infrastructure projects are never terminated at the end of analysis period. One approach to estimating this component is by accounting for the costs of demolition and removal as well as adding the value of the recycled project waste. Another approach is by calculating the relative value of the remaining serviceability of the alternative with respect to the cost of the last rehabilitation activity [34]. Each approach has its own critics, and one way to avoid such added dubious calculations is to adjust the analysis period slightly, so as that the remaining serviceability is the same for all alternatives and the salvage value can be omitted from calculations.

2.6.2. User cost

User costs are costs incurred by the highway user over the life of the project depend on the highway improvements and associated maintenance and rehabilitation strategies over the analysis period. User costs form a substantial part of the total transportation costs [Greenwood et al.,2001] for highway investments and can often be the major determining factor in life-cycle cost analysis.

In LCCA, highway user costs of concern are the differential costs incurred by the motoring public between competing alternative highway improvements and associated maintenance and rehabilitation strategies over the analysis period. In the pavement design arena, the user costs of interest are further limited to the differences in user costs resulting from differences in long-term pavement design decisions and the supporting maintenance and rehabilitation implications. User costs are an aggregation of three separate cost components: vehicle operating costs (VOC), user delay costs, and crash costs [22].

There are two dimensions of highway user cost [33]:

- user cost categories (work zone user costs and non-work zone user costs), and
- user cost components (vehicle operating costs, travel time costs, and crash/accident costs).

User costs are the costs encountered by the project users. These costs generally occur during the lifetime of the project.

1. The cost of travel delay time during normal operation and work-zone operation.
2. Vehicle operating costs during normal operation and work-zone operation (e.g. some LCCA literature considers this type of costs real or out-of-pocket costs). User costs are estimated differently during the normal operation of the facility and during work-zone operation.

2.6.2.1. Normal Operation/Non-Work Zone User Costs

According to [33], the main components of normal operation user costs are Vehicle operating costs, travel time costs, crash costs.

Vehicle operating costs are mileage-dependent costs of running automobiles, trucks, and other motor vehicles on the highway, including the expenses of fuel, tires, engine oil, maintenance and the portion of vehicle depreciation attributable to highway mileage traveled. Factors affecting vehicle operating costs include vehicle type, vehicle speed, speed changes, gradient, curvature, and pavement surface. Vehicle operating costs have long been of interest to engineers since they form a significant portion of road user costs. This has resulted in the development of a wide range of models for VOC computation.

Travel time costs refer to the value of time spent in travel and include costs to businesses of time by their employees, vehicles and goods, and costs to consumers of personal (unpaid) time spent on travel, including time spent parking and walking to and from a vehicle. Travel-time savings is an important component of user benefits because savings in travel time are often the greatest potential benefit of transport improvement. Studies have shown that the value of time is sensitive to a variety of factors such as income level, type of trip made, time of day or amount of time saved and congestion. There are some popular approaches for estimating value of time. These approaches include modal choice approach, route choice approach, speed choice approach, travel demand approach and travel time budget approach. This section reviews four models used for valuing travel time.

Crash costs are costs related to motor vehicle traffic crashes. They include fatality, injury and Property Damage Only (PDO) costs. Usually these costs are estimated by multiplying the number of crashes for each crash type by the average cost per crash. The FHWA *Real-Cost* Software does not consider crash costs for LCCA obviously because an FHWA study (Construction Cost and Safety Impacts of Work-zone Traffic Control Strategies) concluded that there were no significant impacts on crash rates due to work zones. Nevertheless, various research efforts have attempted to provide models for crash costs estimation, particularly during normal operations. Some of the methodologies in use for computing crash costs are discussed in the following sections. As these are for normal operations, they do not vary be pavement design and preservation alternative and are therefore added here only for academic purposes.

2.6.2.1.1. Travel Delay Costs

The cost of travel delay time during normal operation is typically a function of the distance and the vehicle speed, which is dependent on the demand and capacity of the facility. All of these factors are expected to be equivalent for all alternatives in LCCA (i.e. project-level and secondary analysis), which leads to the exclusion of this type of costs. On the other hand, travel delay time during the work zone operation of rehabilitation activities depends on many other factors such as the work-zone plan (i.e. Number of lanes closed, time of day of operation, and number of days of operation),traffic volume and characteristics, and vehicle speed (during normal operation and during work-zone). Even though the calculations needed for this type of costs are cumbersome, some computer programs can be utilized to estimate them independently of LCCA such as Queue work zone, or as part of LCCA such as the FHWA Probabilistic LCCA program, which incorporates a sub-module for calculating the user costs during work zone operation. The importance of including user delay time during work-zone operation has been increasingly emphasized in all LCCA literature. These costs can exceed agency costs during rehabilitation activities by far, especially on highly traveled facilities in urban areas. Moreover, increasing scrutiny by the public of the unwarranted delay time costs they are incurring because of mismanaged work-zone activities makes these costs as relevant as agency costs, if not more. The FHWA technical bulletin [29]provides a detailed eight-step procedure of how to estimate these costs.

2.6.2.1.2. Vehicle Operating Cost

At this level of the LCCA, Vehicle Operating Costs (VOC) is dependent on the facility serviceability (i.e. pavement roughness) and the traffic volume and characteristics only, since the roadway curvature and gradient are similar for all alternatives. The VOC includes fuel consumption, lubricant consumption, tire wear, labor and parts costs for vehicle maintenance, and depreciation. In order to estimate these costs, two types of models are needed; models that accurately predict facility serviceability (i.e., pavement performance models) and models that relate VOC of different types of vehicles (i.e., passenger cars, commercial vehicles) to pavement serviceability.

Academic literature contains many models that have been developed for this purpose. Highway agencies can either utilize general models that are appropriate to their relevance, calibrate available models to local conditions, or develop their own models from databases of their pavement management systems (PMS). The FHWA LCCA technical bulletin considers that vehicle-operating costs (VOC) are equivalent for different alternatives when the level of serviceability is maintained above the threshold (PSI is above 2.5), and accordingly suggests that VOC’s during normal operation can be excluded from LCCA [29].

Other types of user costs include discomfort and reliability. In the LCCA literature there is no evidence that these costs had been included in the analysis mostly because it is not proven that such costs vary between different alternatives [1].

2.6.2.1.3. Accident Cost

Accident costs have been estimated as a dollar per unit length for different types of facilities (rural, urban, freeway, etc.). Some research has estimated accident rates as a function of skid resistance, but this is a special case in which aggregates used in the wearing surface might differ between alternatives. In general, there is not enough research that shows that the accident rate can vary among alternatives with different serviceability, neither is there research about the rates of accidents during work-zone operation even though such costs might vary among alternatives [1].

2.6.2.2. Work Zone User Costs

A work zone is defined in the Highway Capacity Manual (HCM) as a segment of highway in which maintenance and construction operations impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the segment. Work zone is defined in the Manual on Uniform Traffic Control Devices (MUTCD) as an area of a highway with construction, maintenance, or utility work activities. A work zone typically is marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles [35]. The practitioners can use their discretion in selecting appropriate work zone impacts to be used in WZ RUC analysis. Work zone operations results in three types of vehicle operating costs, which include speed change vehicle operating costs, stopping vehicle operating costs and idling vehicle operating costs [36].

2.6.2.2.1. Vehicle Operating Cost

VOC includes the consumption costs of the following resources:

- Fuel consumption.
- Engine oil consumption.
- Tire-wear.
- Repair and maintenance.
- Mileage-related depreciation.

In Work Zone Road User Cost analysis, VOC is an aggregation of the following components [35]:

- **Speed Change Vehicle Operating Costs (VOC):** This is the additional cost under unrestricted conditions associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed after leaving the work zone.
- **Stopping Vehicle Operating Costs (VOC):** This is the additional cost under restricted conditions related with stopping from the upstream approach speed and accelerating back up to the approach speed after traversing work zone.
- **Queue Idling Vehicle Operating Costs (VOC):** This is the additional cost associated with stop-and-go driving in the queue. The idling cost rate multiplied by the additional time spent in the queue is an approximation of actual VOC associated with stop-and-go conditions. When a queue exists,
- stopping delay and VOC replace the free-flow speed change delay and VOC.
- Detour VOC is the additional cost associated with the excess distance to be traveled by selecting a detour route under unrestricted or restricted conditions.

2.6.2.2.2. Travel Delay Costs (TDC)

Travel delay costs constitute a significant proportion of road user costs. The NHCRP report 456 states that travel time savings is usually the primary user benefit for transportation projects. In quantifying travel delays for work-zone operations, four types of delay costs are considered. They include speed change delay, reduced speed delay, stopping delay and queue delays [FHWA, 1998]

- Speed Change Delay Costs (**TDC**): This is the additional time required to decelerate from the upstream approach speed to the work-zone speed and then accelerate back to the initial approach speed in the wake of crossing the work zone.
- Reduced Speed Delay Costs (**TDC**): This is the additional time required to traverse the work zone at the lower posted speed. It relies on the upstream and work zone speed differential and length of the work zone.
- Stopping Delay Costs (**TDC**): This is the additional time required to come to a complete stop from the upstream approach speed and accelerate back to the approach speed after traversing the work zone.
- Queue Reduced Speed Delay Costs (**TDC**): This is the additional time required to go through the queue that is formed as a result of the work-zone.

2.6.3. Environmental Cost

The environmental impacts could affect the air, water, biodiversity, natural resources, noise, and heritage. Among these, only the costs of air pollution and noise have been monetized up to date in transportation evaluation [1].

The environmental effects model of the HDM-4 is a more comprehensive model and was used in this study. It generates the environmental costs based on three major environmental effects: Air pollution from vehicle emissions and noise pollution. The HDM-4 model primarily estimates effect of the following air pollutants associated with vehicle emissions: Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO2), Nitric Oxides (NOx), Sulphur Dioxide (SO2), Lead (Pb) and Particulate Matter (PM). The model predicts the emission rates (g/km) as follows [37]:

$$TPEi = EOEi * CPFi \qquad \text{Equation 4}$$

Where TPE_i is the tailpipe emissions in g/km for emission type i; EOE_i is the engine out emission in g/km for emission type i and CPF_i is the catalyst pass fraction for emission type i.

2.7. Construction Cost Estimation Models

Cost estimation of construction projects with accuracy at the early phase of project development is crucial for planning and feasibility studies. However, a number of difficulties arise when conducting cost estimation during the early phase. Major problems include lack of preliminary information, lack of database of works costs, lack of appropriate cost estimation methods, and the involvement of many environmental, political, social and external uncertainties. Given its significance, conventional tools such as regression analysis have been widely employed to tackle the problem [38].

Levinson et al., (2003) have developed a regression model to predict the cost of new links and expansion as a function of the year of completion, duration of, and the distance from the nearest downtown. According to (Sodikov, 2005) Regression models have been proven to be reliable and used for decades. Regression models have an advantage in that they can be defined by mathematical expression and explain relationship between dependent variable and independent variables. They are widely used and have been proven to be reliable in cost estimation for decades [38].

In the case of Ethiopia, a conceptual and preliminary cost estimating models was developed for asphalt road construction projects using historic data, statistical tools such as SPSS, and Rsoftware's by [38] based on sixteen sets of data collected in the Federal Road Projects. As a result, six regression cost estimating models which include bid quantities, and project size (i.e. road length and road width) as input variables were developed to estimate the total cost of road construction project.

Model №	**Regression models**
1	Total cost (ETB)= 26.58X1 + 119.4X2 + 97.62X 3
2	Total project cost =45.7 X1 + 151.4X2 +195.24X3
3	Total project cost = 1067.57X3
4	Total project cost = 7888.25X5
5	Total project cost = 747.85X4 *X5
6	Total project cost = Earthworks cost + Sub base and Base coarse works cost + Asphalt works cost + Furniture cost. Where; Earthworks cost = 55.76X4X5, Sub base and Base works cost = 83.42X4X5, Asphalt works cost = 109.85X4X5, Furniture works cost = 23.38X4X5.

Where,

X1 = Earthwork; cut, fill, and topping quantities (m3)

X2 = Sub base and Base coarse quantity (m3)

X3 = Asphalt quantity (m2)

X4 = Road width (m)

X5 = Road length (m)

4 of the above models include bid quantities as independent variables (models 1 through 4), while the other two models include road length and road width as independent variables (**Models 5 and 6**). It should be noticed that in the very early stages the bill of quantity (**BOQ**) is not available, meaning that the models using road width and length (Models 5 and 6) are easier and more fit to be used. Later, when the BOQ is

available, the models based on BOQ (models 1 through 4) may be used.

2.8. Economic Evaluation

In principle, economic evaluation is performed by accounting for all the monetary equivalency of costs and benefits resulting from project implementation, taking into account their respective times of occurrence. At times economic analysis is confused with financial analysis, so it is imperative to differentiate between these two types of analyses. This will eliminate any possible ambiguity in the theoretical basis of LCCA [1, 31].

Financial analysis comprises the comparison of revenues and expenses (initial investment, maintenance, and operating costs) recorded by the concerned fiscal agents in each project alternative (if relevant) and working out the corresponding financial return ratios. Economic analysis, on the other hand, consists of identifying and comparing fiscal as well as social benefits and costs accruing to the economy as a whole, setting aside, for example, monetary transfers between economic agents [1].

Life Cycle Cost Analysis is an economic evaluation technique that has been particularly valuable when there is a need to compare competing alternatives for projects with entailing costs and benefits that stretch over long spans of time. As a starting point, it is necessary to expound on three underlying principles that mold LCCA in the approach currently employed in transportation evaluation and recognized by its analysts. The three topics cover financial analysis and economic analysis, the systems method, and the levels of analysis [1].

2.9. Past Studies

Sprague et al. (1989) conducted a short-term and long-term field evaluation on using separation geosynthetic in a permanent road. A LCCA which included agency costs only was included in the study to examine the cost-effectiveness of using geosynthetic in the pavement. A 2.5 km trial section was built in Greenville County, Virginia. Three pavement cross-sections: 64mm full depth HMA, 38mm HMA over 76mm stone base, and a triple treatment surface course over 75mm stone base were evaluated. Approximately 150m each of three different types of geotextiles, 135 and 203 g/m2 needle-punched nonwoven geotextile and a 135 g/m2 silt film woven geotextile, were installed between the subgrade and each pavement section. The remaining length of the road was to act as a control section for the long-term evaluation of each pavement section. Periodically, an independent pavement visual surface inspection program was applied through the sections. A pavement management computer program, Micro Paver, was utilized in this study. The result shows that geotextiles provide subgrade/stone base interface stability which increases the life and reduces the maintenance cost of a pavement section [39]

When evaluating the use of geosynthetic materials as reinforcement in aggregate placed over soft subgrades, the initial soil strength of the test area was too high for the research objectives, so the test site area was flooded for nearly eight months. The flooded area was drained, resulting in a CBR value of approximately 1% for the test site subgrade. The subgrade was covered with a geosynthetic materials, and then overlaid with an aggregate layer of varying thickness. It was found that geosynthetic materials improved the performance of the pavement [40].

Studies show that pavement sections with geosynthetic materials can carry three times the number of loads as conventional unreinforced pavements, and allowed up to 50% reduction in the base course thickness [41]. When evaluated in terms of effectiveness, geosynthetic materials can improve the performance of road. By reducing the undercut and thickness of base and subbase layers, geosynthetic materials can save initial construction cost of road also the life cycle cost by increasing the design life of the road. It is recommended to perform an economic evaluation of a proposed reinforced pavement with life-cycle cost analysis to conclude effectiveness of geosynthetic on permanent paved roads [42].

CHAPTER III

RESEARCH METHODOLOGY

3.1. Study Area

This research was conducted in Addis Ababa the capital city of Ethiopia which had founded in 1886, it is the largest city in Ethiopia, with a population of 3,384,569 according to the 2014 population census with annual growth rate of 3.8%. Addis Ababa is located in geographic coordinates between 9° 1′ 48″ *N* and 38° 44′ 24″ E and elevation of 2,355 m above mean sea level. Due to large traffic the city administration construct and maintain the roads more highly than ever. The place where geosynthetic material application conducted was on National theater center and around Gandhi Hospital which is located in Kirkos sub-city in Addis Ababa city administration [43].

The total length of the road segment up on which geosynthetic material applied was around 1.25 km. Of this length a unit length was considered in this analysis since majority of the user costs are calculated per vehicle kilometer.

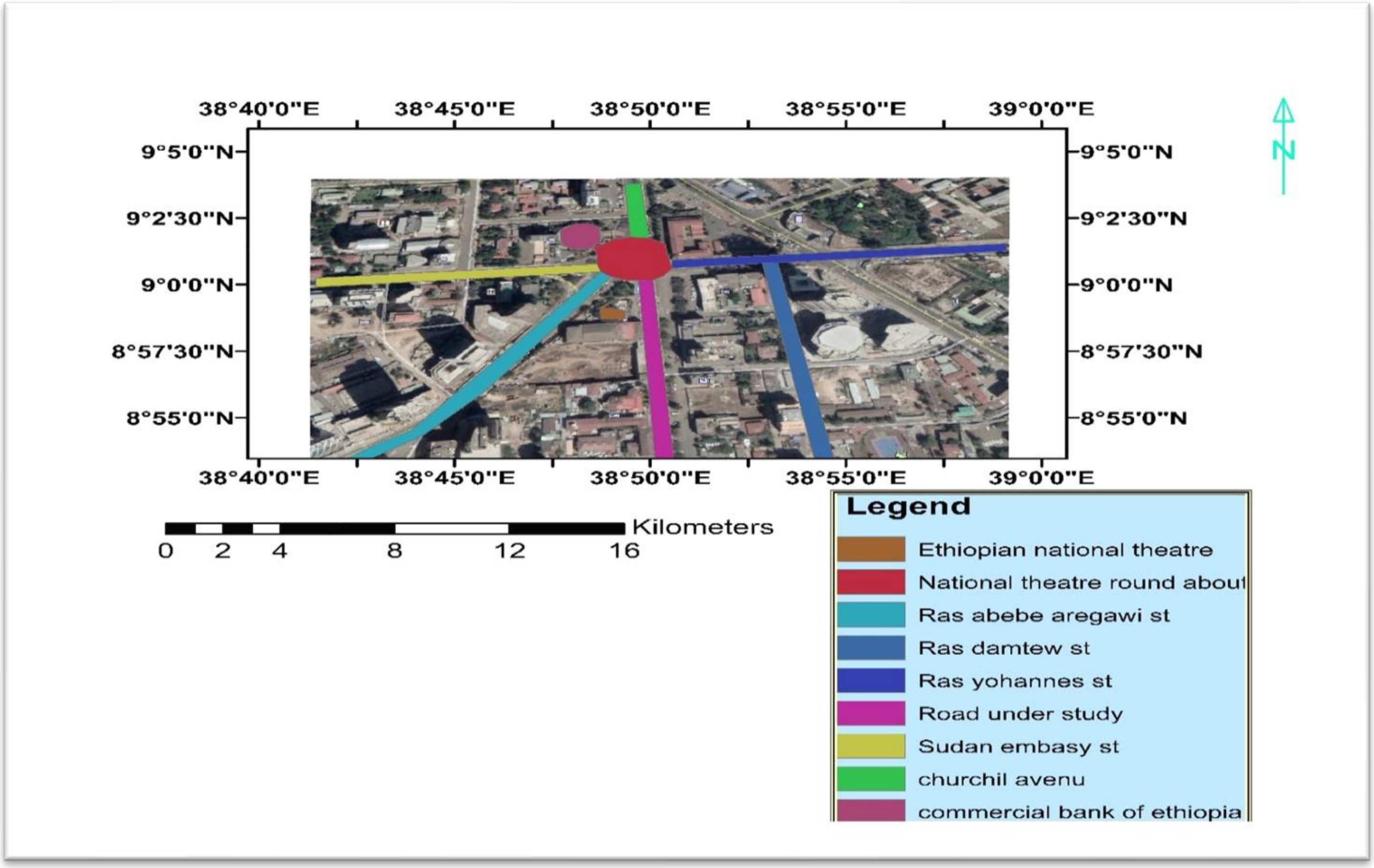


Figure 5: Map of Study Area

3.2. Research design

The present study utilized quantitative methodology. It employed an informal interview and field survey as the research instrument. The data collection was based on interview and field survey and these served as the primary instrument. The review of desk researches was conducted in order to accumulate enough information pertaining to the objectives of the study.

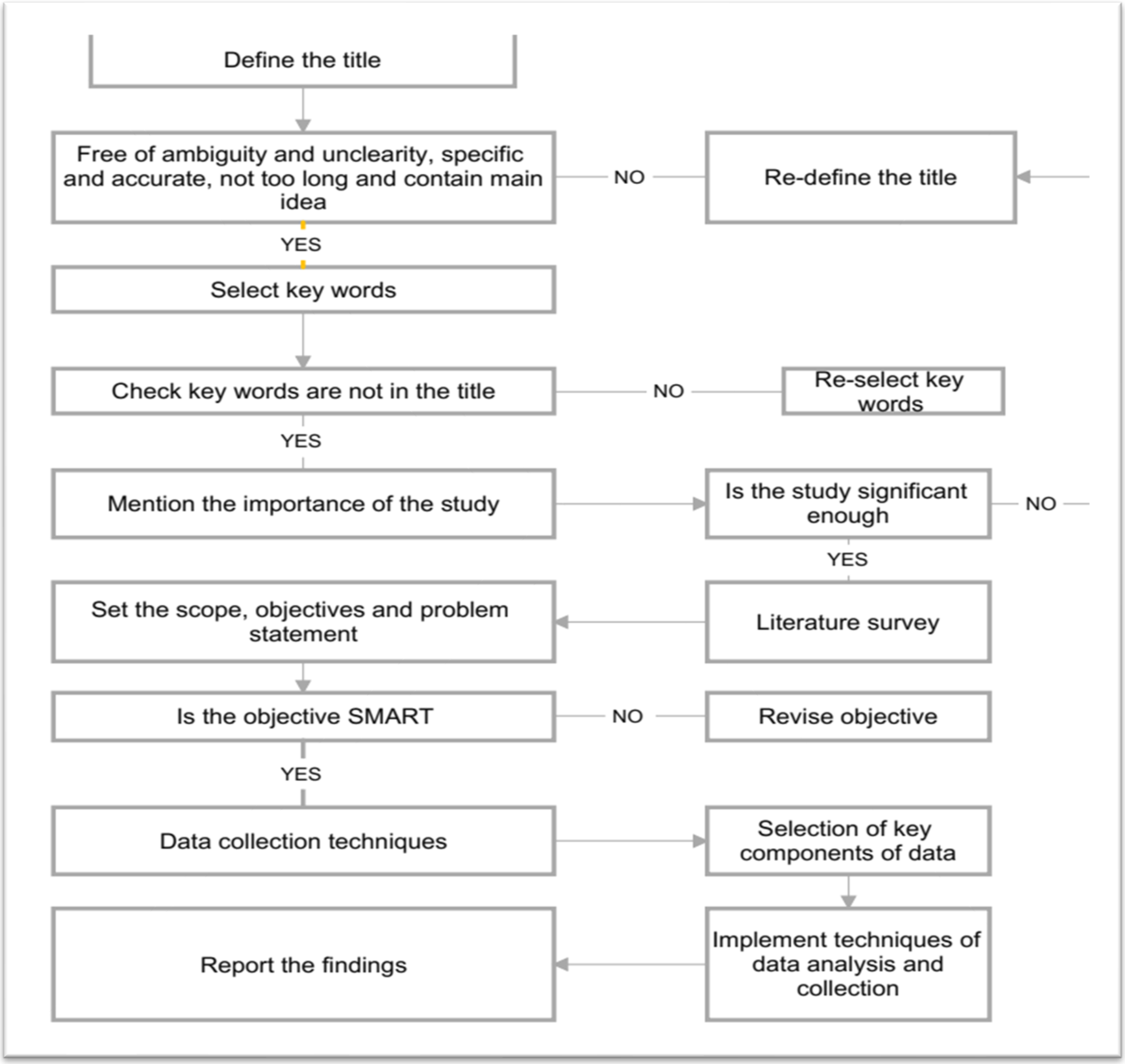


Figure 6: Designed Research design frame work

3.3. Target Population

The study targeted the Addis Ababa road project which have flexible pavement with geosynthetic materials along the stretch in general and to have optimum comparison to meet the desired objectives. The selected road project was particularly the road around the national theater in front of Gandhi hospital.

3.4. Study Variables

A variable is an empirically applicable concept that takes on two or more values.

- **Dependent variables**

These are the variable that are going to be explained and are the expected outcome of the independent variables. These are;

- Life cycle cost of flexible pavement with and without geosynthetic materials.

- **Independent variables**

These are Explanatory variables and are the hypothesized cause of a dependent variables. In this study;

- Initial construction cost
- Maintenance/Rehabilitation cost
- Vehicle operating cost
- Travel time cost
- Traffic volume/AADT
- Design period
- Analysis period
- Road way capacity
- Travel speed on the road segment
- CBR

3.5. Type and Sources of Data

Collecting reliable and accurate data is the most determinant factor for any research as it determines the quality of research. The most important data for this research was design periods, analysis periods, pavement layers data, updated traffic data (AADT, traffic growth rate, percentage of passenger cars, percentage of single unit truck), travel speed on the road segment, traffic accident data, CBR of soil, market survey (unit rate), maintenance and rehabilitation strategies. To obtain these data secondary data sources were used. These are pavement design documents, manuals, internet, research reports, books, journals and other documents in governmental institutions.

Table 1: Data Type and Source of Data

No	Types of Data	Source of Data
1	Design and analysis period	ERA, Addis Ababa City Road Authority, FHWA.
2	Traffic data (AADT)	ERA, Addis Ababa City Road Authority, Road Transport Bureau
3	Vehicle growth rate	ERA, Addis Ababa City Road Authority, Road Transport Bureau
4	Material properties	ERA, Addis Ababa City Road Authority
5	Market survey data	ERA, Addis Ababa City Road Authority
6	Percentage of Vehicles	Field Survey Taking a Sample
7	Roadway Data	Field Measurement
8	Other relevant data	ERA, AACRATB, AASHTO, FHWA, HCM, websites

3.6. Data Collection Methods and Instruments

The specific techniques to be used in the collection of data was document review, websites, field measurement and manual review. The instrumentation to be used in data collection was internet and recommendation letter. The informal interview has also played a great role in collecting important data.

3.7. Data processing and analysis

The data gathered were analysed for the purpose of answering the research questions. They were presented narratively, tabularily and graphically. Demographic variables of the respondents were also collected to support data to understand the overall analysis. The data analysis utilized was the the excel spreade sheet. This was done through the following governing steps.

Selection of Analysis Period

As per the brief recommendation presented in chapter two of this document a period of 25 years was considered for the analysis assuming costs and benefits of the most durable option, discounted to present day terms, become negligible at this time.

Design Period

Since the road under consideration is a link road as it connects different major roads and hence the design period of 20 years for flexible pavement with geosynthetic materials and conventional pavement for reconstruction was taken from the design document of road under study.

Table 2: Design Period [46]

Road Classification	Design Period (years)

Trunk Road	20
Link Road	20
Main Access Road	15
Other Roads	10

Interest Rate

In Ethiopia, interest rates decisions are taken by Monetary Committee of the National Bank of Ethiopia. The official rate is the bank's savings rate. The benchmark interest rate in Ethiopia was last recorded at 7 percent by the end of the first quarter 2019, according to Trading Economics global macro models and analysts' expectations which shown in figure 11 below. Looking forward, they estimated Interest Rate in Ethiopia to stand at 7.00 in 12 months' time. In the long-term, the Ethiopia Interest Rate is projected to trend around 7.00 percent in 2020, according to our econometric models. Interest Rate in Ethiopia averaged 5.21 percent from 1995 until 2019, reaching an all-time high of 11 percent in December of 1995 and a record low of 3 percent in April of 2002 [47]. Therefore, the interest rate adopted in this particular case was 7.00%

Agency cost determination

Step 1- Using CBR values of the subgrade adjusted for geosynthetic and traffic data; pavement thickness was determined using traffic class and subgrade strength class. Using this thickness and unit rate;

- Flexible pavement with geosynthetic materials will be taken as an experimental group
- Quantity Take off will be prepared, Cost break down will be done, and Initial construction cost will be estimated.

Step 2- Determining schedule (frequency) of activities

Having data such as analysis period, maintenance as well as rehabilitation schedule and frequency in a year, future costs to the agency will be determined.

Step 3- Determine agency cost by summing up initial construction cost and future maintenance cost.

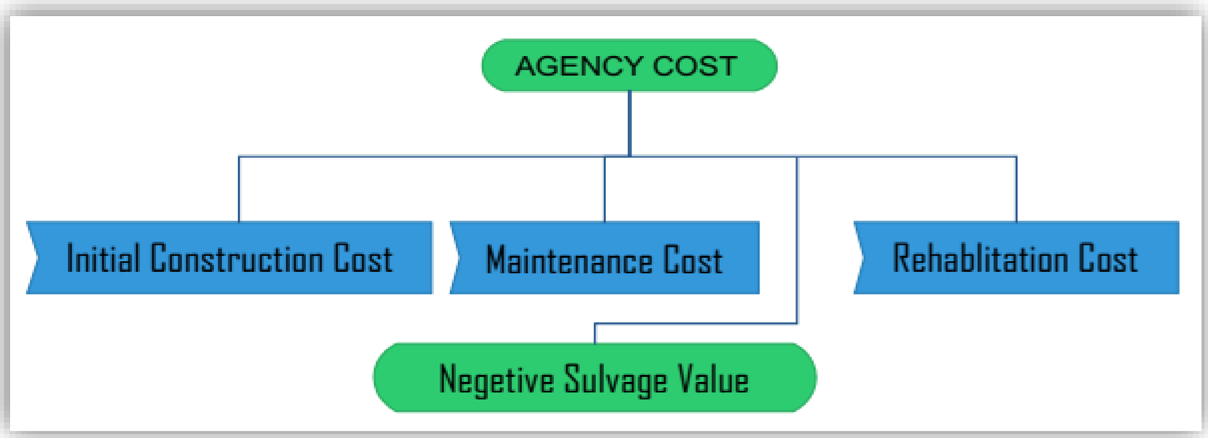


Figure 7: Agency Cost Components [30]

Road User cost determination

According to Greenwood et al., 2001, the two broad categories of user cost will be adopted. Work-zone user costs and non -work-zone user costs. Consequently, LCCA with respect to transport usually considers the following user cost components in both categories: Vehicle operating cost, Travel time cost, and Accident/crash cost.

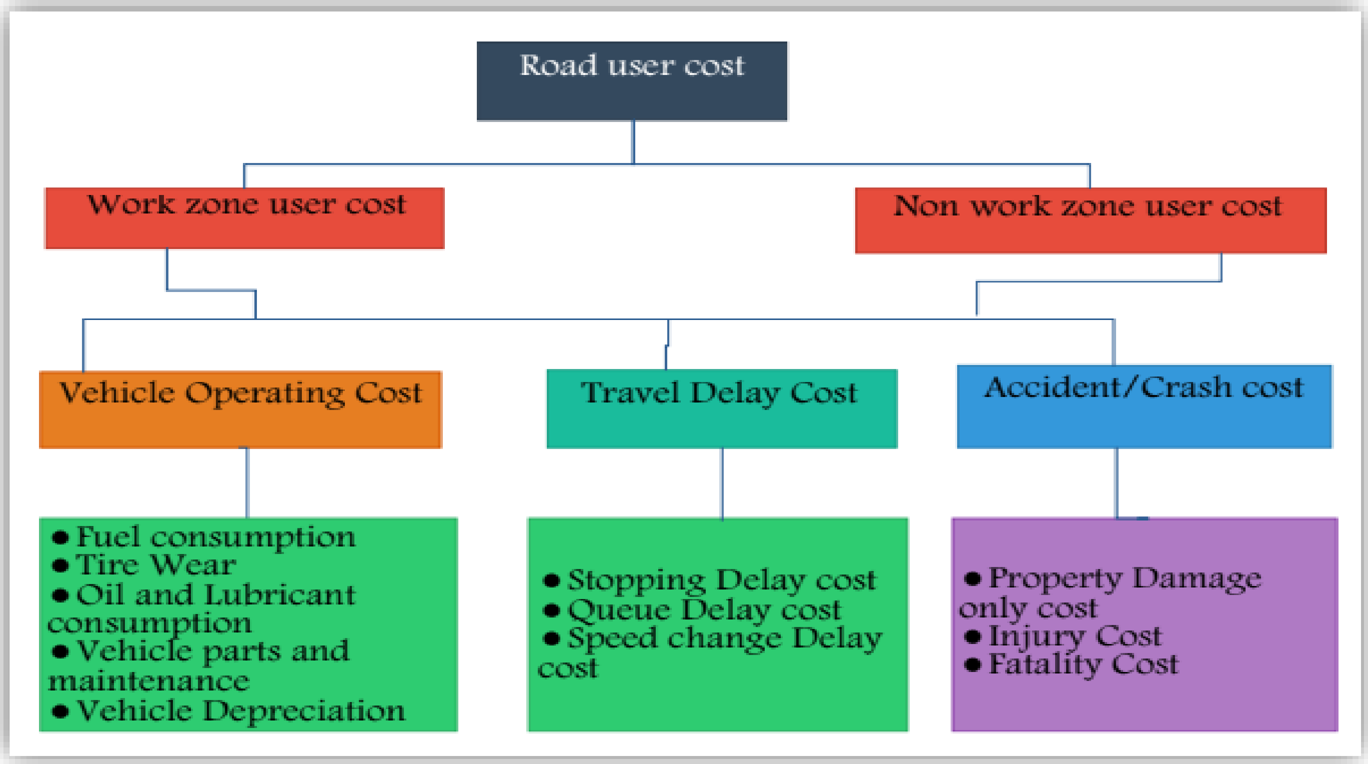


Figure 8: User cost categories and components [30]

1. Work Zone User Cost Determination

Step 1. Project Future Year Traffic Demand (forecasting traffic)

The value of vehicle classes (passenger cars, single unit trucks, and combination trucks) as percentage of AADT and project future year hourly traffic demand volumes for each vehicle class for the year the work zones will be in place, from current or base year AADT will be determined, using compound traffic growth factors. The following formula applies [22]:

$AADT_F = AADT_B * VC (\%) * (1+G_r)^{(FY-BY)}$ Equation 5

Where: $AADT_F$ = Future Year AADT, $AADT_B$ = Base Year AADT, VC= Vehicle class, G_r = growth rate, ^{FY} = Future Year, BY = Base Year

Step 2. Calculate Work Zone Directional Hourly Demand

Directional hourly traffic distribution was determined from agency traffic data on the roadway being analyzed. The following formula applies [22]:

$\text{WZ directional hourly demand} = \text{future year AADT} * \%\text{ADT} * \text{directional factor } \%$ Equation 6

Step 3. Determine Roadway Capacity

There are three capacities that need to be determined in analyzing work zone user costs [22]:

a) The free flow capacity of the facility under normal operating condition,

b) The capacity of the facility when the work zone is in place, and

c) The capacity of the facility to dissipate traffic from a standing queue.

1. The free flow capacity of the facility under normal operating condition

The real-world free-flow capacity of the facility is determined by applying the following formula [44]:

$\boldsymbol{S}\mathbf{fi} = \mathbf{MSFi} * \mathbf{N} * \mathbf{fw} * \mathbf{fHV} * \mathbf{fp}$ Equation 7

Where;

SFi = service flow rate for LOS i under prevailing roadway and traffic conditions for N lanes in one direction in vehicles per hour (VPH),

MSFi = Maximum service flow rate for LOS i for N lanes in one direction (VPH)

N = number of lanes in one direction of the freeway,

fw= factor to adjust for the effects of restricted lane widths and lateral clearances,

fHV = factor to adjust for the effect of heavy vehicles on the traffic stream, and

fp= factor to adjust for the effect of recreational or unfamiliar driver populations.

Values for the above different factors will be taken from highway capacity manual.

2. The capacity of the facility when the work zone is in place

Traffic capacity in the work zone can be estimated from research on the capacity associated with various lane closures on multilane facilities [44].

3. **The capacity of the facility to dissipate traffic from a standing queue.**

Capacity during queue dissipation is less than the capacity for free-flow conditions, even though the lanes are unrestricted [44]. According to this manual, the following formula applies:

$$\mathbf{Capacity = Demand - Queue\ rate} \qquad \text{Equation 8}$$

Step 4. Identify the User Cost Components

With the roadway capacities established, the fourth step is to compare the roadway capacity with the hourly demand for the facility. Using spreadsheet software program is a convenient way to compare capacity and hourly demand, and it forms the basis for determining the user cost components that come into play [44].

Step 5. Quantify Traffic Affected by Each Cost Component

The next step is to quantify the number of vehicles involved with each cost component. Total number of vehicles that [44]:

- traverse the work zone,
- traverse the queue,
- stop for the queue, and
- those that merely must slow down over the 24- hour period will be determined.

Step 6. Compute Reduced Speed Delay

According to [44], the following formulas apply:

$$\mathbf{WZ\ delay} = \frac{\mathbf{WZ\ length}}{\mathbf{WZ\ speed}} - \frac{\mathbf{WZ\ length}}{\mathbf{upstream\ speed}} \qquad \text{Equation 9}$$

$$\mathbf{Queue\ delay} = \frac{\mathbf{Queue\ length}}{\mathbf{queue\ speed}} - \frac{\mathbf{Queue\ length}}{\mathbf{upstream\ speed}} \qquad \text{Equation 10}$$

Speed through the queue can be determined by using the Forced-Flow Average Speed versus Volume to Capacity (V/C) ratio graphs for level of service F contained in the Highway Capacity Manual. Using the volume through the queue and the Free-Flow capacity of the road, the V/C ratio was calculated for each period and used to find the corresponding speed. The queue length varies throughout the day with changes in directional hourly demand and capacity through the work zone section and hence it is in the hand of analysts to use the alternate approach [44].

Step 7. Select and Assign VOC Rates

The factors VOC associated with stopping vehicles from a particular speed and returning them to that speed for the three vehicle classes (for Passenger cars and both Single-Unit and Combination trucks) were obtained from NCHRP report 133 and adjusted to ethiopian context. This factor will also be used to determine the cost and time factors associated with slowing down vehicles from certain speed to certain speed.

Step 8. Select and Assign Delay Cost Rates

These user delay cost rates were adopted as per the Ethiopian and Addis Ababa Road Authority perspective.

Step 9. Assign Traffic to Vehicle Classes

At this point the directional traffic affected by the various cost components was distributed to the appropriate vehicle classes for each cost component.

Step 10. Compute User Cost Components by Vehicle Class

Daily user costs by vehicle class for each cost component were computed by multiplying the affected traffic by the appropriate unit cost rates (either VOC or delay) for the various components.

Step 11. Total Work Zone User Costs

The dedetermined VOC and TDC for WZ operating condition were summed up to give the tota work zone user cost.

Step 12. Accident/Crash Cost

The highway safety community has replaced the term accident with the term crash because the term accident implies that they are unavoidable. In reality; highway crashes to a large extent are avoidable [44]. Since the core points of the study were cost comparison, accident cost was excluded from the analysis.

2. Non-work zone user cost determination (normal operation)

2.1. Vehicle operating cost

According to FHWA, this process was done in three steps, which include [45]:

- Constant speed operating cost which are calculated as a function of average speed, average grade, and pavement condition
- Excess operating costs due to speed change cycles
- Excess operating costs due to the road curvature. The results of these three steps are summed up to give the total vehicle operating costs.

$$VOC = \Sigma(CSOPCSTvt + VSOPCSTvt + COPCSTvt) \qquad \text{Equation 11}$$

Where CSOPCSTvt is the constant speed operating cost for vehicle type vt; VSOPCSTvt is the excess operating cost due to speed change cycles or speed variability for vehicle type vt and COPCSTvt is the excess VOC due to curves for vehicle type vt. The model relies upon consumption rates & cost values.

2.2. Travel Time Costs

Travel Time was estimated using the HDM-4 models [45]. The models establish the number of hours per 1000 veh-km for passenger working and non-working time, crew time, and cargo time. The travel time is given as.

Travel Time = PWH + PNH + CH + CARGOH Equation 12

Where PWH is the annual number of working passenger hours per 1000 veh-km; PNH is the annual number of non-working passenger hours per 1000 veh-km; CH is the number of hours per crew member per 1000 veh-km; CARGOH is the annual number of cargo handling hours per1000 veh-km. These values will be multiplied by the appropriate unit cost for time to establish the total time cost. The escalation factor will be used if values of time are not up to date using the following formula [22].

$$\text{Escalation Factor} = \frac{\text{CPIcurrent year}}{\text{CPIbase year}}$$ Equation 13

where

CPIcurrent year - All Items Component of the CPI for current year

CPIbase year - All Items Component of the CPI for base year.

2.3. Crash Costs

According to the FHWA (1998), fatality, injury and Property Damage Only (PDO) costs must be calculated when analyzing LCC. Usually these costs are estimated by multiplying the number of crashes for each crash type by the average cost per crash. The crash cost function is given as follows [22]:

$$\text{Crash costs} = \sum_{i=1}^{n} \sum_{j=1}^{m} (UACij * CRASH\ RATESij * LEN * AADT)$$ Equation 14

Where UACij is the unit crash costs for crash type j of cost category i; Crashes Ratesij are the crash rates for crash type j of cost category i; i is the crash cost category, including highway segment, intersection /interchange, railroad crossing, and bridge; j is the crash type, including fatality, injury, and property damage only; LEN is the length of project.

2.4. Environmental Costs

The environmental effects model of the HDM-4 is a more comprehensive model and was used in this study. It generates the environmental costs based on three major environmental effects: Air pollution from vehicle emissions, noise pollution and energy effects. The HDM-4 model primarily estimates effect of the following air pollutants associated with vehicle emissions: Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO2), Nitric Oxides (NOx), Sulphur Dioxide (SO2), Lead (Pb) and Particulate Matter (pm).

The model predicts the emission rates (g/km) as follows [37]:

$TPE_i = EOE_i \times CPF_i$

Where TPEi is the tailpipe emissions in g/km for emission type i; EOEi is the engine out emission in g/km for emission type i and CPFi is the catalyst pass fraction for emission type i. Once cost for both categories calculated, these values were summed up and discounted to present to give the net present value of road user cost.

Life Cycle Cost Determination (Net Present Value Calculation)

The life cycle cost calculation component takes the events and their timing and assigns a cost for each applicable component of each event. Net Present Value (NPV) was considered as the economic efficiency indicator of choice [22].

3.8. Measurements of Variables

From previous studies and standards, formulas or scales to be used in this study was adopted. Ethiopian road authority design manual, AASHTO standard specification, manual of federal highway administration, highway capacity manual 1994 and other relevant previous studies were used.

3.9. Ethical Considerations

The permission of the Jimma University Technology Institute and ERA must be acquired in order to conduct the research and must be approved by the ethics review committee to make sure the study is not violating any of the ethics consideration. The confidentiality of the data should be ensured & when reporting the result, only what observed and what done should be reported.

CHAPTER IV

ANALYSIS, RESULT AND DISCUSION

4.1. Inflation and Inflation adjusted Rate

Inflation Rate in Ethiopia is expected to be 19.10 percent by the end of the first quarter of 2019, according to Trading Economics global macro models and analysts' expectations [47]. Assuming that goods have higher opportunity to continue as it is

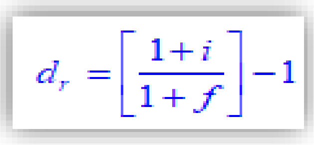
Inflation rate f=19.10%

Inflation adjusted interest rate if = $i + f + if$ Equation 15

=0.07+0.191+(0.07) (0.191) = 0.27437 = <u>27.437%</u>

4.2. Selection of Discount Rate

Even if calculation and selection of the discount rate is quite complex and is the subject of ongoing debate in academic circles, the exact mathematical relationship between the discount rate, the interest rate, and the inflation rate presented by [31] was employed in selecting a discount rate for this particular case. Recalling equation 3 presented in chapter two of this paper.



$$d_r = \left[\frac{1+i}{1+f}\right] - 1$$

Given; f = inflation rate in decimal = 0.186 I = interest rate in decimal = 0.070

$$d_r = \left[\frac{1+0.07}{1+0\cdot186}\right] - 1 = \underline{\underline{-0.102}}$$

A negative discount rate means that present value of a future liability is higher today than at the future date when that liability will have to be paid and this is due to a high inflation rate in Ethiopia. The discount rate is a function of risk and return, there is no such thing as negative risk and it is illogical. Every company has systemic and non-systemic risk inherent in its model. Therefore, it was found good to use the maximum allowable value presented in [36] in such case. Hence, a discount rate of 3.5% was adopted in this particular case.

4.3. Activity Parameters and Cost Schedules

As per the recommendation of ERA manual 2013, based on the number of ESALs, the following time-based pavement strategy was adopted.

Table 3: Activity Timing

Options	Remedial type	Activity Time	Cost Base Line	Remark
Flexible pavement with geosynthetic materials	Initial Construction	In 2019 G.C.	Cost of 2019 G.C.	Projected with consideration of time value of money.
	Routine Maintenance	Once Every Two Years		
	Periodic Maintenance	Once Every 4 Years		
	Rehabilitation	Once Every 10 Years Of 25 Year (2029 and 2039)		
	user cost	During Maintenance & Rehabilitation		
	salvage value	At 25th Year (2044 G.C.)		
conventional pavement	Initial Construction	In 2019 G.C.		
	Routine Maintenance	once every year		
	Periodic Maintenance	Once Every Three Years		
	Rehabilitation	Once Every 8 Years of 25 Year (2027, 2035, and 2043)		
	user cost	During Maintenance & Rehabilitation		
	salvage value	At 25th Year (2044 G.C.)		

4.4. Cost Determination

Neglecting the components common to both alternatives; the following costs were determined in this particular case. This was done because of the fact that costs in normal operation are assumed to be equavalent for both alternatives in LCCA principles. The same principle applied to Environmental cost.

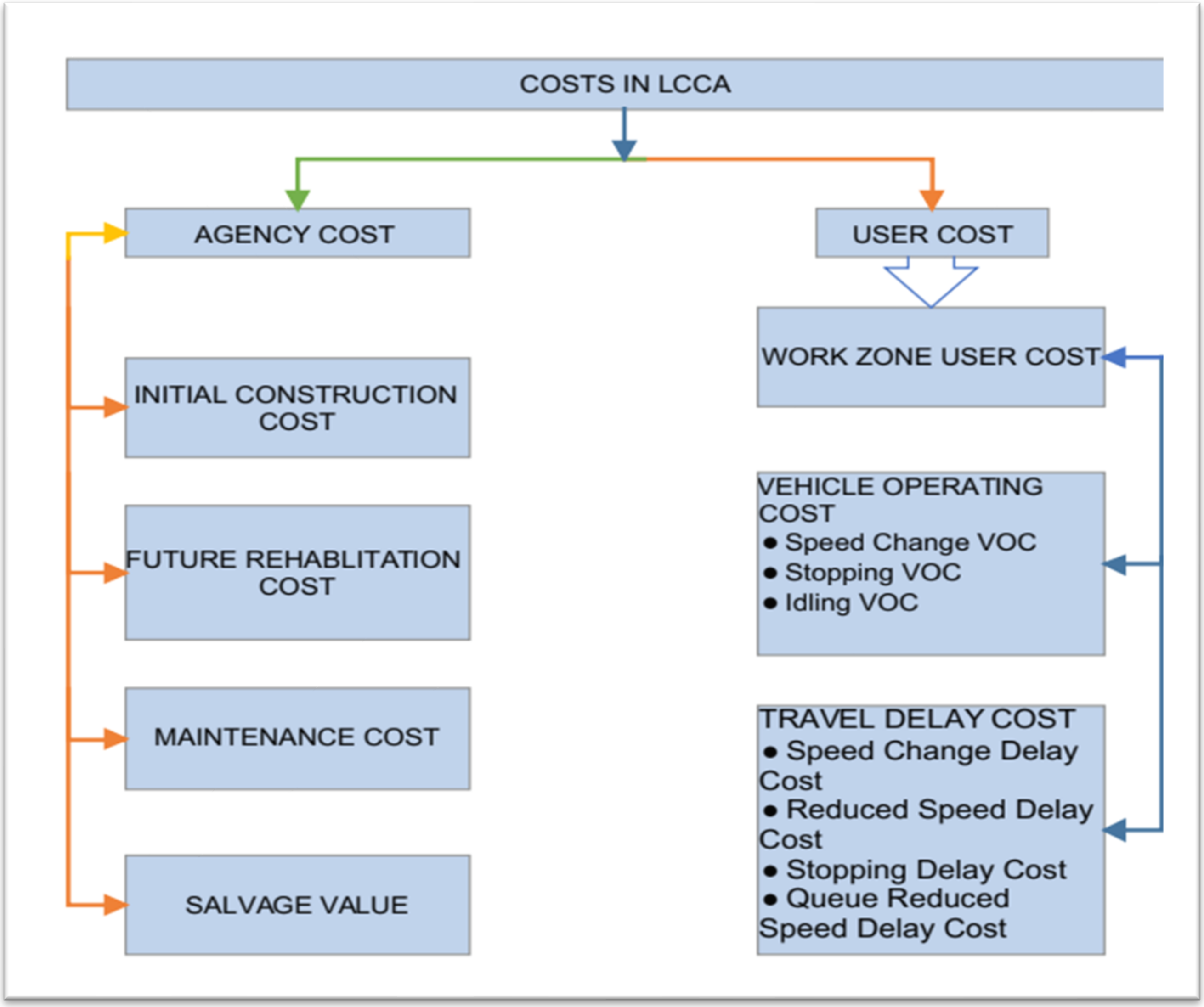


Figure 9: Cost Components Uncommon to Both Alternatives [36]

4.4.1.Determination of Agency Cost

As briefly presented in chapter two of this paper; preliminary costs such as feasibility and engineering studies, contract administration cost, the associated administrative cost, maintenance of traffic signal cost, operating costs such as pump station energy costs, tunnel lighting, and ventilation are excluded, as they are typically common among all pavement alternatives and LCCA needs only consider differential costs between alternatives. Therefore, agency costs determined in this case were initial construction cost, future rehabilitation cost, maintenance cost and salvage/disposal/residual/terminal/scrap value. This cost is the arthimetic sum of initial construction cost and future maintenance/rehablitation costs and its summary is going to be tabulated below.

Table 4: Agency Cost Summary

Serial №	Description	Cost (ETB)	Difference
1	Conventional Flexible Pavement	**3,182,653,893.00**	1,602,209,998.00
2	Flexible Pavement with Geosynthetic Materials	**1,580,443,895.00**	

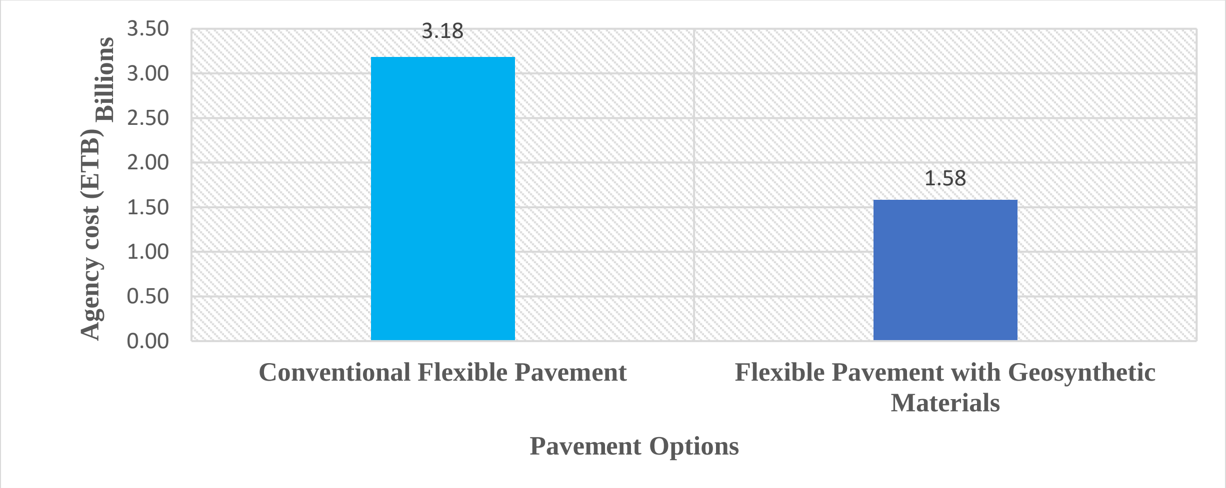


Figure 10: Agency Cost Summary Comparison

4.4.1.1. Initial Construction Cost

The initial construction cost was calculated using the collected quantity data and the unit rate from recent market survey. A 1km road segment and 10-meter (taken from field measurement) road width on the typical road section were considered. The break down values include direct and indirect costs. Other costs like overhead, contingency and value added taxes are ignored since they have the same effect on comparison of the pavement costs [48].

Using the mean absolute percentage error (MAPE) as the method of Testing Accuracy of the Developed Models; model **№ 6** is best suited to be used since it has better accuracy than others [38]. But in this case, the second model is best fit since relying on width and length is not logical in a case where thickness is the main issue. Therefore, Total project cost =45.7 X1 + 151.4X2 +195.24X3 was adopted in this study.

X1 = Earthwork; cut, fill, and topping quantities (m3)

X2 = Sub base, Base coarse and capping layer quantity (m3)

X3 = Asphalt quantity (m2)

For conventional flexible pavement;

Width = 10.5m (one way), length = 1000m

Excavation and earth work = X_1 = 10000m3

Sub-Base Course = X_2 = (2500 + 1500 + 7500) = 11500 m^3

Asphalt quantity = X3 = 10.5*1000 = 10500M^2

Total Cost= 45.7 X1 + 151.4X2 +195.24X3

= 45.7(10000) +151.4(11500) +195.24 (10500)

= 2,198,100+ 195.24 (10500) = 4,248,120 ETB

Similarly; for flexible pavement with geosynthetic materials

Width = 10.5m (one way), length = 1000m

Excavation and earth work = 5000m^3

Sub-Base Course = X_2 = (1750 + 750 +4000) = 6500 m^3

Asphalt quantity = X3 = 10.5*1000 = 10500M^2

Geomembrane = 10.5*1000* = 10500 M^2

Total Cost= 45.7 X1 + 151.4X2 +195.24X3

= 45.7 (5000) + 151.4 (6500) + 10500 (100) + 195.24 (10500)

= 2,262,600 + 195.24 (10500) = 4,312,620 ETB

Table 5:Initial Construction Cost Summary

Serial №	Description	Cost (ETB)	Difference (ETB)
1	Conventional Flexible Pavement	4,248,120	64,500
2	Flexible Pavement with Geosynthetic Materials	4,312,620	

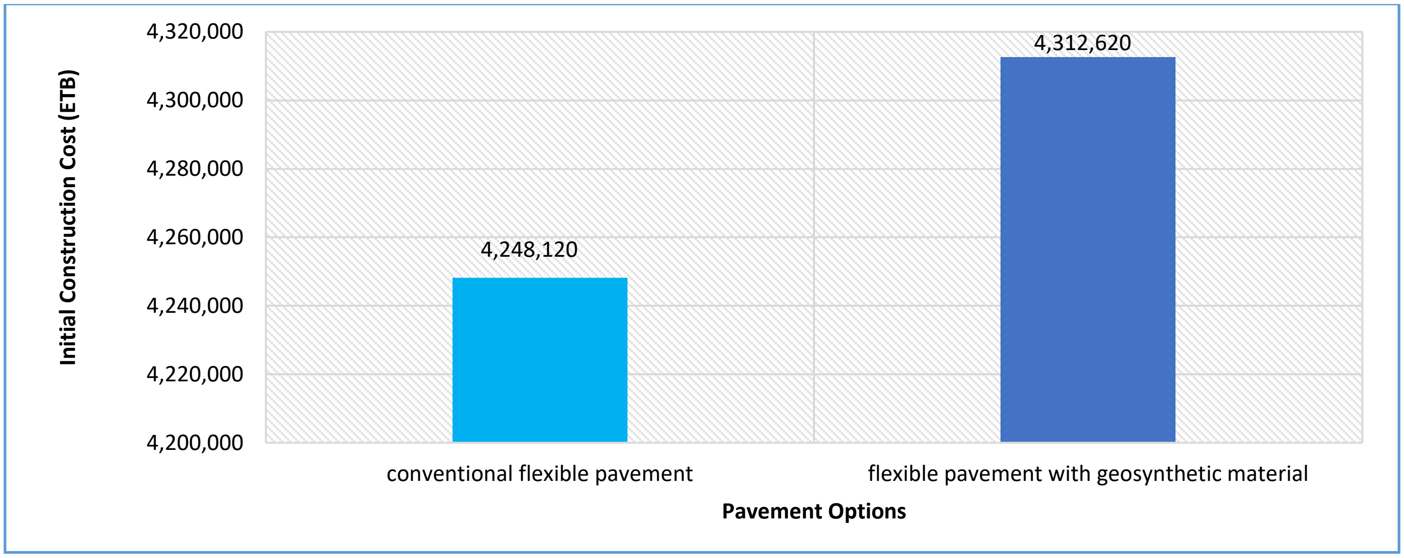


Figure 11: Initial Construction Cost Summary Comparison.

4.4.1.2. Maintenance Cost

Maintenance costs include all Laboure, machinery and materials costs for routine, periodic and rehabilitation maintenance. Consistent with FHWA methodology, maintenance costs are considered part of the 'cost' measurement in the LCCA. This recognizes an assumption that the road agency's objective is to efficiently utilize all resources, not only its capital budget.

M= Mainline **OS=** Outside Shoulder **IS=** Inside Shoulder

Roadway Data:

Mainline: Length = 1000m, Width = 10.5m, IS = 1.22m, OS = 2.44m

Total width = 10.5+1.22+2.44 = 14.16m

Mainline Area = 10.5*1000 = 10500M^2

Area ((1) 1.22m Inside Shoulders) = 1.22*1000 = 1220m^2

Area ((1) 2.44m Outside Shoulders) = 2.44*1000 = 2440m^2

Total Area = Mainline Area + Area ((1) 1.22m Inside Shoulders) + Area ((1) 2.44m Outside Shoulders) or

= Total width * Mainline Length

= 14.16 m * 1000 m = 14160 m^2

Datas in the following table were used in determining future maintenance cost and fixing maintenance cost ay the end of 2019 (*Source: Thesis Report on Cost and Benefit Analysis of Flexible and Rigid Pavement by Yonas Katema in JiT; 2015)*

Table 6: maintenance quantity as percentage of consstruction quantity.

Name of Activity	**Unit**	**Quantity in % per Km**
Routine maintenance		
Asphalt Patching (Seal Coat)	m2	5%
Asphalt Patching (Single Surface Treatment)	m2	2%
Asphalt Patching (Double Surface Treatment)	m2	2%
Asphalt Patching (Hot-Mini Mix)	m3	5%
Crack Sealing (Individual Cracks) (>3mm)	Lm	5%
Pothole Reinstatement (Hot Mini-Mix) 150mm avg. thickness	m3	2%
Pothole (Base Failure Repair) for **100mm avg. thickness**	m3	2%
Periodic Maintenance		
Sand seal coat	m2	10%
Single Bituminous Surface Treatment (SBST)	m2	10%
Name of Activity	**Unit**	**Quantity in % per Km**
Routine maintenance		
Double Bituminous Surface Treatment (DBST)	m2	10%

Mix-In-Place Overlay (Cold Mix) for 50mm thickness	m3	10%
Asphaltic Concrete Overlay for 40mm thickness	m3	15%
Bitumen Prime Coat (0.3lt/m2)	Lt	60%
Bitumen Tack Coat (0.5lt/m2)	Lt	60%
Pavement Reconstruction (Aggregate Road base)	m3	10%
Rehabilitation		
Asphaltic Concrete Overlay for 50mm thickness	m3	100%
Bitumen Tack Coat (0.5lt/m2)	Lt	100%
Pavement Reconstruction (Aggregate Road base)	m3	100%

Routine maintenance cost of Flexible pavement at end of 2019

Asphalt Patching (Seal Coat) quantity for entire lane including shoulders (14.16m)

= 5% of the area =0.05(length * width) = 0.05(14.16m * 1000m) = $\underline{\underline{708\ m^2}}$

Asphalt Patching (Single Surface Treatment) quantity for entire lane including shoulders (14.16m)

= 2% of the area = .02 (length * width) = .02 (14.16m * 1000m) = $\underline{\underline{283.2m^2}}$

Asphalt Patching (Double Surface Treatment) quantity for entire lane including shoulders (14.16m)

= 2% of the area = 0.02 (length * width) = 0.02 (14.16m * 1000m) = $\underline{\underline{283.2m^2}}$

Asphalt Patching (Hot-Mini Mix) quantity for entire lane (14.16m)

= 5% of the entire quantity to a thickness of 100mm = 0.05 (.1m*14.16m*1000m) = 0.05 (1416) m^3 = $\underline{\underline{70.8m^3}}$

Crack Sealing (Individual Cracks) (>3mm)

= 5% of entire length = 0.05 * 1000m = $\underline{\underline{50m}}$

Pothole Reinstatement (Hot Mini-Mix) 150mm avg. thickness for entire lane

= 2% of the entire quantity to a thickness of 150mm

= 0.02 (0.15m * 14.16m * 1000m) = 0.02 (2124) m^3 = $\underline{\underline{42.48m^3}}$

Pothole (Base Failure Repair) for 100mm avg. thickness quantity for entire lane (14.16m)

= 2% of the entire quantity =0.02 (0.1m * 14.16m * 1000m) = 0.02 (1416) m^3 = $\underline{\underline{28.32m^3}}$

By using unite rates of 2019, Routine maintenance cost of flexible pavement at the end of 2019 was determined and tabulated in the following table.

Table 7: Routine maintenance cost of flexible pavement at the end of 2019

Name of Activity **775, 219.4888**	Unit	Unit Rate	Entire Lane Quantity	Amount (ETB)
Asphalt Patching (Seal Coat)	m2	70.98	708	50253.8
Asphalt Patching (Single Surface Treatment)	m2	78.48	283.2	22225.5
Asphalt Patching (Double Surface Treatment)	m2	144.26	283.2	40854.4
Asphalt Patching (Hot-Mini Mix)	m3	4,650.10	70.8	329227
Crack Sealing (Individual Cracks) (>3mm)	Lm	60.31	50	3015.5
Pothole Reinstatement (hot mini-mix) 150mm avg. thickness	m3	7235.68	42.48	307372
Pothole (Base Failure Repair) for 100mm avg. thickness	m3	786.42	28.32	22271.4
Total Cost (ETB/KM)	**775, 219.4888**			

Table 8: Routine Maintenance Cost Summary for conventional pavement in the Analysis Period

age in years		1+if	(1+if) ^n	Routine maintenance at the end of 2019 (PV)	Routine maintenance cost in analysis period (FV) = PV (1+if) ^n
0	2019				
1	2020	1.27437	1.27437	775219.4889	987916.46
2	2021	1.27437	1.62402	775219.4889	1258971.10
3	2022	1.27437		775219.4889	
4	2023	1.27437	2.63744	775219.4889	2044592.86
5	2024	1.27437	3.36107	775219.4889	2605567.80
6	2025	1.27437		775219.4889	
7	2026	1.27437	5.45844	775219.4889	4231491.34
8	2027	1.27437		775219.4889	
9	2028	1.27437		775219.4889	
10	2029	1.27437	11.2968	775219.4889	8757498.55
11	2030	1.27437	14.3963	775219.4889	11160293.42
12	2031	1.27437		775219.4889	
13	2032	1.27437	23.3799	775219.4889	18124527.42
14	2033	1.27437	29.7946	775219.4889	23097354.00
15	2034	1.27437		775219.4889	
16	2035	1.27437		775219.4889	

age in years		1+if	(1+if) ^n	Routine maintenance at the end of 2019 (PV)	Routine maintenance cost in analysis period (FV) = PV (1+if) ^n
17	2036	1.27437	61.6629	775219.4889	47802306.05
18	2037	1.27437		775219.4889	
19	2038	1.27437	100.142	775219.4889	77631848.35
20	2039	1.27437	127.618	775219.4889	98931698.58
21	2040	1.27437		775219.4889	
22	2041	1.27437	207.253	775219.4889	160666948.00
23	2042	1.27437	264.118	775219.4889	204749138.52
24	2043	1.27437		775219.4889	
25	2044	1.27437		775219.4889	
Grand Total (ETB/KM)					**662,050,152.44**

The determination of this cost is quite wide and as such, the summary of its determination from appendix was summarized and tabulated in the following table.

Table 9: Maintenance Cost Summary Arrived from Appendix B.2

Serial №	Description		Cost (ETB)	Total (ETB)
1	Conventional Flexible Pavement	Routine Maintenance	662050152	**3,178,405,773.00**
		Periodic Maintenance	441293636	
		Rehabilitation	2075061985	
2	Flexible Pavement with Geosynthetic Material	Routine Maintenance	779,553,308	**2,097,665,531.89**
		Periodic Maintenance	582627383	
		Rehabilitation	735484839	

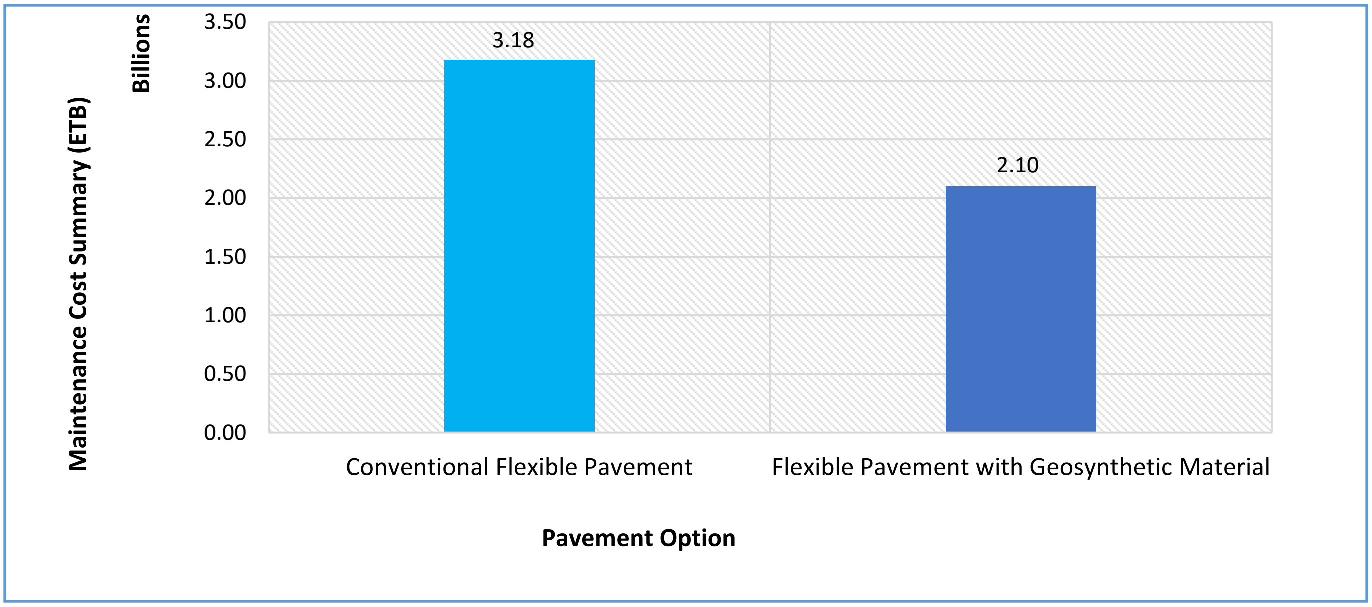


Figure 12: Maintenance Cost Summary Comparison.

4.4.1.3. Salvage values

While many sources of literature consider the terms salvage value, residual value, and remaining service life to be synonymous, the FHWA appropriately makes a clear distinction between these terms. The FHWA attaches a physical connotation to the concept of salvage value and argues that it is strictly defined as the value of recovered, recycled or scrap materials, and can only be realized when the entire pavement structure is excavated at the end of the analysis period and the pavement materials are actually reclaimed. In that case, the value of the salvage is treated as a negative agency cost. It is the estimated remaining value of the project at the end of the analysis period. It represents the capacity of the asset to accrue benefits past the end of the evaluation period.

According to [22] salvage value represents value of an investment alternative at the end of the analysis period. The two fundamental components associated with salvage value are residual value and serviceable life.

Residual Value refers to the net value from recycling the pavement. The differential residual value between pavement design strategies is generally not very large, and, when discounted over 35 years, tends to have little effect on LCCA results.

Serviceable Life represents the more significant salvage value component and is the remaining life in a pavement alternative at the end of the analysis period. It is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period. For example, over a 35-year analysis, Alternative A reaches terminal serviceability at year 35, while Alternative B requires a 10-year design rehabilitation at year 30. In this case, the serviceable life of Alternative A at year 35 would be 0, as it has reached its terminal serviceability. Conversely, Alternative B receives a 10-year design rehabilitation at year 30 and will have 5 years of serviceable life at year 35, the year the analysis terminates. The value of the serviceable life of Alternative B at year 35 could be calculated as a percent of design life remaining at the end of the analysis period (5 of 10 years or 50 percent) multiplied by the cost of Alternative B’s rehabilitation at year 30.

There is no general consensus on how to estimate the salvage value, primarily because infrastructure projects are never terminated at the end of analysis period. One approach to estimating this component is by accounting for the costs of demolition and removal as well as adding the value of the recycled project waste. Another approach is by calculating the relative value of the remaining serviceability of the alternative with respect to the cost of the last rehabilitation activity [34]. Each approach has its own critics, and one way to avoid such added dubious calculations is to adjust the analysis period slightly, so as that the remaining serviceability is the same for all alternatives and the salvage value can be omitted from calculations.

According to [34], the following equation was adopted in this case to calculate salvage value.

$$\mathbf{sv} = LC\left[\frac{ERL}{TEL}\right] \qquad \text{Equation 16}$$

Where, SV= salvage value, LC = Last Rehabilitation Cost of The Pavement, ERL = Expected Remaining Life of The Last Rehabilitation of The Pavement, TEL = Total Expected Life of The Last Rehabilitation of The Pavement. Therefore, SV for conventional flexible pavement is;

SV = cost of rehabilitation at year 43[(44-43)/ (43-35)]

= 1,782,047,223.16[1/8] = 222,755,902.90 ETB

In similar token, the SV for flexible pavement with geosynthetic material is;

SV = 675,673,757.55[(44-39)/10] = 337,836,878.78 ETB

4.4.2. User Cost

User costs are costs incurred by the highway user over the life of the project depend on the highway improvements and associated maintenance and rehabilitation strategies over the analysis period. User costs form a substantial part of the total transportation costs [Greenwood et al.,2001] for highway investments and can often be the major determining factor in life-cycle cost analysis. Determined in this case using the following 11 steps under heading 4.7.2.2 below were work zone operation user costs ignoring costs in normal operation as they are a function of the differential pavement performance (roughness) of the alternatives [22, 49].

4.4.2.1. Normal Operation User Costs

4.4.2.1.1. Travel Delay Costs

As briefly presented in chapter two of this paper, the cost of travel delay time during normal operation is typically, a function of the distance and the vehicle speed, which is dependent on the demand and capacity of the facility. All of these factors are expected to be equivalent for all alternatives in LCCA which leads to the exclusion of this type of costs.

4.4.2.1.2. Vehicle Operating Cost

Considered factors at this level of the LCCA were facility serviceability (i.e. pavement roughness), the traffic volume and traffic characteristics only. This was because of similar roadway curvature and gradient for both alternatives (that is a gradient of 2.5% taken from ERA manual). In this sense VOC's during normal operation can be excluded from LCCA.

Besides, the FHWA LCCA technical bulletin considers that vehicle-operating costs (VOC) are equivalent for different alternatives when the level of serviceability is maintained above the threshold (PSI is above 2.5) and accordingly suggests that VOC’s during normal operation can be excluded from LCCA [10].

4.4.2.1.3. Accident Cost

Accident costs have been estimated as a dollar per unit length for different types of facilities (rural, urban, freeway, etc.). Some research has estimated accident rates as a function of skid resistance, but this is a special case in which aggregates used in the wearing surface might differ between alternatives [1]. In this particular case, aggregates used in the wearing surface are similar and hence accident cost in normal operation was excluded from LCCA.

4.4.2.2. Work Zone User Costs

It was assumed that the initial construction period for the flexible pavement with geosynthetic material and conventional flexible pavement is the same and therefore work zone user cost during the initial construction period was not considered [36]. As briefly presented in chapter two of this paper, work zone operation results in two types of user costs namely Vehicle Operating Cost and Travel Delay Cost. The following 11 steps are a foundation for determination of work zone user cost.

Step 1. Project Future Year Traffic Demand (Forecasting Traffic)

The value of vehicle classes (passenger cars, single unit trucks, and combination trucks) as percentage of AADT and project future year hourly traffic demand volumes for each vehicle class for the year the work zones in place, from current or base year AADT was determined, using compound traffic growth factors and the following formula.

Future Year AADT = Base Year AADT x Vehicle class % x (1 + growth rate) $^{\text{(Future Year. – Base Year)}}$

Where base year = 2019, base year traffic ($AADT_{2019}$) = 20739. Using these input data; the AADT on a facility in each year was determined from a 2019 base year AADT of 20739 by applying the growth rate factor of 5% for all classification.

$AADT_{2020}$ for passenger cars = $AADT_{2019}$ * %ge of passenger cars $(1+0.05)^{2020-2019}$

$= 20739 * 0.65\ (1.05)^1$

$= 20739 * 0.6825 = \underline{\underline{14154}}$

$AADT_{2020}$ for single unite truck = $AADT_{2019}$ * %ge of single unite truck $(1+0.05)^{2020-2019}$

$= 20739 * 0.20 * 1.05 = \underline{\underline{4355}}$

$AADT_{2020}$ for combination truck = $AADT_{2019}$ * %ge of combination truck $(1+0.05)^{2020-2019}$

$= 20739 * 0.15 * 1.05 = \underline{\underline{3267}}$

Total $AADT_{2020}$ = 14154 + 4355 + 3267 = $\underline{\underline{21776}}$

Following similar procedures for the rest the years in analysis period, future forecasted traffic was determined and summarized in table 37 of this paper in appendix C.1.1.1.

Based on these new numbers, total traffic in each year was as shown in column five of table 37 in appendix C.1.1.1 and because of the linear traffic growth rates for all classification, the future years vehicle mix was taken approximately 65 percent for passenger vehicles, 20 percent for single-unit trucks, and 15 percent for combination trucks.

Step 2. Calculate Work Zone Directional Hourly Demand

Using the future year AADT determined in step 1 above, the next is determining directional hourly traffic distribution which is determined from agency traffic data on the roadway being analyzed. Table 39 of this paper presented default hourly distributions from MicroBENCOST and they were adopted in determining Work zone directional hourly demand for future years. The following equation was used in determining demand for each respective hour.

$$\text{WZ directional hourly demand} = \text{future year AADT} * \%\text{ADT} * \text{directional factor }\%$$

WZ Directional Hourly Demand$_{2020\ (12\text{-}1)}$ = AAADT$_{2020}$ * 0.012 * 0.53 = $\underline{\underline{138}}$ Vph

WZ Directional Hourly Demand$_{2020\ (1\text{-}2)}$ = AAADT$_{2020}$ * 0.008 * 0.57 = $\underline{\underline{99}}$ Vph

In similar manner WZ Directional Hourly Demand of each year for each respective hour was determined and summarized in table 40 through and 43 of this paper in appendix for all vehicle classes.

Inspection of table 40 of this paper reveals that a.m. outbound demand for year 2020 peaks at 679 vehicles per hour in the 7 to 8 a.m. period, while the p.m. outbound demand peaks at 1111 vehicles per hour in the 5 to 6 p.m. time period.

Step 3. Determine Roadway Capacity

Briefly mentioned in literature part of this paper, there are three capacities that need to be determined in analyzing work zone user costs.

1. The free flow capacity of the facility under normal operating condition

According to the 1994 HCM, the maximum capacity for a 2-lane directional freeway under ideal conditions is 2,200 passenger cars per hour per lane (pcphpl) and 2,300 pcphpl for a 3- or more lane directional freeway. The 1994 HCM points out the need to reduce the above ideal condition capacities for such real-world factors as restricted lane widths, reduced lateral clearances, the presence of trucks and recreational vehicles, and the presence of a driver population unfamiliar with the area. But due to un availability of these factors, Maximum mixed vehicle traffic capacities for trucks in the traffic stream was adopted from 1994 HCM table 3-6 assuming a truck equivalency factor of 1.5. Therefore, for a truck equivalency factor of 1.5 and future year percent trucks of 15 percent, table 20 of this paper in appendix reveals a free-flow capacity of 2140 vehicles per lane per hour, or 6420 vph for all 3 lanes.

2. The capacity of the facility when the work zone is in place

Traffic capacity in the work zone can be estimated from research on the capacity associated with various lane closures on multilane facilities [44]. Table 22 of this paper reflects observed work zone mixed vehicle flow capacities at several real-world work zones under several lane closure scenarios. But in Ethiopia, it is accustomed to work under one extra lane closure condition. That is closing two lanes if work zone operation is on one lane. Therefore, the capacity of the work zone was taken to be 1170 vph and 1170 vplph as the road under consideration is a three lanes directional facility and operates under one lane during work zone.

3. The capacity of the facility to dissipate traffic from a standing queue (Queue Dissipation Rates).

Table 21 of this paper reflects observed saturation flow rates. Using an average of 1,818, with a standard deviation of 144 from analysis of the traffic signal analogy adopted from 1994 HCM in table 16 of this paper, there is a 68 percent probability that the queue dissipation rate would be somewhere between 1,674 and 1,962. Alternately, there is a 95.5 percent probability that it would be somewhere between 1,530 and 2,106. Hence 95.5 percent probability and 50 percent reliability were adopted in this particular case.

The queue dissipation capacity selected here was therefore, (1530+2106)/2 = 1818 vehicles per lane.

With three lanes open, total dissipation capacity becomes 5454 vph.

Step 4. Identify the User Cost Components

With the roadway capacities established, the fourth step is to compare the roadway capacity with the hourly demand for the facility determined in step 2. The work zone analysis matrix presented in tables 44 through 46 of this paper provide a convenient way to compare capacity and hourly demand, and they formed the basis for determining the user cost components that come into play. The following table is a sample taken from appendix.

Table 48: work zone analysis matrix for year 2042

AADT of year 2042 = 63700			Queue Rate	Num. of Queued Vehicles	Lanes Open	Operating Conditions	Cost Factors
hour	demand	capacity					
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
12-1	405	1170	-765	0	1	free flow, work zone in place, no queue	free flow only costs
1-2	290	1170	-880	0	1		
2-3	241	1170	-929	0	1		
3-4	166	1170	-1004	0	1		

AADT of year 2042 = 63700			Queue Rate	Num. of Queued Vehicles	Lanes Open	Operating Conditions	Cost Factors
hour	demand	capacity					
4-5	192	1170	-978	0	1	free flow, work zone in place, no queue	free flow only costs
5-6	455	1170	-715	0	1		
6-7	1202	1170	32	32	1	Forced Flow WZ in place Queue Exists	WZ Delay and Queuing (5 costs)
7-8	1987	1170	817	849	1		
8-9	1645	1170	475	1325	1		
9-10	1491	1170	321	1645	1		
10-11	1617	1170	447	2092	1		
11-12	1722	1170	552	2644	1		
12-13	1784	1170	614	3258	1		
13-14	1815	1170	645	3903	1		
14-15	1917	1170	747	4650	1		
15-16	2236	1170	1066	5716	1		
16-17	2768	1170	1598	7313	1		
17-18	3249	1170	2079	9392	1		
18-19	2029	1170	859	10252	1		
19-20	1292	1170	122	10373	1		
20-21	1114	1170	-56	0	1	free flow work zone in place no queue	free flow only costs
21-22	945	1170	-225	0	1		
22-23	762	1170	-408	0	1		
23-24	596	1170	-574	0	1		

Inspection of table 40 above shows the work zone is in place for 24 hours and that capacity is restricted to work zone capacity (1170 vph). As traffic demand is lower than capacity for the period from 12-1 to 5-6, the facility operates under free-flow conditions. There is no queue and no vehicles have to stop. Under these conditions the work zone results in three free-flow user costs: the VOC and delay cost of the speed change associated with slowing down (50-30-50) for the work zone, and the delay cost of traversing the work zone at a reduced speed (50-30-50).

During the period from 6-7 to 19-20 the demand exceeds the capacity. In this period a queue forms and the facility operates under forced flow condition. Therefore, there is a total of five user cost components. They are the four forced-flow user costs associated with queuing (stopping VOC and delay costs, idling VOC, and delay cost of crawling through the queue) as well as the free-flow delay in traversing the work zone. The speed change delay and VOC cost factors have been replaced by the delay and VOC stopping cost factors.

At 20-21 to 23-24. the demand falls below the capacity and hence there is no queue and no vehicles have to stop. Under these conditions the work zone results in three free-flow user costs: the VOC and delay cost of the speed change associated with slowing down for the work zone, and the delay cost of traversing the work zone at a reduced speed. Similar analysis can be made for the rest of the tables.

Step 5. Quantify Traffic Affected by Each Cost Component

The next step is to quantify the number of vehicles involved with each cost component. The tables 47 through 49 of this paper in appendix are a modification of tables 44 through 46 in appendix. The three columns that described operating conditions (f through h) have been replaced with four columns (f) through (i) that provide information on the number of vehicles. These four columns were used to identify the number of vehicles involved in the seven user cost components. The following table highlights this concept.

As provided in table 49 below, the traffic that traverses the work zone in column (f) is generally the traffic demand on the facility during the hours the work zone is in place. Although this is the case under free-flow operating conditions, under forced-flow conditions, the maximum number of vehicles that can traverse the work zone is limited to the capacity of the work zone.

During the period 12-1 to 5-6, the facility was identified to operate under free flow condition in step 4 above traffic that traverses the work zone is the demand during the period.

By the same token, during the period from 6-7 to 19-20 the facility is operating under forced flow condition and hence traffic that traverses the work zone is restricted to the capacity. Throughout 24 hours, the number of vehicles traversing the work zone is therefore **32901** vehicles.

Table 49: expanded work zone matrix for the year 2042

AADT of year 2042 = 63700			Queue Rate	Num. of Queued Vehicles	Number of Vehicles that			
Hour	Demand	Capacity			Traverse WZ	Traverse Queue	Stop 50-0-50 (km/hr)	Slow Down 50-30-50 (km/hr)
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
12-1	405	1170	-765	0	405	0	0	405
1-2	290	1170	-880	0	290	0	0	290
2-3	241	1170	-929	0	241	0	0	241
3-4	166	1170	-1004	0	166	0	0	166

AADT of year 2042 = 63700			Queue Rate	Num. of Queued Vehicles	Number of Vehicles that			
Hour	Demand	Capacity			Traverse WZ	Traverse Queue	Stop 50-0-50 (km/hr)	Slow Down 50-30-50 (km/hr)
4-5	192	1170	-978	0	192	0	0	192
5-6	455	1170	-715	0	455	0	0	455
6-7	1202	1170	32	32	1170	1170	1202	0
7-8	1987	1170	817	849	1170	1170	1987	0
8-9	1645	1170	475	1325	1170	1170	1645	0
9-10	1491	1170	321	1645	1170	1170	1491	0
10-11	1617	1170	447	2092	1170	1170	1617	0
11-12	1722	1170	552	2644	1170	1170	1722	0
12-13	1784	1170	614	3258	1170	1170	1784	0
13-14	1815	1170	645	3903	1170	1170	1815	0
14-15	1917	1170	747	4650	1170	1170	1917	0
15-16	2236	1170	1066	5716	1170	1170	2236	0
16-17	2768	1170	1598	7313	1170	1170	2768	0
17-18	3249	1170	2079	6926	3636	3636	3249	0
18-19	2029	1170	859	5320	3636	3636	2029	0
19-20	1292	1170	122	2975	3636	3636	1292	0
20-21	1114	1170	-56	453	3636	3636	1114	0
21-22	945	1170	-225	0	1399	613	159	786
22-23	762	1170	-408	0	1170	0	0	762
23-24	596	1170	-574	0	1170	0	0	596
24 hours	31919				32901	28027	28027	3892

All vehicles that approach the work zone when a physical queue exists must stop and work their way through the queue before entering the work zone. Throughout 24 hours t total of 28027 vehicles traversed the queue as shown at the bottom of column (g) above.

Every vehicle that encounters a physical queue must come to a complete stop before traversing the queue. A total of 28027 vehicles must stop over the 24-hour period, as shown at the bottom of column (h). Column (i) reveals that, only small portion of the daily traffic has to just slow down to traverse the work zone. The number of vehicles that just have to slow down prior to traversing the work zone (as opposed to coming to a complete stop) are those vehicles encountering the work zone under free-flow conditions. Therefore, a total of 3892 vehicles must slow down over the 24-hour period, as shown at the bottom of column (i).

Table 50 in appendix has summarized the traffic affected for all years in the analysis period.

Step 6. Compute Reduced Speed Delay

Before computing actual user cost, it is important to know the number vehicles subjected to speed changes, the number of vehicles that stop, and the delay time through both the work zone and the queue. The number of vehicles that undergo speed changes and that stop is directly related to the affected traffic, which has already been determined in step 5. The amount of delay was computed from the work zone and queue area lengths and the speeds through them. The delay time through the work zone and through the queue was computed in the same manner. In each case, the delay was determined by subtracting the time it takes to traverse either the work zone or queue length when they are present from the time it takes to travel the same distance when they are not present. Both calculations depend on the length to be traversed and the appropriate travel speeds when a work zone and/or a queue are present and when they are not. Equations [9] and [10] presented in previous chapter were taken in this case.

Work Zone Reduced Speed Delay

Using the above formula, it was determined and summarized in table 60 of this paper in the appendix adopting the upstream and work zone speed of 55 km/hr and 30 km/hr respectively for a 1 km work zone length. Because it was assumed that upstream posted speed and work zone speed remains similar for all future years throughout the analysis period, the WZ reduced speed delay calculation reveals identical result i.e. 0.015152 hours/vehicle.

Queue Reduced Speed Delay

Queue reduced speed delay is computed in the same manner, however, in this case the queue speed and queue length were not known. It was therefore found necessary, in this case, to determine the queue speed and queue length for each of the analysis time periods where queues exist before calculating queue reduced speed delay.

Queue Speed Calculation

Speed through the queue can be determined by using the Forced-Flow Average Speed versus Volume to Capacity (V/C) ratio graphs for level of service F contained in the Highway Capacity Manual [44]. Using the volume through the queue and the Free-Flow capacity of the road, the V/C ratio was calculated for each period and used to find the corresponding speed. Using the graph in figure 14 below and a conversion rate of 1.6092 for miles per hour to kilometer per hour; the result was summarized in table 61 of this paper in appendix. Accordingly, a zero km/hr queue speed for years 2020 through 2025, 3.2184 km/hr for years 2026 through 2029, 4.8276 km/hr for years 2030 through 2031 and 41.8392 for years 2038 through 2043.

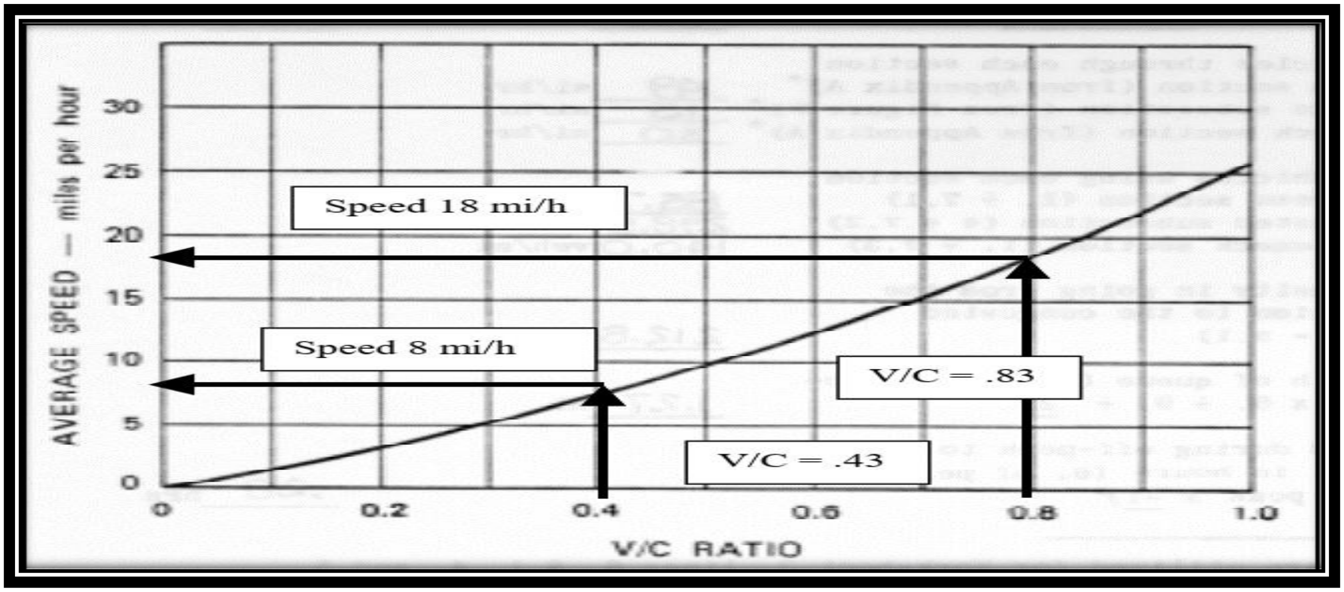


Figure 13: Volume to Capacity Ratio for Corresponding Average Speed (Source: HCM-1994)

Queue Length Calculations

The queue length varies throughout the day with changes in directional hourly demand and capacity through the work zone section. Queue delay computations are generally based on the average queue length over the queue period. An average queue length was computed for each hour that a queue exists. The maximum queue length during the day occurs when the maximum number of vehicles are queued. Because the case under study does not reflect uniform queue growth or dissipation rates, the more detailed hour-by-hour analysis was found more appropriate. The first step is to determine the average number of vehicles queued in each hour. This is simply the arithmetic average of the number of queued vehicles at the beginning and end of each hour. Having the determined average number of queued vehicles, average number of queue length was obtained by dividing average number of queued vehicles to the density. The detailed summary of this step was presented in table 56 of this paper in appendix.

Inspection of table 56 reflects that the average queue length was zero for years 2020 through 2025 and largely deviated from the reality (a queue length of 1013.437 km in 2043). This was because of the effect of speed and it has no effect on the target result.

Finally, having average queue speed and average queue length, time in queue and upstream of the work zone has been determined using a relation between speed and length. That is from the definition; speed is a unit distance travelled in specific duration of time, that time is the duration it takes to travel unit distance with this speed. Then the queue delay time was taken as the difference between time taken in queue and upstream as shown in column (g) of table 57 below.

Table 57: Summary of Average Queue Delay Per Vehicles

Years	Average Queue Length	Queue Speed @		Time (Hours)@		Average Queue Delay Per Vehicles	
		Queue	Upstream	Queue	Upstream	Hours	Minute
a	b	c	d	e	f	g= e-f	h=(e-f) *60
2020	0.0000	0	55	-	-	-	-
2022	0.0000	0	55	-	-	-	-
2023	0.0000	0	55	-	-	-	-
2024	0.0000	0	55	-	-	-	-
2025	0.0000	0	55	-	-	-	-
2026	0.3050	3.2184	55	0.094780302	0.00610082	0.09	5.32
2027	0.4386	3.2184	55	0.136294355	0.008773	0.13	7.65
2028	0.6368	3.2184	55	0.197865852	0.01273623	0.19	11.11
2029	0.8939	3.2184	55	0.277744639	0.01787787	0.26	15.59
2030	1.8970	4.8276	55	0.392951226	0.03794023	0.36	21.30
2032	4.5395	8.0460	55	0.564197861	0.09079072	0.47	28.40
2034	15.0501	12.874	55	1.169063701	0.30100117	0.87	52.08
2035	27.8599	16.092	55	1.731290439	0.55719851	1.17	70.45
2036	18.7703	24.138	55	0.777626208	0.37540683	0.40	24.13
2037	46.5880	28.966	55	1.608389239	0.93175919	0.68	40.60
2038	141.447	41.839	55	3.380738392	2.82894779	0.55	33.11
2039	76.9310	41.839	55	1.838729737	1.53861962	0.30	18.01
2040	243.157	41.839	55	5.811706836	4.86314329	0.95	56.91
2042	384.277	41.839	55	9.184625134	7.68554736	1.50	89.94
2043	1013.44	41.839	55	24.22219525	20.2687454	3.95	237.21

Step 7. Select and Assign VOC Rates

Due to the unavailability of data in Ethiopia, table 5 of NCHRP (National Cooperative Highway Research Program) Report 133, Procedures for Estimating Highway User Costs, was used to determine VOC rates for stopping/speed changes and idling, as well as associated delay times for stopping/speed changes. A compressed version of NCHRP 133 table 5 was reproduced as table 18 of this paper.

Table 18 of this paper shows additional hours of delay and additional VOC associated with stopping 1,000 vehicles from a particular speed and returning them to that speed. In addition, the table includes a vehicle operating cost associated with idling while stopped. The cost factors reflect 1996 prices based on ETB 18.9 ($3) per hour value of time for passenger vehicles and ETB 31.5 ($5) per hour for all trucks. To make these factors applicable to current analysis, the values shown have been escalated to reflect more current year dollars. The escalation factor for VOC is determined by using the transportation component of the Consumer Price Index (CPI) for the base year (1996) and the current year (2019). The transportation component of the CPI was 142.8 in 1996 and 153.9 in 2019 [47]. The VOC escalation factor used to escalate 1996 prices to 2019 prices is:

$$\text{Escalation Factor (VOC)} = \frac{\text{CPI (2019)}}{\text{CPI (1996)}} = 153.90/142.80 = \underline{\underline{1.039}}$$

The table 58 of this paper was designed to determine stopping cost, but it can also be used to determine the speed change cost, which is additional cost (VOC and delay) of slowing from one speed to another and returning to the original speed. Speed change costs are calculated by subtracting the cost and time factors of stopping at one speed from the cost and time factors of stopping at another speed. Additionally, this table is designed to determine stopping cost, it can also be used to determine the cost and time factors associated with slowing from 50 km/hr to 30 km/hr. This is accomplished by subtracting the cost and time factors for stopping associated with each speed from one another. Since the value of added time for these speeds is not in the table, it can be found by interpolation from the values of 24, 32, 48, and 56 km/hr and tabulated below.

Table 10: Speed Change Computations

Initial Speed (mi/h)	*Initial speed (km/hr)*	*Added Time (Hr/1,000 Stops) (Excludes Idling Time)*			*Added Cost (ETB/1,000 Stops) (Excludes Idling Time)*		
		Pass Cars	*Single-Unit Truck*	*Combination Truck*	*Pass Cars*	*Single-Unit Truck*	*Combination Truck*
15	*24*	*2*	*2.2*	*3.48*	*27.02*	*60.41*	*231.67*
19	*30*	*2.36*	*2.73*	*4.41*	*35.57*	*79.25*	*309.71*
20	*32*	*2.49*	*2.93*	*4.76*	*38.76*	*86.27*	*338.78*
30	*48*	*3.46*	*4.4*	*7.56*	*64.35*	*143.02*	*585.05*
31	*55*	*3.56*	*4.56*	*7.91*	*67.39*	*149.38*	*613.93*

Initial Speed (mi/h)	*Initial speed (km/hr)*	*Added Time (Hr/1,000 Stops) (Excludes Idling Time)*			*Added Cost (ETB/1,000 Stops) (Excludes Idling Time)*		
		Pass Cars	*Single-Unit Truck*	*Combination Truck*	*Pass Cars*	*Single-Unit Truck*	*Combination Truck*
35	*56*	*3.94*	*5.13*	*9.19*	*78.54*	*172.68*	*719.86*
31-19-31	*55-30-55*	*1.21*	*1.82*	*3.50*	*31.82*	*70.12*	*304.22*
31-0-31	*55-0-55*	*3.56*	*4.56*	*7.91*	*67.39*	*149.38*	*613.93*
Idling Cost (ETB/Veh-Hr)					*1.23*	*1.37*	*1.47*

Step 8. Select and Assign Delay Cost Rates

This user delay cost rates will be adopted as per Ethiopian perspective. According to [50], assuming 26 effective working days per month and 6 effective working hours per day, recommended value of travel time was taken and hence value of 18, 42, and 50 ETB/Veh-Hr) for passenger cars, single unit trucks and combination trucks respectively were used.

Step 9. Assign Traffic to Vehicle Classes

At this point the directional traffic affected by the various cost components will be distributed to the appropriate vehicle classes for each cost component. Table 61 of this paper in appendix lays out the overall traffic associated with each of the user cost components to the appropriate vehicle classes. The last column of this table is just a mathematical check to ensure that the traffic assigned to the vehicle classes totals back to the original traffic volume.

Step 10. Compute User Cost Components by Vehicle Class

By the same token, daily user costs by vehicle class for each cost component was computed by multiplying the affected traffic by the appropriate unit cost rates (either VOC or delay) for the various components and was summarized in table 62 through 68 of this paper in appendix.

Step 11. Total Work Zone User Costs

Table 69 through 82 of this paper in appendix show a master summary of all costs, and the percent distributions of those costs. The first three cost components (Speed Change VOC, Speed Change Delay Cost, Work Zone Reduced Speed Delay) represent the cost associated with free-flow, while the remaining four cost components (Stopping VOC, Stopping Delay Cost, Idling VOC, Queue Reduced Speed Delay Cost) represent the forced-flow queuing costs. Examination of these tables immediately reveals that the high user costs are not a LCCA problem, but are a traffic control problem.

Assuming the work zone to be in place for 10, 60, and 120 days for routine maintenance, periodic maintenance and rehabilitation respectively and considering activty timings for both options, the following table summarizes total user costs during each activity for each alternative.

Table 11: User Cost Summary Arrived from Appendix C

Serial №	Description		Cost (ETB/day)	Days WZ in place	Total cost (ETB)	Total Cost (ETB)
1	Conventional Flexible	During Routine Maintenance	22,018,718.20	10	220,187,182	14,178,855,923
		During Periodic Maintenance	11,251,638.83	60	675,098,330	
		During Rehabilitation	110,696,420.09	120	13,283,570,411	
1	Flexible Pavement with Geosynthetic	During Routine Maintenance	31,211,865.50	10	312,118,655	4,120,182,985
		During Periodic Maintenance	59,711,980.17	60	3,582,718,810	
		During Rehabilitation	1,877,879.33	120	225,345,520	

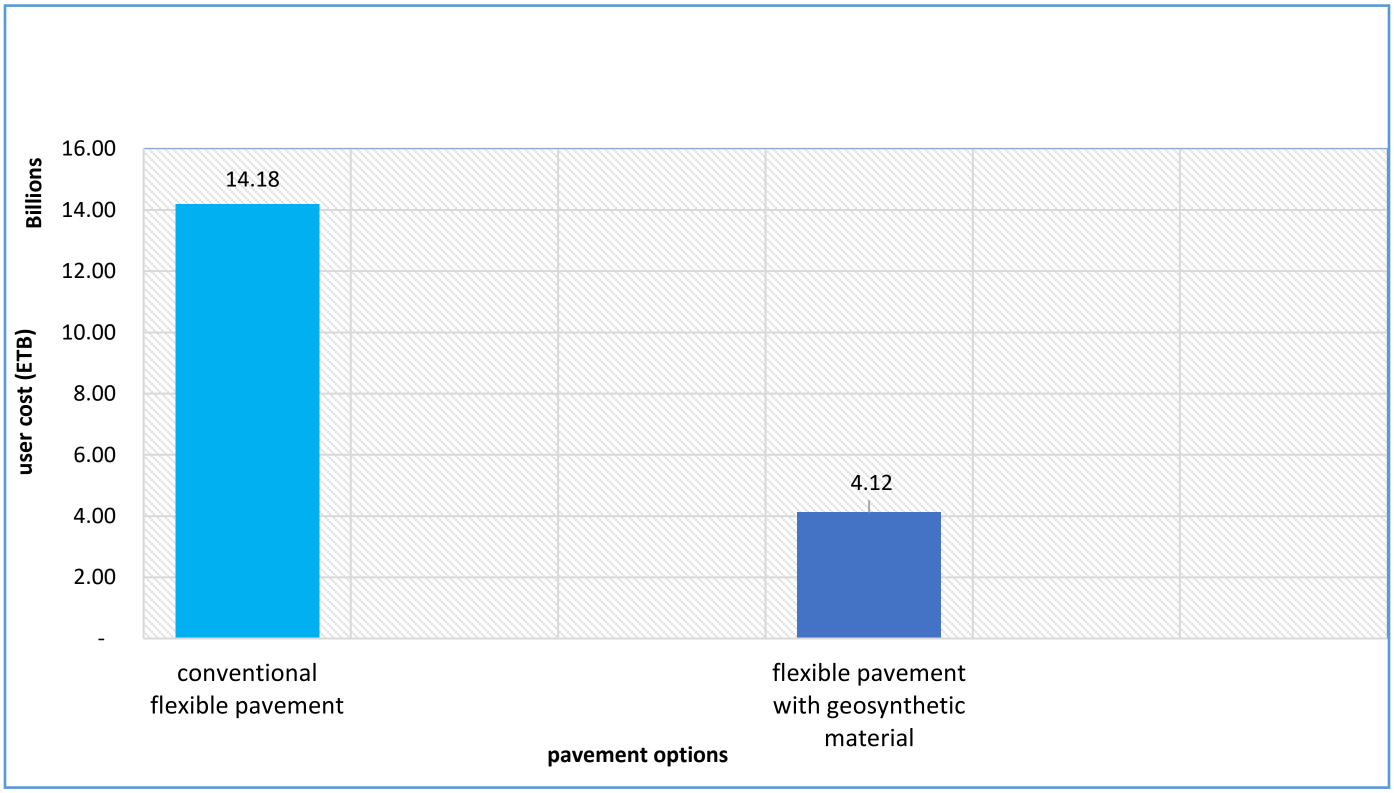


Figure 14: User Cost Summary Comparison

4.4.2.2.1. Vehicle Operating Cost

In Work Zone Road User Cost analysis, VOC is an aggregation of speed change vehicle operating cost, stopping vehicle operating cost, and queue idling vehicle operating cost [35]. VOC is about two times greater for conventional flexible pavement than that with geosynthetic material. The summary of these costs is listed in the following table from appendix C

Table 12: Work Zone Vehicle Operating Cost Summary Arrived from Appendix C.

Serial №	Description	Activity	VOC	Total VOC (ETB)
1	Conventional Flexible Pavement	Routine maintenance	161,610,467	**7,385,166,481**
		Periodic maintenance	558,134,169	
		Rehabilitation (upgrading)	6,665,421,844	
2	Flexible Pavement with Geosynthetic Material	Routine maintenance	242,582,409	**3,712,330,308**
		Periodic maintenance	3,340,653,075	
		Rehabilitation (upgrading)	129,094,823	

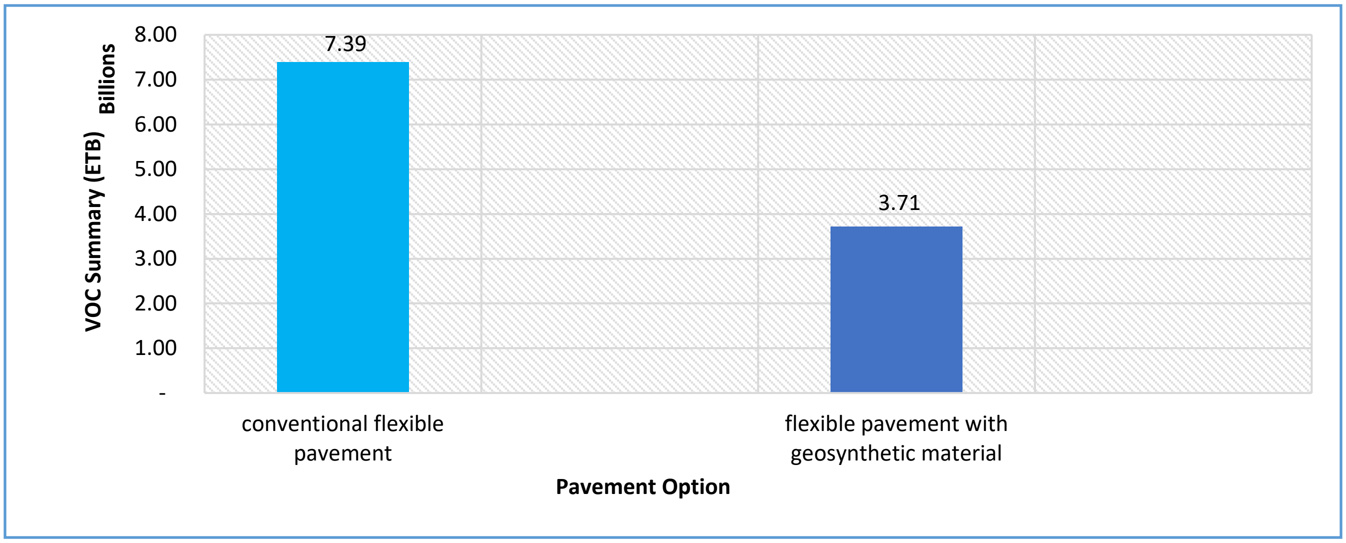


Figure 15: Work Zone Vehicle Operating Cost Summary (VOC) Arrived from Appendix C.

4.4.2.2.2. Travel Delay Costs (TDC)

Unlike travel delay time in the normal operation, travel delay time during the work zone operation of rehabilitation activities depends on many other factors such as the work-zone plan (i.e. Number of lanes closed, time of day of operation, and number of days of operation), traffic volume and characteristics, and vehicle speed (during normal operation and during work-zone). Accordingly, four types of delay costs were considered in quantifying travel delays for work-zone operations. These are, Speed Change Delay Costs

(**TDC**), Reduced Speed Delay Costs (**TDC**), Stopping Delay Costs (**TDC**), and Queue Reduced Speed Delay Costs (**TDC**). The values for these costs were determined and summarized as in the following table.

Table 13: Work Zone Travel Delay Cost Summary arrived from Appendix C.

Serial №	Description	Activity	TDC	Total TDC (ETB)
1	Conventional Flexible Pavement	Routine maintenance	58,576,715	**6,793,689,443**
		Periodic maintenance	116,964,161	
		Rehabilitation (upgrading)	6,618,148,567	
2	Flexible Pavement with Geosynthetic Material	Routine maintenance	69536246	**407,852,679**
		Periodic maintenance	242065735	
		Rehabilitation (upgrading)	96,250,697	

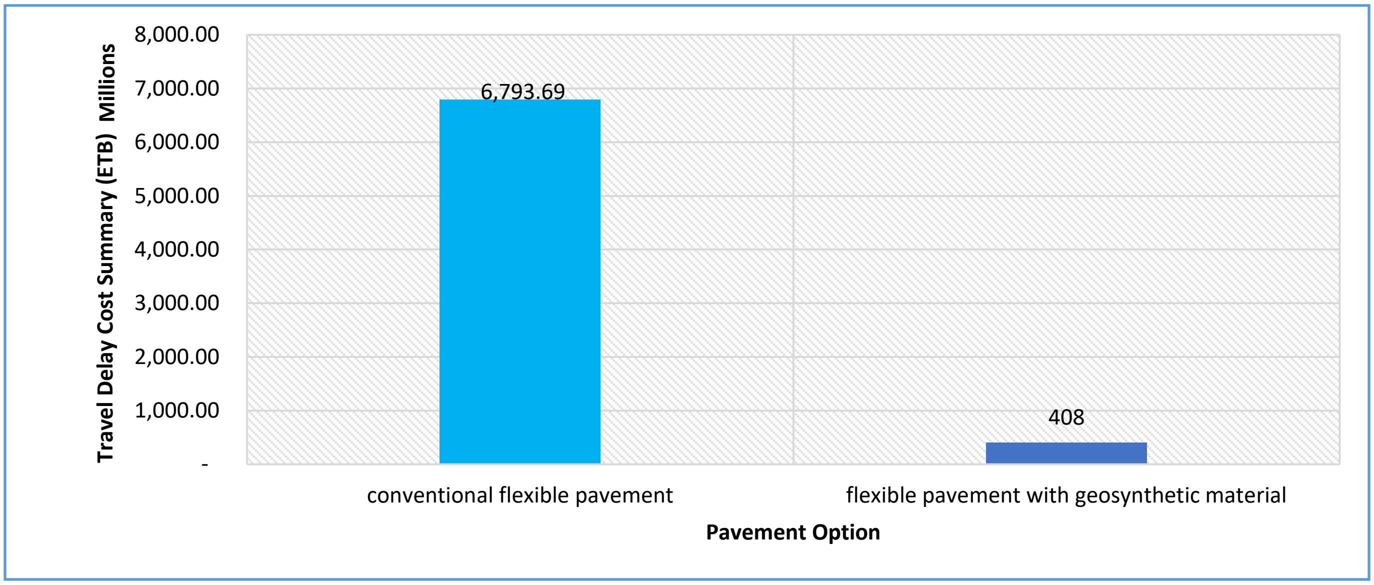


Figure 16: Work Zone Travel Delay Cost Summary comparison.

4.4.3. Environmental cost

This is the most recognized, but rarely included in the analysis. The environmental impacts could affect the air, water, biodiversity, natural resources, noise, and heritage. Among these, only the costs of air pollution and noise have been monetized up to date in transportation evaluation [1]. In general, there is not enough research that shows the vary among alternatives with different serviceability. In the same token, recognizing unavailability of data this cost was excluded in this case from analysis.

4.5. Net present value calculation

As briefly presented in chapter two of this paper equation (1) was used in this particular case to determine the net present value of each alternatives. Recalling the equation; each of the values were determined in appendix C of this paper and summarized in the following tables.

$$\boldsymbol{NPV = IC} + \sum_{k}^{N} \mathbf{MC}\left[\frac{\mathbf{1}}{\mathbf{1+d_r}}\right]^{nk} + \sum_{k}^{N} \mathbf{RC}\left[\frac{\mathbf{1}}{\mathbf{1+d_r}}\right]^{nk} + \sum_{k}^{N} \mathbf{UC}\left[\frac{\mathbf{1}}{\mathbf{1+d_r}}\right]^{nk} - \mathbf{SV}\left[\frac{\mathbf{1}}{\mathbf{1+d_r}}\right]^{n}$$

Where;
IC = initial construction cost; MC= maintenance cost; RC= rehabilitation cost; UC= user cost; SV = salvage value; n= analysis period, years; nk = number of years from the initial construction to the kth expenditure; N= number of future costs incurred over the analysis period; dr = discount rate.

Table 14: Discounted Sum for Conventional Pavement in the Analysis Period Arrived from Appendix C

Cost Components	IC Cost (ETB)	Maintenance Cost (ETB)	Rehabilitation Cost (ETB)	User Cost (ETB)	Salvage Value (ETB)
Discounted Sum	4,248,120.00	571,024,920	956,172,516	3,609,374,568	94,258,489

Table 15: Discounted Sum for Conventional Pavement in the Analysis Period Arrived from Appendix C

Cost Components	IC Cost (ETB)	Maintenance Cost (ETB)	Rehabilitation Cost (ETB)	User Cost (ETB)	Salvage Value (ETB)
Discounted Sum	4,312,620	934,202,945	381,971,780	1,937,802,270	142,954,658

Using the values in above tables, net present values of each alternatives were determined and summarized in the following table considering salvage value as a negative cost.

NPV for conventional FP = 4,248,120.00 + 571024920.4 + 956172516.1 + 3609374568- 94258489.65

= 5,042,313,514.84 ETB

NPV of FP with geosynthetic materials = 4,312,620 + 934,202,945 + 381,971,780 + 1,937,802,270

- 142,954,658

= 3,111,022,338.85 ETB

Table 16 : Net Present Values of the Two Alternatives.

Serial №	Alternatives	Net Present Value (NPV)
1	Conventional Flexible Pavement	5,042,313,514.84 ETB
2	Flexible Pavement with Geosynthetic Materials	3,111,022,338.85 ETB

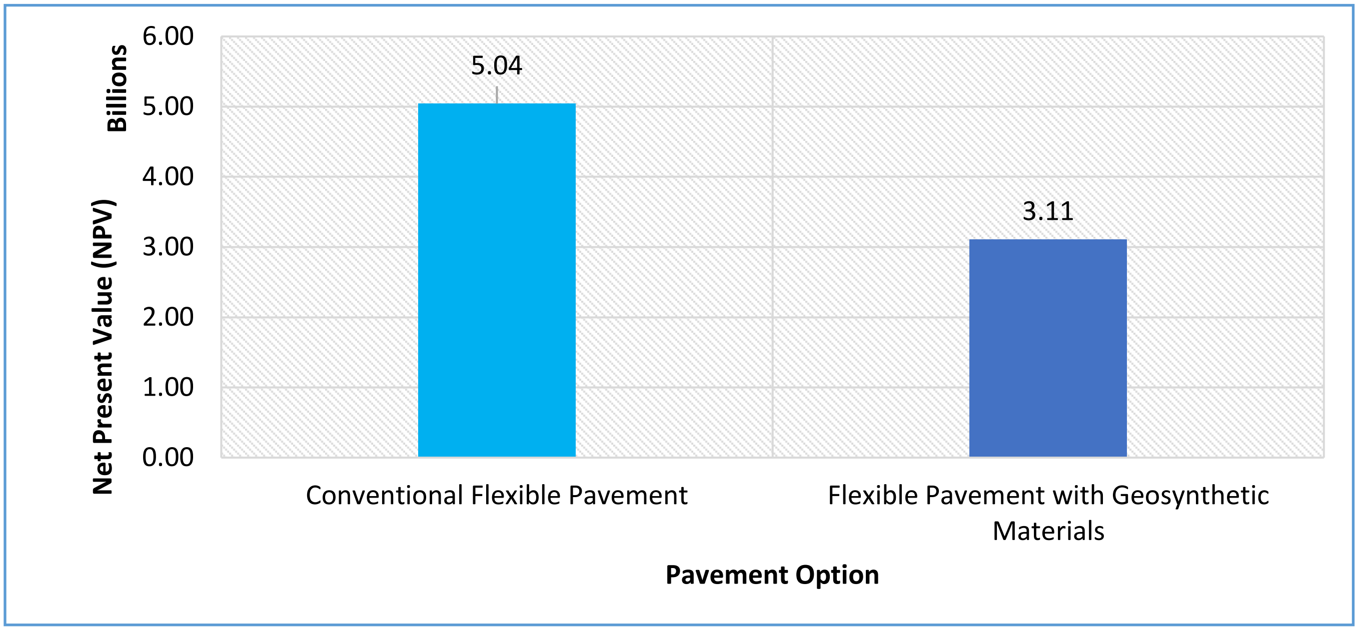


Figure 17: Net Present Value Comparison

The core purpose of the life cycle cost analysis to compare the agency and user cots to draw a wise decision on investement selection. The following table summarizes the Discounted cost components of the two alternatives.

Table 17: Discounted Cost Components

Option	conventional flexible pavement		flexible pavement with geosynthetic materials	
Cost component	Agency Cost (ETB)	User Cost (ETB)	Agency Cost (ETB)	User Cost (ETB)
NPV	1,437,187,066.81	3,609,374,568.03	1,177,532,688.72	1,937,802,270.13

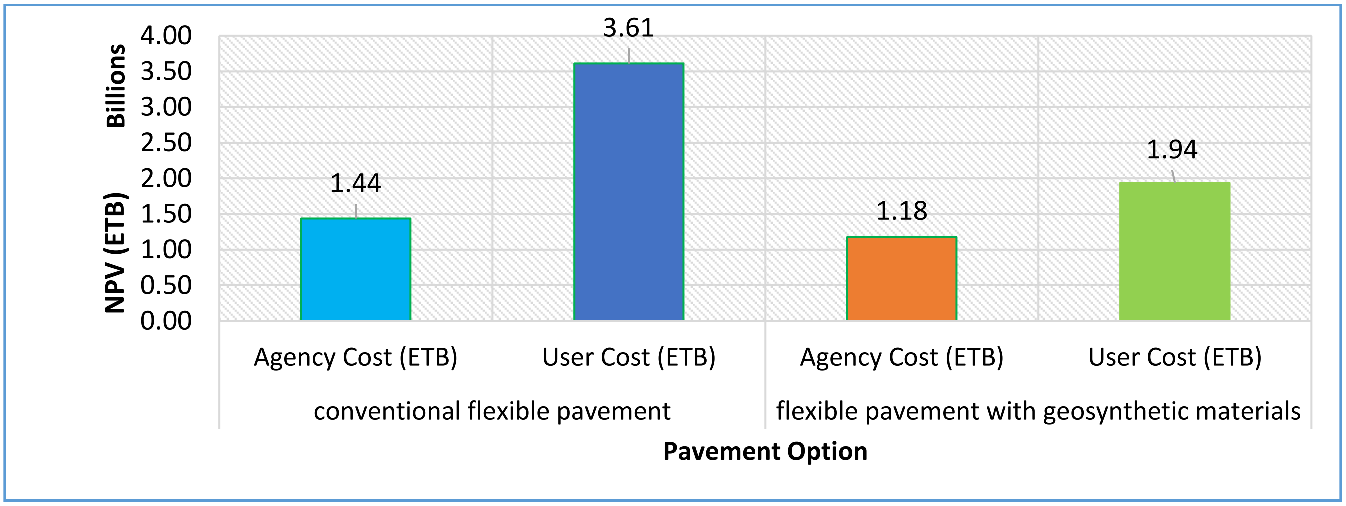


Figure 18: Discounted Cost Components comparison.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Presented in this paper was a brief over view of the sustainable and economical pavement option by making life cycle cost comparisons and economic analysis of flexible pavement with and without geosynthetic materials in Addis Ababa.

Estimation of construction, maintenance and rehabilitation costs was done specific to each construction, maintenance and rehabilitation treatment. Two alternative methodologies were provided to determinine agency cost associated with maintenance and rehabilitation fixing the costs to 2019 dollars and the initial construction cost of both alternatives. The Agency costs determined for conventional flexible pavement and that with geosynthetic material was to be 3,182,653,893 and 1,580,443,895 ETB respectively. This conveys a message that using geosynthetic material in flexible pavement can reduce an Agency cost by 50.34 % which can outweigh the applicablity of using lower initial construction cost as standard. The seven user cost components associated to work zone operations (Travel Delay Costs & Vehicle Operating Costs) were determined. Only work zone user costs were given prominent coverage in this paper and costs associated with noise, and pollution should not be a formidable concern as they are not expected to vary significantly by LCCA alternative. Accordingly, Inspection of analysis part in this paper reveals that, user cost was determined to be 14,178,855,923 & 4,120,182,985 ETB respectively putting the former one conventional FP. This implies that about 70.9% of user cost can be avoided when using a geosynthetic materials.

Economic evaluation of flexible pavement with geosynthetic materials and without geosynthetic materials on selected road segment was carried out using the NPV as economic indicator. As such incorporating geosynthetic material in pavement was found more economical and most effective alternative pavement option.

Finnally; Overlooking life cycle cost analysis or wasting a budget on trying to avoiding it leads to managing asset cost reactively adopting the minimum construction cost as standard. Regardless to the policy of avoiding future economic surprise, decisions made in any area of construction industry has been failed to avoid it. To do right from the beginning, decision makers need to consider the comprehensive LCCA of pavements options including initial construction, future maintenance, rehabilitation, environmental, and user costs.

5.2. Recommendation

5.2.1. Recommendation for further studies

1. One of the challenges faced in estimating future maintenance cost in this study is the absence of reliable data base in road asset management in Ethiopia. FHWA states that maintenance costs may be expressed as a function of pavement condition or may be expressed as a function of pavement age and maintenance costs increases as a structures age [23]. Therefore, pavement maintenance cost models which based on pavement condition (PSI) and traffic volumes should be developed for road infrastructures in Addis Ababa.
2. Due to the absence of some important data in ethiopia data from abroad such as directional factor was adopted in this study. This may have a significant effect on queue length calculation. There fore, more research needs to be done using an hour-by-hour roadway capacity, directional factor consistent to Ethiopia and traffic demand in Addis Ababa.
3. A formidable concern for detour was not given in this study. When work zone is in place, there is additional mileage that users travel, either voluntarily or involuntarily. This additional mileage is described by circuity. There fore, circuity costs should be determined in future study If traffic is forced to detour (formal detour is established.

5.2.2. Recommendation for Agencies

Inspection reveals that more than 90 percent of the user costs result from the forced flow queuing costs. Therefore, approximately 90 percent of the user costs can be avoided by not allowing the queues to develop in the first place. In the case under study, the queuing situation could be drastically reduced, if not completely avoided, if work zone operations could be limited to evening work between. By limiting the contractor to evening work hours only, the queue cost in queue period would be completely eliminated and the evening rush hour would not have to deal with the built-up queue from the midday work zone! The contractor's productivity rate would suffer dramatically during the midday use of the facility because the contractor's delivery vehicles would have to deal with the same delays as the general traffic stream. It is therefore not a large penalty on the contractor to be unable to work during midday. Therefore, it is advisable to practice the decision of limiting the contractor to evening work hours only.

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Appendix A: Major data collected

Appendix A. 1: Pavement data

№	*Description of parameters*	*Flexible pavement with geosynthetic material*			*Conventional flexible pavement*		
2	*Design Life*	*20*			*20*		
3	*Traffic data (AADT)*	*41478*			*41478*		
	Analysis Period	*25*			*25*		
4	*Traffic Growth Rate*	*5%*			*5%*		
5	*California Bearing Ratio*	*penetration*	*load*	*CBR*	*penetration*	*load*	*CBR*
		2.54	*290*	*93.34%*	*2.54*	*221*	*71.73*
		5.08	*457.5*	*97.73%*	*5.08*	*339*	*72.42*
6	*Design CBR*	*97.73% (ratio @ 2.54mm < 5.08mm)*			*72.42%*		
7	*Layer Thickness (mm)*						
8	*Capping Layer Under the Sub Base*	*400*			*750*		
9	*Sub-Base Course*	*175*			*250*		
10	*Base Course*	*75*			*150*		

BOQ for flexible pavement of 1km and three lanes (as per the typical road section)

Item №	***Description***	***Unit***	***Quantity***	***Rate***	***Amount***
1.	***Bituminous Surfacing***				
1.1	*Bituminous Prime Coat*				
1.1.1.	*MC-30 cut back bitumen applied at 1 liter per square meter*	*liter*	*14160*	*45*	*637200*
2.	***Tack Coat***				
2.1.	*RC-70 cut back bitumen applied at 1 liter per square meter*	*liter*	*14160*	*43*	*608880*
3.	***Asphaltic Surfacing***				
3.1.	*50mm asphaltic surfacing with penetration grade of 80/100 bitumen*	M^2	*14160*	*218*	*3086880*
3.2.	*Dense Bitumen Macadam (145mm)*	M^3	*2053*	*3259*	*6690727*

Flexible pavement maintenance activities in Ethiopian context [51]

Type	*Code*	*Name of Activity*	*Unit*
Routine Maintenance	*210*	*Asphalt Patching (Seal Coat)*	*m2*
	211	*Asphalt Patching (Single Surface Treatment)*	*m2*
	212	*Asphalt Patching (Double Surface Treatment)*	*m2*
	213	*Asphalt Patching (Cold Mix)*	*m3*
	214	*Asphalt Patching (Hot-Mini-Mix)*	*m3*
	215	*Crack Sealing (Individual Cracks)*	*Lm*
	219	*Pothole (Base Failure Repair)*	*m3*
Periodic Maintenance	*309*	*Sand seal coat m2*	*m2*
	310	*Single Bituminous Surface Treatment (SBST) m2*	*m2*
	311	*Double Bituminous Surface Treatment (DBST)*	*m2*
	312	*Mix-In-Place Overlay (Cold Mix)*	*m3*
	313	*Asphaltic Concrete Overlay*	*m3*
	314	*Bitumen Prime Coat*	*Lt*
	315	*Bitumen Tack Coat*	*Lt*
	316	*Pavement Reconstruction (Aggregate Road base)*	*m3*

Appendix A.1 Traffic data

Table 18 : Average Annual Daily Traffic (Source: Addis Ababa City Road Authority)

1. Month	*2. Total monthly volume (vehs)*	*4. ADT (vehs/day)*
January	*645840*	*21528*
February	*642960*	*21432*
March	*613950*	*20465*
April	*663690*	*22123*
May	*599610*	*19987*
June	*646380*	*21546*
July	*604350*	*20145*
August	*596910*	*19897*
September	*643710*	*21457*
October	*649620*	*21654*
November	*607350*	*20245*
December	*655350*	*21845*
Total	***7569720***	***-***
AADT	***20739***	

Table 19: Vehicle Groups, Classifications and Percentage of AADT (IDOT Classification Method)

Vehicle Classification	*Description*	*Volume & % of AADT*	
1. passenger vehicles		***65%***	***13480***
Motorcycles	*All two or three-wheeled motorized vehicles*		
All Sedans, Coupes, and Station Wagons	*Those cars pulling recreational/ other light trailers*		
Campers, Motorhomes, Ambulances	*Two-Axle, Four-Tire Single Unit Vehicles*		
2. Single Unit Truck		***20%***	***4148***
Buses	*Buses with 2 axles and 6 tires or 3 or more axles.*		
Trucks, Recreational Vehicles, motors	*Two-Axle, Six-Tire, with dual rear wheels.*		
Trucks, Recreational Vehicles, Motors	*All vehicles on a single frame with three axles.*		
Trucks, Recreational Vehicles, Motors	*All trucks on a single frame with four or more axles.*		
3. Combination Trucks		***15%***	***3111***
Single-Trailer Trucks	*All vehicles with four or fewer axles, five-axle, six or more axles consisting of two units, one of which is a tractor or straight truck power unit.*		
Multi-Trailer Trucks	*All vehicles with five or fewer axles, six-axle, seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.*		

Table 20: Maximum mixed vehicle traffic capacities for trucks in the traffic stream (Source: HCM-1994)

% Trucks	***Truck Equivalency Factor***									
	1.5	***2.0***	***2.5***	***3.0***	***3.5***	***4.0***	***4.5***	***5***	***5.5***	***6***
0.0%	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*
2.0%	*2,277*	*2,255*	*2,233*	*2,212*	*2,190*	*2,170*	*2,150*	*2,130*	*2,110*	*2,091*
4.0%	*2,255*	*2,212*	*2,170*	*2,130*	*2,091*	*2,054*	*2,018*	*1,983*	*1,949*	*1,917*
5.0%	*2,244*	*2,190*	*2,140*	*2,091*	*2,044*	*2,000*	*1,957*	*1,917*	*1,878*	*1,840*
6.0%	*2,233*	*2,170*	*2,110*	*2,054*	*2,000*	*1,949*	*1,901*	*1,855*	*1,811*	*1,769*
8.0%	*2,212*	*2,130*	*2,054*	*1,983*	*1,917*	*1,855*	*1,797*	*1,742*	*1,691*	*1,643*
10.0%	*2,190*	*2,091*	*2,000*	*1,917*	*1,840*	*1,769*	*1,704*	*1,643*	*1,586*	*1,533*
12.0%	*2,170*	*2,054*	*1,949*	*1,855*	*1,769*	*1,691*	*1,620*	*1,554*	*1,494*	*1,438*
14.0%	*2,150*	*2,018*	*1,901*	*1,797*	*1,704*	*1,620*	*1,544*	*1,474*	*1,411*	*1,353*
15.0%	*2,140*	*2,000*	*1,878*	*1,769*	*1,673*	*1,586*	*1,508*	*1,438*	*1,373*	*1,314*
16.0%	*2,130*	*1,983*	*1,855*	*1,742*	*1,643*	*1,554*	*1,474*	*1,402*	*1,337*	*1,278*
18.0%	*2,110*	*1,949*	*1,811*	*1,691*	*1,586*	*1,494*	*1,411*	*1,337*	*1,271*	*1,211*

% Trucks	***Truck Equivalency Factor***									
	1.5	***2.0***	***2.5***	***3.0***	***3.5***	***4.0***	***4.5***	***5***	***5.5***	***6***
20.0%	*2,091*	*1,917*	*1,769*	*1,643*	*1,533*	*1,438*	*1,353*	*1,278*	*1,211*	*1,150*
22.0%	*2,072*	*1,885*	*1,729*	*1,597*	*1,484*	*1,386*	*1,299*	*1,223*	*1,156*	*1,095*
24.0%	*2,054*	*1,855*	*1,691*	*1,554*	*1,438*	*1,337*	*1,250*	*1,173*	*1,106*	*1,045*
25.0%	*2,044*	*1,840*	*1,673*	*1,533*	*1,415*	*1,314*	*1,227*	*1,150*	*1,082*	*1,022*

Table 21: Observed saturation flow rates per hour of green time (Source: Table 2-13, of the 1994 HCM).

1,470	1,572	1,651	1,682	1,785	1,791
1,832	1,840	1,875	1,827	1,896	1,905
1,910	1,936	1,937	2,000	2,000	-
Average					1,818
Standard Deviation					144

Table 22: Measured Average Work Zone Capacities (Source: HCM - 1994)

Directional Lanes		Number of Studies	Average Capacity	
Normal Operations	Work Zone Operations		Vehicles Per Hour	Vehicles per Lane per Hour
3	1	7	1,170	1,170
2	1	8	1,340	1,340
5	2	8	2,740	1,370
4	2	4	2,960	1,480
3	2	9	2,980	1,490
4	3	4	4,560	1,520

Table 23: Added time and vehicle running cost/1,000 stops and idling costs (1996 $).

Initial Speed (mi/h)	Added Time (Hr/1,000 Stops) (Excludes Idling Time)			Added Cost ($/1,000 Stops) (Excludes Idling Time)		
	Pass Cars	Single-Unit Truck	Combination Truck	Pass Cars	Single-Unit Truck	Combination Truck
5	1.02	0.73	1.1	0.71	2.43	8.83
10	1.51	1.47	2.27	2.32	5.44	20.35
15	2	2.2	3.48	3.98	8.9	34.13
20	2.49	2.93	4.76	5.71	12.71	49.91
25	2.98	3.67	6.1	7.53	16.8	67.37
30	3.46	4.4	7.56	9.48	21.07	86.19
35	3.94	5.13	9.19	11.57	25.44	106.05
40	4.42	5.87	11.09	13.84	29.93	126.63
45	4.9	6.6	13.39	16.3	34.16	147.62
50	5.37	7.33	16.37	18.99	38.33	168.7
55	5.84	8.07	20.72	21.92	42.25	189.54
60	6.31	8.8	27.94	25.13	47	209.82

Initial Speed (mi/h)	Added Time (Hr/1,000 Stops) (Excludes Idling Time)			Added Cost ($/1,000 Stops) (Excludes Idling Time)		
	Pass Cars	Single-Unit Truck	Combination Truck	Pass Cars	Single-Unit Truck	Combination Truck
65	6.78	9.53	NA	28.63	51.43	NA
70	7.25	NA	NA	32.46	NA	NA
75	7.71	NA	NA	36.64	NA	NA
80	8.17	NA	NA	41.19	NA	NA
Idling Cost ($/Veh-Hr)				0.1819	0.2017	0.2166

Source: R. Winfrey, Economic Analysis for Highways, and table 5, NCHRP Report 133. Added Cost ($/1,000 Stops) includes fuel, tires, engine oil, maintenance, and depreciation. Idling Cost ($/Veh-Hr) includes fuel, engine oil, maintenance, and depreciation.

Between 1996 and 2000 the birr went from about 6.4 birr to 1 dollar, to 8.3 birr to 1 dollar [52]. Using 6.4 rate, table 18 above was adjusted to ETB as follow.

Table 24: Added time and vehicle running cost/1,000 stops and idling costs (1996 ETB).

Initial Speed (mi/h)	Added Time (Hr/1,000 Stops) (Excludes Idling Time)			Added Cost (ETB/1,000 Stops) (Excludes Idling Time)		
	Pass Cars	Single-Unit Truck	Combination Truck	Pass Cars	Single-Unit Truck	Combination Truck
5	1.02	0.73	1.1	4.47	15.31	55.63
10	1.51	1.47	2.27	14.62	34.27	128.21
15	2	2.2	3.48	25.07	56.07	215.02
20	2.49	2.93	4.76	35.97	80.07	314.43
25	2.98	3.67	6.1	47.44	105.84	424.43
30	3.46	4.4	7.56	59.72	132.74	543.00
35	3.94	5.13	9.19	72.89	160.27	668.12
40	4.42	5.87	11.09	87.19	188.56	797.77
45	4.9	6.6	13.39	102.69	215.21	930.01
50	5.37	7.33	16.37	119.64	241.48	1062.81
55	5.84	8.07	20.72	138.10	266.18	1194.10
60	6.31	8.8	27.94	158.32	296.10	1321.87
65	6.78	9.53	NA	180.37	324.01	NA
70	7.25	NA	NA	204.50	NA	NA
75	7.71	NA	NA	230.83	NA	NA
80	8.17	NA	NA	259.50	NA	NA
Idling Cost (ETB/Veh-Hr)				1.1460	1.2707	1.3646

Appendix A.2 Living wages (Source: https://wageindicator.org/salary/living-wage/ethiopia-living-wage-series-january-2018-countryoverview)

Wage indicators	Years			
	2015	2016	2017	2018
Minimum wage	420	420	420	420
Living Wage - Single Adult	-	-	-	1960-3510
Living Wage - Typical Family	-	-	-	2670-4580
Real wage of low-skilled worker	1150-1720	1260-1780	1000-1530	2540-4110
Real wage of medium-skilled worker	1610-2490	1710-2510	1520-2400	3010-4880
Real wage of high-skilled worker	2200-3090	2570-3420	2490-3560	4370-6500

Appendix B Agency cost calculation

Table 25: Activity Timings (Source: Addis Ababa City Road Authority Maintenance Manual)

Options	**Remedial type**	**Activity Time**	**cost base line**	**remark**
Flexible pavement with geosynthetic materials	Initial Construction	In 2019 G.C.	Cost of 2019 G.C.	projected with consideration of time value of money.
	Routine Maintenance	Once Every Years		
	Periodic Maintenance	Once Every 4 Years		
	Rehabilitation	Once Every 10 Years of 25 Year (2029 and 2039)		
	user cost	During Maintenance & Rehabilitation		
	salvage value	At 25th Year (2044 G.C.)		
conventional Flexible pavement	Initial Construction	In 2019 G.C.		
	Routine Maintenance	once every year		
	Periodic Maintenance	Once Every Three Years		
	Rehabilitation	Once Every 8 Years of 25 Year (2027, 2035 and 2043)		
	user cost	During Maintenance & Rehabilitation		
	salvage value	At 25th Year (2039 G.C.)		

Appendix B.1 Maintenance cost calculation

Abbreviation:

M= Mainline **OS=** Outside Shoulder **IS=** Inside Shoulder **R=** Ramps

Roadway Data: Mainline: Length = 1000m, Width = 10.5m, IS = 1.22m, OS = 2.44m, Total width = 10.5+1.22+2.44 = 14.16m, Area = 10.5*1000 = 10500M^2

Area ((1) 1.22m Inside Shoulders) = 1.22*1000 = 1220m^2

Area ((1) 2.44m Outside Shoulders) = 2.44*1000 = 2440m^2

Table 26 : Conventional Flexible pavement cost schedule in the 25 years analysis period (2019-2044)

Age in Years		Construction	Maintenance		Rehabilitation	Salvage Value
			Routine	Periodic		
0	2019	✍				
1	2020		✍			
2	2021		✍			
3	2022			✍		
4	2023		✍			
5	2024		✍			
6	2025			✍		
7	2026		✍			
8	2027				✍	
9	2028			✍		
10	2029		✍			
11	2030		✍			
12	2031			✍		
13	2032		✍			
14	2033		✍			
15	2034			✍		
16	2035				✍	
17	2036		✍			
18	2037			✍		
19	2038		✍			
20	2039		✍			
21	2040			✍		
22	2041		✍			
23	2042		✍			
24	2043				✍	
25	2044					✍

Table 27 : Flexible pavement with geosynthetic materials cost schedule in the 25 years analysis period (2019-2044

Age in Years		Construction	Maintenance		Rehabilitation	Salvage Value
			Routine	Periodic		
0	2019	✍				
1	2020		✍			
2	2021		✍			
3	2022		✍			
4	2023			✍		
5	2024		✍			
6	2025		✍			
7	2026		✍			
8	2027			✍		

9	2028		✍			
10	2029				✍	
11	2030		✍			
12	2031			✍		
13	2032		✍			
14	2033		✍			
15	2034		✍			
16	2035			✍		
17	2036		✍			
18	2037		✍			
19	2038		✍			
20	2039				✍	
21	2040		✍			
22	2041		✍			
23	2042		✍			
24	2043			✍		
25	2044					✍

Appendix B 1.1Routine maintenance Cost

Table 28: Routine maintenance cost of flexible pavement at the end of 2019

Code	Name of Activity	Unit	Unit Rate	Entire Lanes Quantity	Amount (ETB)
210	Asphalt Patching (Seal Coat)	m2	70.98	708	50253.8
211	Asphalt Patching (Single Surface Treatment)	m2	78.48	283.2	22225.5
212	Asphalt Patching (Double Surface Treatment)	m2	144.26	283.2	40854.4
214	Asphalt Patching (Hot-Mini Mix)	m3	4,650.10	70.8	329227
215	Crack Sealing (Individual Cracks) (>3mm)	Lm	60.31	50	3015.5
218	Pothole Reinstatement (Hot Mini-Mix) 150mm avg. thickness	m3	7235.68	42.48	307372
219	Pothole (Base Failure Repair) for 100mm avg. thickness	m3	786.42	28.32	22271.4
Total Cost (ETB/KM)		**775, 219.4888**			

Table 29: Routine Maintenance Cost Summary for conventional pavement in the Analysis Period

age in years		1+if	(1+if) ^n	Routine maintenance at the end of 2019 (PV)	Routine maintenance cost in analysis period (FV) = PV (1+if) ^n
0	2019				
1	2020	1.27437	1.27437	775219.4889	987916.46
2	2021	1.27437	1.62402	775219.4889	1258971.10
3	2022	1.27437		775219.4889	

age in years		1+if	(1+if) ^n	Routine maintenance at the end of 2019 (PV)	Routine maintenance cost in analysis period (FV) = PV (1+if) ^n
4	2023	1.27437	2.63744	775219.4889	2044592.86
5	2024	1.27437	3.36107	775219.4889	2605567.80
6	2025	1.27437		775219.4889	
7	2026	1.27437	5.45844	775219.4889	4231491.34
8	2027	1.27437		775219.4889	
9	2028	1.27437		775219.4889	
10	2029	1.27437	11.2968	775219.4889	8757498.55
11	2030	1.27437	14.3963	775219.4889	11160293.42
12	2031	1.27437		775219.4889	
13	2032	1.27437	23.3799	775219.4889	18124527.42
14	2033	1.27437	29.7946	775219.4889	23097354.00
15	2034	1.27437		775219.4889	
16	2035	1.27437		775219.4889	
17	2036	1.27437	61.6629	775219.4889	47802306.05
18	2037	1.27437		775219.4889	
19	2038	1.27437	100.142	775219.4889	77631848.35
20	2039	1.27437	127.618	775219.4889	98931698.58
21	2040	1.27437		775219.4889	
22	2041	1.27437	207.253	775219.4889	160666948.00
23	2042	1.27437	264.118	775219.4889	204749138.52
24	2043	1.27437		775219.4889	
25	2044	1.27437		775219.4889	
Grand Total (ETB/KM)					**662,050,152.44**

Table 30: Routine Maintenance Cost Summary for flexible pavement with geosynthetic materials in the Analysis Period

n	Years	1+if	(1+if) ^n	Routine Maintenance at The End of 2019 (PV)	Routine Maintenance Cost in Analysis Period (FV) = PV (1+if) ^n
0	2019				-
1	2020	1.27437	1.27437	775219.4889	987916.4601
2	2021	1.27437	1.624018897	775219.4889	1258971.099
3	2022	1.27437	2.069600962	775219.4889	1604395.000
4	2023	1.27437		775219.4889	
5	2024	1.27437	3.361071071	775219.4889	2605567.798
6	2025	1.27437	4.28324814	775219.4889	3320457.434
7	2026	1.27437	5.458442933	775219.4889	4231491.340
8	2027	1.27437		775219.4889	
9	2028	1.27437	8.86461447	775219.4889	6872021.899

n	Years	1+if	(1+if) ^n	Routine Maintenance at The End of 2019 (PV)	Routine Maintenance Cost in Analysis Period (FV) = PV (1+if) ^n
10	2029	1.27437		775219.4889	
11	2030	1.27437	14.39630141	775219.4889	11160293.420
12	2031	1.27437		775219.4889	
13	2032	1.27437	23.37986554	775219.4889	18124527.420
14	2033	1.27437	29.79459925	775219.4889	23097354.000
15	2034	1.27437	37.96934345	775219.4889	29434575.02
16	2035	1.27437		775219.4889	
17	2036	1.27437	61.66293126	775219.4889	47802306.05
18	2037	1.27437	78.58138971	775219.4889	60917824.77
19	2038	1.27437	100.1417656	775219.4889	77631848.35
21	2040	1.27437	162.6321197	775219.4889	126075588.7
22	2041	1.27437	207.2534944	775219.4889	160666948
23	2042	1.27437	264.1176356	775219.4889	204749138.5
25	2044			775219.4889	
Grand Total (ETB/KM)					**779,553,308.83**

Appendix B 1.2 Periodic maintenance cost

Periodic maintenance cost of Flexible pavement at end of 2019

Sand seal coat quantity for entire lanes including shoulders (14.16m)

= 10% of the area = 0.10 (width * length) = 0.10 (14.16m * 1000m) = $\underline{\underline{1416m^2}}$

Single Bituminous Surface Treatment quantity for entire lane including shoulders (14.16m)

= 10% of the area = 0.10 (width * length) = 0.10 (14.16m * 1000m) = $\underline{\underline{1416m^2}}$

Double Bituminous Surface Treatment quantity for entire lanes including shoulders (14.16m)

= 10% of the area = 0.10 (width * length) = 0.10 (14.16m * 1000m) = $\underline{\underline{1416m^2}}$

Mix-In-Place Overlay (Cold Mix) for 50mm thickness quantity for entire lanes (14.16m)

= 10% of the quantity = 0.10 (width * thickness * length) = 0.10 (14.16m * 0.05m * 1000m) = $\underline{\underline{70.8m^3}}$

Asphaltic Concrete Overlay for 40mm thickness quantity for entire lanes (14.16m)

= 15% of the quantity = 0.15 (width * thickness * length) = 0.15 (14.16m * 0.04m * 1000m) = $\underline{\underline{84.96m^3}}$

Bitumen Prime Coat (0.3lt/m2) quantity for entire lanes (14.16m)

= 60% of the quantity = 0.6 (0.3 liters/m^2 * 14160m^2) = $\underline{\underline{2548.8\text{liters}}}$

Bitumen Tack Coat (0.5lt/m2) quantity for entire lanes (14.16m)

= 60% of the quantity = 0.6 (0.5 liters/m^2 * 14160m^2) = $\underline{\underline{4248\text{liters}}}$

Pavement Reconstruction (Aggregate Road base to 150mm) quantity for entire lanes (14.16m)

= 10% of the quantity = 0.10 (width * thickness * length) = 0.10 (14.16m * 0.15m * 1000m) = $\underline{\underline{212.4m^3}}$

Table 31 : Periodic maintenance cost of flexible pavement at the end of 2019 (Source: Thesis Report on Cost and Benefit Analysis of Flexible and Rigid Pavement by Yonas Katema in JiT; 2015)

Code	Name of Activity	Unit	Unit Rate (ETB/unit)	Entire lane quantity	Amount (ETB)
309	Sand seal coat	m2	49.3086	1416	69,820.98
310	Single Bituminous Surface treatment (SBST)	m2	51.6104	1416	73,080.26
311	Double Bituminous Surface Treatment (DBST)	m2	106.74	1416	151,143.59
312	Mix-in-place overlay (cold mix) of 50mm thick	m3	3972.2	70.8	281,231.51
313	Asphaltic concrete overlay for 40mm thickness	m3	4435.13	84.96	376,809.04
314	Bitumen Prime Coat (0.3lt/m2)	Lt	38.516	2548.8	98,169.45
315	Bitumen Tack Coat (0.5lt/m2)	Lt	42.8126	4248	181,867.71
316	Pavement Reconstruction (aggregate road base)	m3	842.297	212.4	178,903.94
Total Cost			**1,411,026.48**		

Table 32:Periodic Maintenance Cost Summary for conventional flexible pave. in the Analysis Period

n	Years	1+if	(1+if) ^n	Periodic maintenance at the end of 2019 (PV)	Periodic maintenance cost in analysis period (FV) = PV (1+if) ^n
0	2019				
1	2020	1.27437		1,411,026.48	
2	2021	1.27437		1,411,026.48	
3	2022	1.27437	2.0696	1,411,026.48	2920261.76
4	2023	1.27437		1,411,026.48	
5	2024	1.27437		1,411,026.48	
6	2025	1.27437	4.28325	1,411,026.48	6043776.547
7	2026	1.27437		1,411,026.48	
8	2027	1.27437		1,411,026.48	
9	2028	1.27437	8.86461	1,411,026.48	12508205.75
10	2029	1.27437		1,411,026.48	
11	2030	1.27437		1,411,026.48	
12	2031	1.27437	18.3462	1,411,026.48	25886994.65
13	2032	1.27437		1,411,026.48	
15	2034	1.27437	37.9693	1,411,026.48	53575749.03
17	2036	1.27437		1,411,026.48	
18	2037	1.27437	78.5814	1,411,026.48	110880421.7
19	2038	1.27437		1,411,026.48	

n	Years	1+if	(1+if) ^n	Periodic maintenance at the end of 2019 (PV)	Periodic maintenance cost in analysis period (FV) = PV (1+if) ^n
21	2040	1.27437	162.632	1,411,026.48	229478227.4
22	2041	1.27437		1,411,026.48	
23	2042	1.27437		1,411,026.48	
24	2043	1.27437		1,411,026.48	
25	2044	1.27437		1,411,026.48	
Grand Total					**441,293,636.9**

Table 33 : periodic Maintenance Cost Summary for flexible pavement with geosynthetic materials in the Analysis Period

Age in Years		1+if	(1+if) ^n	periodic maintenance at the end of 2019 (PV)	periodic maintenance cost in analysis period (FV) = PV (1+if) ^n
0	2019	1.27437			
1	2020	1.27437		1,411,026.48	-
2	2021	1.27437		1,411,026.48	-
3	2022	1.27437		1,411,026.48	-
4	2023	1.27437	2.63744	1,411,026.48	3,721,493.98
5	2024	1.27437		1,411,026.48	-
6	2025	1.27437		1,411,026.48	-
7	2026	1.27437		1,411,026.48	-
8	2027	1.27437	6.95608	1,411,026.48	9,815,207.32
9	2028	1.27437		1,411,026.48	-
10	2029	1.27437		1,411,026.48	-
11	2030	1.27437		1,411,026.48	-
12	2031	1.27437	18.3462	1,411,026.48	25,886,994.65
13	2032	1.27437		1,411,026.48	-
14	2033	1.27437		1,411,026.48	-
15	2034	1.27437		1,411,026.48	-
16	2035	1.27437	48.387	1,411,026.48	68,275,327.29
17	2036	1.27437		1,411,026.48	-
18	2037	1.27437		1,411,026.48	-
19	2038	1.27437		1,411,026.48	-
20	2039	1.27437		1,411,026.48	-
21	2040	1.27437		1,411,026.48	-
22	2041	1.27437		1,411,026.48	-
23	2042	1.27437		1,411,026.48	-
24	2043	1.27437	336.584	1,411,026.48	474,928,360.12
25	2044	1.27437		1,411,026.48	-

Grand Total (ETB/KM)	**582,627,383.36**

Appendix B 1.3Rehabilitation cost

<u>Rehabilitation cost of flexible pavement at end of 2019</u>

Asphaltic Concrete Overlay for 50mm thickness for entire lanes including shoulders (14.16m)

= 100% of the quantity = 1 (width * thickness * length) = 14.16m * 0.05m * 1000m = $\underline{\underline{708m^3}}$

Bitumen Tack Coat (0.5lt/m2) quantity for entire lane including shoulders (14.16m)

= 100% of the area = 0.5liters/m^2 * 14.16m *1000m = $\underline{\underline{7080liters}}$

Pavement Reconstruction (Aggregate Road base to 150mm) quantity for entire lanes (14.16m)

= 100% of the quantity = 14.16m * 0.15m * 1000m = $\underline{\underline{2124m^3}}$

Table 34 : Rehabilitation cost of flexible pavement at the end of 2019

Name of Activity	Unit	Unit Rate (ETB/unit)	Entire Lane Quantity	Amount (ETB)
Asphaltic Concrete Overlay for 50mm thickness	m3	4435.13466	708.00	3,140,075.34
Bitumen Tack Coat (0.5lt/m2)	Lt	51.61035	7,080.00	365,401.28
Pavement Reconstruction (Aggregate Road base)	m3	842.29728	2,124.00	1,789,039.42
Total Cost	**5,294,516.04**			

Table 35 : Rehabilitation Cost Summary for conventional flexible pavement in the Analysis Period

Age in Years		1+if	(1+if) ^n	Rehabilitation Cost at the end of 2019 (PV)	Rehabilitation Cost in analysis period (FV) = PV (1+if) ^n
0	2019				
1	2020	1.27437		5294516.04	-
2	2021	1.27437		5294516.04	-
3	2022	1.27437		5294516.04	-
4	2023	1.27437		5294516.04	-
5	2024	1.27437		5294516.04	-
7	2026	1.27437		5294516.04	-
8	2027	1.27437	6.95608	5294516.04	36,829,055.53
9	2028	1.27437		5294516.04	-
10	2029	1.27437		5294516.04	-
11	2030	1.27437		5294516.04	-
12	2031	1.27437		5294516.04	-
14	2033	1.27437		5294516.04	-
15	2034	1.27437		5294516.04	-
16	2035	1.27437	48.387	5294516.04	256,185,706.37
17	2036	1.27437		5294516.04	-
18	2037	1.27437		5294516.04	-
19	2038	1.27437		5294516.04	-

Age in Years		1+if	(1+if) ^n	Rehabilitation Cost at the end of 2019 (PV)	Rehabilitation Cost in analysis period (FV) = PV (1+if) ^n
21	2040	1.27437		5294516.04	-
22	2041	1.27437		5294516.04	-
23	2042	1.27437		5294516.04	-
24	2043	1.27437	336.584	5294516.04	1,782,047,223.16
25	2044	1.27437		5294516.04	-
Grand Total (ETB/KM)					**2,075,061,985.06**

Table 36 : Rehabilitation Cost Summary for flexible pavement with geosynthetic materials in the Analysis Period

Age in Years		1+if	(1+if) ^n	Rehabilitation cost at the end of 2019 (PV)	Rehabilitation cost in analysis period (FV) = PV (1+if) ^n
0	2019				
1	2020	1.27437		5,294,516.04	-
2	2021	1.27437		5,294,516.04	-
3	2022	1.27437		5,294,516.04	-
4	2023	1.27437		5,294,516.04	-
5	2024	1.27437		5,294,516.04	-
6	2025	1.27437		5,294,516.04	-
7	2026	1.27437		5,294,516.04	-
8	2027	1.27437		5,294,516.04	-
9	2028	1.27437		5,294,516.04	-
10	2029	1.27437	11.2968	5,294,516.04	59,811,082.14
11	2030	1.27437		5,294,516.04	-
12	2031	1.27437		5,294,516.04	-
13	2032	1.27437		5,294,516.04	-
14	2033	1.27437		5,294,516.04	-
15	2034	1.27437		5,294,516.04	-
16	2035	1.27437		5,294,516.04	-
17	2036	1.27437		5,294,516.04	-
18	2037	1.27437		5,294,516.04	-
19	2038	1.27437		5,294,516.04	-
20	2039	1.27437	127.618	5,294,516.04	675,673,757.55
21	2040	1.27437		5,294,516.04	-
22	2041	1.27437		5,294,516.04	-
23	2042	1.27437		5,294,516.04	-
24	2043	1.27437		5,294,516.04	-
25	2044	1.27437		5,294,516.04	-

Grand Total (ETB/KM)	**735,484,839.70**

Appendix CRoad User Cost

Appendix C.1 Work zone operation user cost

Appendix C 1.1 Work zone operation user cost for conventional flexible pavement

Appendix C.1.1.1 Work zone operation user cost for conventional flexible pavement during routine maintenance

Step 1. Project Future Year Traffic Demand (Forecasting Traffic)

Table 37: Future Year Traffic Demand (Forecasted Traffic)

Forecasted Year	*Passenger Cars*	*Single Unit Truck*	*Combination Trucks*	*Total Sum*	*Class Percentage (%)*			*Total Percentage*
					Passenger	*Single Unit Truck*	*Combination trucks*	
1	*2*	*3*	*4*	*5=2+3+4*	*6= (2/5) *100*	*7= (3/5) *100*	*8= (4/5) *100*	*9=6+7+8*
2019	*13480*	*4148*	*3111*	*20739*	*64.998*	*20.001*	*15.001*	*100*
2020	*14154*	*4355*	*3267*	*21776*	*64.998*	*20.001*	*15.001*	*100*
2021	*14862*	*4573*	*3430*	*22865*	*64.998*	*20.001*	*15.001*	*100*
2022	*15605*	*4802*	*3601*	*24008*	*64.998*	*20.001*	*15.001*	*100*
2023	*16385*	*5042*	*3781*	*25208*	*64.998*	*20.001*	*15.001*	*100*
2024	*17204*	*5294*	*3971*	*26469*	*64.998*	*20.001*	*15.001*	*100*
2025	*18064*	*5559*	*4169*	*27792*	*64.998*	*20.001*	*15.001*	*100*
2026	*18968*	*5837*	*4377*	*29182*	*64.998*	*20.001*	*15.001*	*100*
2027	*19916*	*6128*	*4596*	*30641*	*64.998*	*20.001*	*15.001*	*100*
2028	*20912*	*6435*	*4826*	*32173*	*64.998*	*20.001*	*15.001*	*100*
2029	*21957*	*6757*	*5067*	*33782*	*64.998*	*20.001*	*15.001*	*100*
2030	*23055*	*7094*	*5321*	*35471*	*64.998*	*20.001*	*15.001*	*100*
2031	*24208*	*7449*	*5587*	*37244*	*64.998*	*20.001*	*15.001*	*100*
2032	*25419*	*7822*	*5866*	*39106*	*64.998*	*20.001*	*15.001*	*100*
2033	*26689*	*8213*	*6160*	*41062*	*64.998*	*20.001*	*15.001*	*100*
2034	*28024*	*8623*	*6468*	*43115*	*64.998*	*20.001*	*15.001*	*100*
2035	*29425*	*9055*	*6791*	*45271*	*64.998*	*20.001*	*15.001*	*100*
2036	*30896*	*9507*	*7130*	*47534*	*64.998*	*20.001*	*15.001*	*100*
2037	*32441*	*9983*	*7487*	*49911*	*64.998*	*20.001*	*15.001*	*100*
2038	*34063*	*10482*	*7861*	*52406*	*64.998*	*20.001*	*15.001*	*100*
2039	*35766*	*11006*	*8254*	*55027*	*64.998*	*20.001*	*15.001*	*100*
2040	*37555*	*11556*	*8667*	*57778*	*64.998*	*20.001*	*15.001*	*100*
2041	*39433*	*12134*	*9100*	*60667*	*64.998*	*20.001*	*15.001*	*100*
2042	*41404*	*12741*	*9556*	*63700*	*64.998*	*20.001*	*15.001*	*100*
2043	*43474*	*13378*	*10033*	*66885*	*64.998*	*20.001*	*15.001*	*100*
2044	*45648*	*14047*	*10535*	*70230*	*64.998*	*20.001*	*15.001*	*100*

Step 2. Calculate Work Zone Directional Hourly Demand

Table 38: Default hourly distributions from MicroBENCOST (all functional classes).

Hour (24-HrC lock)	Rural			Urban		
	% AADT	Direction %		% AADT	Direction %	
		Inbound	Outbound		Inbound	Outbound
12-1	1.8	48	52	1.2	47	53
1-2	1.5	48	52	0.8	43	57
2-3	1.3	45	55	0.7	46	54
3-4	1.3	53	47	0.5	48	52
4-5	1.5	53	47	0.7	57	43
5-6	1.8	53	47	1.7	58	42
6-7	2.5	57	43	5.1	63	37
7-8	3.5	56	44	7.8	60	40
8-9	4.2	56	44	6.3	59	41
9-10	5	54	46	5.2	55	45
10-11	5.4	51	49	4.7	46	54
11-12	5.6	51	49	5.3	49	51
12-13	5.7	50	50	5.6	50	50
13-14	6.4	52	48	5.7	50	50
14-15	6.8	51	49	5.9	49	51
15-16	7.3	53	47	6.5	46	54
16-17	9.3	49	51	7.9	45	55
17-18	7	43	57	8.5	40	60
18-19	5.5	47	53	5.9	46	54
19-20	4.7	47	53	3.9	48	52
20-21	3.8	46	54	3.3	47	53
21-22	3.2	48	52	2.8	47	53
22-23	2.6	48	52	2.3	48	52
23-24	2.3	47	53	1.7	45	55

Table 39: Outbound Work zone directional hourly demand (all vehicle classes) for year 2020

AADT of year 2020 = 21776	Outbound Urban Interstate					Inbound Urban Interstate		
(24-Hr Clock)	% AADT		Directional Factor %		Demand	Directional Factor		Demand
12-1	1.20	0.01	53.00	0.53	138	47.00	0.47	123
1-2	0.80	0.01	57.00	0.57	99	43.00	0.43	75
2-3	0.70	0.01	54.00	0.54	82	46.00	0.46	70
3-4	0.50	0.01	52.00	0.52	57	48.00	0.48	52
4-5	0.70	0.01	43.00	0.43	66	57.00	0.57	87

AADT of year 2020 = 21776	Outbound Urban Interstate					Inbound Urban Interstate		
(24-Hr Clock)	% AADT		Directional Factor %		Demand	Directional Factor		Demand
5-6	1.70	0.02	42.00	0.42	155	58.00	0.58	215
6-7	5.10	0.05	37.00	0.37	411	63.00	0.63	700
7-8	7.80	0.08	40.00	0.40	679	60.00	0.60	1019
8-9	6.30	0.06	41.00	0.41	562	59.00	0.59	809
9-10	5.20	0.05	45.00	0.45	510	55.00	0.55	623
10-11	4.70	0.05	54.00	0.54	553	46.00	0.46	471
11-12	5.30	0.05	51.00	0.51	589	49.00	0.49	566
12-13	5.60	0.06	50.00	0.50	610	50.00	0.50	610
13-14	5.70	0.06	50.00	0.50	621	50.00	0.50	621
14-15	5.90	0.06	51.00	0.51	655	49.00	0.49	630
15-16	6.50	0.07	54.00	0.54	764	46.00	0.46	651
16-17	7.90	0.08	55.00	0.55	946	45.00	0.45	774
17-18	8.50	0.09	60.00	0.60	1111	40.00	0.40	740
18-19	5.90	0.06	54.00	0.54	694	46.00	0.46	591
19-20	3.90	0.04	52.00	0.52	442	48.00	0.48	408
20-21	3.30	0.03	53.00	0.53	381	47.00	0.47	338
21-22	2.80	0.03	53.00	0.53	323	47.00	0.47	287
22-23	2.30	0.02	52.00	0.52	260	48.00	0.48	240
23-24	1.70	0.02	55.00	0.55	204	45.00	0.45	167
Total					**10912**			**10864**

Table 40: Outbound Work zone directional hourly demand for years affected in analysis period-1

Outbound Urban Interstate			Average Annual Daily Traffic of Work Zone Periods (AADT)									
			2020 = 21776	2023 = 25208	2024 = 26469	2026 = 29182	2030 = 35471	2032 = 39106	2036 = 47534	2038 = 52406	2039 = 55027	2042 = 63700
(24-Hr Clock)	% ADT	Direct. Factor %	Demand	Demand	Demand	Demand	Demand	Demand	Demand	Demand	Demand	Demand
12-1	1.2	53	138	160	168	186	226	249	302	333	350	405
1-2	0.8	57	99	115	121	133	162	178	217	239	251	290
2-3	0.7	54	82	95	100	110	134	148	180	198	208	241
3-4	0.5	52	57	66	69	76	92	102	124	136	143	166
4-5	0.7	43	66	76	80	88	107	118	143	158	166	192
5-6	1.7	42	155	180	189	208	253	279	339	374	393	455
6-7	5.1	37	411	476	499	551	669	738	897	989	1038	1202
			Average Annual Daily Traffic of Work Zone Periods (AADT)									

Outbound Urban Interstate			*2020 = 21776*	*2023 = 25208*	*2024 = 26469*	*2026 = 29182*	*2030 = 35471*	*2032 = 39106*	*2036 = 47534*	*2038 = 52406*	*2039 = 55027*	*2042 = 63700*
(24-Hr Clock)	*% ADT*	*Direct. Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
7-8	*7.8*	*40*	*679*	*786*	*826*	*910*	*1107*	*1220*	*1483*	*1635*	*1717*	*1987*
8-9	*6.3*	*41*	*562*	*651*	*684*	*754*	*916*	*1010*	*1228*	*1354*	*1421*	*1645*
9-10	*5.2*	*45*	*510*	*590*	*619*	*683*	*830*	*915*	*1112*	*1226*	*1288*	*1491*
10-11	*4.7*	*54*	*553*	*640*	*672*	*741*	*900*	*993*	*1206*	*1330*	*1397*	*1617*
11-12	*5.3*	*51*	*589*	*681*	*715*	*789*	*959*	*1057*	*1285*	*1417*	*1487*	*1722*
12-13	*5.6*	*50*	*610*	*706*	*741*	*817*	*993*	*1095*	*1331*	*1467*	*1541*	*1784*
13-14	*5.7*	*50*	*621*	*718*	*754*	*832*	*1011*	*1115*	*1355*	*1494*	*1568*	*1815*
14-15	*5.9*	*51*	*655*	*759*	*796*	*878*	*1067*	*1177*	*1430*	*1577*	*1656*	*1917*
15-16	*6.5*	*54*	*764*	*885*	*929*	*1024*	*1245*	*1373*	*1668*	*1839*	*1931*	*2236*
16-17	*7.9*	*55*	*946*	*1095*	*1150*	*1268*	*1541*	*1699*	*2065*	*2277*	*2391*	*2768*
17-18	*8.5*	*60*	*1111*	*1286*	*1350*	*1488*	*1809*	*1994*	*2424*	*2673*	*2806*	*3249*
18-19	*5.9*	*54*	*694*	*803*	*843*	*930*	*1130*	*1246*	*1514*	*1670*	*1753*	*2029*
19-20	*3.9*	*52*	*442*	*511*	*537*	*592*	*719*	*793*	*964*	*1063*	*1116*	*1292*
20-21	*3.3*	*53*	*381*	*441*	*463*	*510*	*620*	*684*	*831*	*917*	*962*	*1114*
21-22	*2.8*	*53*	*323*	*374*	*393*	*433*	*526*	*580*	*705*	*778*	*817*	*945*
22-23	*2.3*	*52*	*260*	*301*	*317*	*349*	*424*	*468*	*569*	*627*	*658*	*762*
23-24	*1.7*	*55*	*204*	*236*	*247*	*273*	*332*	*366*	*444*	*490*	*515*	*596*
Total			*10911*	*12631*	*10912*	*12631*	*13263*	*14623*	*17774*	*19595*	*23818*	*26260*

Table 41: Inbound Work Zone Directional Hourly Demand for Years Affected in Analysis Period-1

Inbound Urban Interstate			*Average Annual Daily Traffic of Work Zone Periods (AADT)*									
			2020 = 21776	*2023 = 25208*	*2024 = 26469*	*2026 = 29182*	*2030 = 35471*	*2032 = 39106*	*2036 = 47534*	*2038 = 52406*	*2039 = 55027*	*2042 = 63700*
(24-Hr Clock)	*% ADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
12-1	*1.2*	*47*	*123*	*142*	*6593*	*165*	*200*	*221*	*268*	*296*	*310*	*359*
1-2	*0.8*	*43*	*75*	*87*	*6488*	*100*	*122*	*135*	*164*	*180*	*189*	*219*
2-3	*0.7*	*46*	*70*	*81*	*6575*	*94*	*114*	*126*	*153*	*169*	*177*	*205*
3-4	*0.5*	*48*	*52*	*60*	*6607*	*70*	*85*	*94*	*114*	*126*	*132*	*153*
4-5	*0.7*	*57*	*87*	*101*	*6488*	*116*	*142*	*156*	*190*	*209*	*220*	*254*
5-6	*1.7*	*58*	*215*	*249*	*6448*	*288*	*350*	*386*	*469*	*517*	*543*	*628*
6-7	*5.1*	*63*	*700*	*810*	*6170*	*938*	*1140*	*1256*	*1527*	*1684*	*1768*	*2047*
			Average Annual Daily Traffic of Work Zone Periods (AADT)									

Inbound Urban Interstate			*2020 = 21776*	*2023 = 25208*	*2024 = 26469*	*2026 = 29182*	*2030 = 35471*	*2032 = 39106*	*2036 = 47534*	*2038 = 52406*	*2039 = 55027*	*2042 = 63700*
(24-Hr Clock)	*% ADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
7-8	*7.8*	*60*	*1019*	*1180*	*6353*	*1366*	*1660*	*1830*	*2225*	*2453*	*2575*	*2981*
8-9	*6.3*	*59*	*809*	*937*	*6403*	*1085*	*1318*	*1454*	*1767*	*1948*	*2045*	*2368*
9-10	*5.2*	*55*	*623*	*721*	*6551*	*835*	*1014*	*1118*	*1359*	*1499*	*1574*	*1822*
10-11	*4.7*	*46*	*471*	*545*	*6575*	*631*	*767*	*845*	*1028*	*1133*	*1190*	*1377*
11-12	*5.3*	*49*	*566*	*655*	*6615*	*758*	*921*	*1016*	*1234*	*1361*	*1429*	*1654*
12-13	*5.6*	*50*	*610*	*706*	*6617*	*817*	*993*	*1095*	*1331*	*1467*	*1541*	*1784*
13-14	*5.7*	*50*	*621*	*718*	*6617*	*832*	*1011*	*1115*	*1355*	*1494*	*1568*	*1815*
14-15	*5.9*	*49*	*630*	*729*	*6615*	*844*	*1025*	*1131*	*1374*	*1515*	*1591*	*1842*
15-16	*6.5*	*46*	*651*	*754*	*6575*	*873*	*1061*	*1169*	*1421*	*1567*	*1645*	*1905*
16-17	*7.9*	*45*	*774*	*896*	*6551*	*1037*	*1261*	*1390*	*1690*	*1863*	*1956*	*2265*
17-18	*8.5*	*40*	*740*	*857*	*6353*	*992*	*1206*	*1330*	*1616*	*1782*	*1871*	*2166*
18-19	*5.9*	*46*	*591*	*684*	*6575*	*792*	*963*	*1061*	*1290*	*1422*	*1493*	*1729*
19-20	*3.9*	*48*	*408*	*472*	*6607*	*546*	*664*	*732*	*890*	*981*	*1030*	*1192*
20-21	*3.3*	*47*	*338*	*391*	*6593*	*453*	*550*	*607*	*737*	*813*	*853*	*988*
21-22	*2.8*	*47*	*287*	*332*	*6593*	*384*	*467*	*515*	*626*	*690*	*724*	*838*
22-23	*2.3*	*48*	*240*	*278*	*6607*	*322*	*392*	*432*	*525*	*579*	*607*	*703*
23-24	*1.7*	*45*	*167*	*193*	*6551*	*223*	*271*	*299*	*364*	*401*	*421*	*487*
Total			*10911*	*12631*	*10864*	*12577*	*156718*	*14559*	*17697*	*19511*	*23716*	*26146*

Table 42: Outbound Work Zone Directional Hourly Demand for Years Affected in Analysis Period-2

outbound Urban Interstate			*Average Annual Daily Traffic of Work Zone Periods (AADT)*									
			2022 = 24008	*2025 = 27792*	*2027 = 30641*	*2028 = 32173*	*2029= 33782*	*2034 = 43115*	*2035 = 45271*	*2037 = 49911*	*2040 = 57778*	*2043 = 66885*
(24-Hr Clock)	*% ADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
12-1	*1.2*	*53*	*153*	*177*	*195*	*208*	*215*	*274*	*288*	*317*	*367*	*425*
1-2	*0.8*	*57*	*109*	*127*	*140*	*149*	*154*	*197*	*206*	*228*	*263*	*305*
2-3	*0.7*	*54*	*91*	*105*	*116*	*124*	*128*	*163*	*171*	*189*	*218*	*253*
3-4	*0.5*	*52*	*62*	*72*	*80*	*85*	*88*	*112*	*118*	*130*	*150*	*174*
4-5	*0.7*	*43*	*72*	*84*	*92*	*99*	*102*	*130*	*136*	*150*	*174*	*201*
5-6	*1.7*	*42*	*171*	*198*	*219*	*234*	*241*	*308*	*323*	*356*	*413*	*478*
			Average Annual Daily Traffic of Work Zone Periods (AADT)									

outbound Urban Interstate			*2022 = 24008*	*2025 = 27792*	*2027 = 30641*	*2028 = 32173*	*2029= 33782*	*2034 = 43115*	*2035 = 45271*	*2037 = 49911*	*2040 = 57778*	*2043 = 66885*
(24-Hr Clock)	*% ADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
6-7	*5.1*	*37*	*453*	*524*	*578*	*619*	*637*	*814*	*854*	*942*	*1090*	*1262*
7-8	*7.8*	*40*	*749*	*867*	*956*	*1023*	*1054*	*1345*	*1412*	*1557*	*1803*	*2087*
8-9	*6.3*	*41*	*620*	*718*	*791*	*847*	*873*	*1114*	*1169*	*1289*	*1492*	*1728*
9-10	*5.2*	*45*	*562*	*650*	*717*	*767*	*790*	*1009*	*1059*	*1168*	*1352*	*1565*
10-11	*4.7*	*54*	*609*	*705*	*778*	*832*	*857*	*1094*	*1149*	*1267*	*1466*	*1698*
11-12	*5.3*	*51*	*649*	*751*	*828*	*886*	*913*	*1165*	*1224*	*1349*	*1562*	*1808*
12-13	*5.6*	*50*	*672*	*778*	*858*	*918*	*946*	*1207*	*1268*	*1398*	*1618*	*1873*
13-14	*5.7*	*50*	*684*	*792*	*873*	*934*	*963*	*1229*	*1290*	*1422*	*1647*	*1906*
14-15	*5.9*	*51*	*722*	*836*	*922*	*986*	*1017*	*1297*	*1362*	*1502*	*1739*	*2013*
15-16	*6.5*	*54*	*843*	*975*	*1075*	*1151*	*1186*	*1513*	*1589*	*1752*	*2028*	*2348*
16-17	*7.9*	*55*	*1043*	*1208*	*1331*	*1424*	*1468*	*1873*	*1967*	*2169*	*2510*	*2906*
17-18	*8.5*	*60*	*1224*	*1417*	*1563*	*1672*	*1723*	*2199*	*2309*	*2545*	*2947*	*3411*
18-19	*5.9*	*54*	*765*	*885*	*976*	*1044*	*1076*	*1374*	*1442*	*1590*	*1841*	*2131*
19-20	*3.9*	*52*	*487*	*564*	*621*	*665*	*685*	*874*	*918*	*1012*	*1172*	*1356*
20-21	*3.3*	*53*	*420*	*486*	*536*	*573*	*591*	*754*	*792*	*873*	*1011*	*1170*
21-22	*2.8*	*53*	*356*	*412*	*455*	*486*	*501*	*640*	*672*	*741*	*857*	*993*
22-23	*2.3*	*52*	*287*	*332*	*366*	*392*	*404*	*516*	*541*	*597*	*691*	*800*
23-24	*1.7*	*55*	*224*	*260*	*286*	*307*	*316*	*403*	*423*	*467*	*540*	*625*
Total			*12030*	*13926*	*15354*	*16426*	*16927*	*21604*	*22684*	*25009*	*28951*	*33515*

Table 43: Inbound Work Zone Directional Hourly Demand for Years Affected in Analysis Period-2

Inbound Urban Interstate			*Average Annual Daily Traffic of Work Zone Periods (AADT)*									
			2022 24008	2025 27792	2027 30641	2028 32173	2029= 33782	2034 43115	2035 45271	2037 49911	2040 57778	2043 66885
(24-Hr Clock	*% AADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
12-1	*1.2*	*47*	*135*	*157*	*173*	*181*	*191*	*243*	*255*	*281*	*326*	*377*
1-2	*0.8*	*43*	*83*	*96*	*105*	*111*	*116*	*148*	*156*	*172*	*199*	*230*
2-3	*0.7*	*46*	*77*	*89*	*99*	*104*	*109*	*139*	*146*	*161*	*186*	*215*

Inbound Urban Interstate			*Average Annual Daily Traffic of Work Zone Periods (AADT)*									
			2022 = 24008	*2025 = 27792*	*2027 = 30641*	*2028 = 32173*	*2029= 33782*	*2034 = 43115*	*2035 = 45271*	*2037 = 49911*	*2040 = 57778*	*2043 = 66885*
(24-Hr Clock)	*% AADT*	*Directional Factor %*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*	*Demand*
3-4	*0.5*	*48*	*58*	*67*	*74*	*77*	*81*	*103*	*109*	*120*	*139*	*161*
4-5	*0.7*	*57*	*96*	*111*	*122*	*128*	*135*	*172*	*181*	*199*	*231*	*267*
5-6	*1.7*	*58*	*237*	*274*	*302*	*317*	*333*	*425*	*446*	*492*	*570*	*659*
6-7	*5.1*	*63*	*771*	*893*	*984*	*1034*	*1085*	*1385*	*1455*	*1604*	*1856*	*2149*
7-8	*7.8*	*60*	*1124*	*1301*	*1434*	*1506*	*1581*	*2018*	*2119*	*2336*	*2704*	*3130*
8-9	*6.3*	*59*	*892*	*1033*	*1139*	*1196*	*1256*	*1603*	*1683*	*1855*	*2148*	*2486*
9-10	*5.2*	*55*	*687*	*795*	*876*	*920*	*966*	*1233*	*1295*	*1427*	*1652*	*1913*
10-11	*4.7*	*46*	*519*	*601*	*662*	*696*	*730*	*932*	*979*	*1079*	*1249*	*1446*
11-12	*5.3*	*49*	*623*	*722*	*796*	*836*	*877*	*1120*	*1176*	*1296*	*1500*	*1737*
12-13	*5.6*	*50*	*672*	*778*	*858*	*901*	*946*	*1207*	*1268*	*1398*	*1618*	*1873*
13-14	*5.7*	*50*	*684*	*792*	*873*	*917*	*963*	*1229*	*1290*	*1422*	*1647*	*1906*
14-15	*5.9*	*49*	*694*	*803*	*886*	*930*	*977*	*1246*	*1309*	*1443*	*1670*	*1934*
15-16	*6.5*	*46*	*718*	*831*	*916*	*962*	*1010*	*1289*	*1354*	*1492*	*1728*	*2000*
16-17	*7.9*	*45*	*853*	*988*	*1089*	*1144*	*1201*	*1533*	*1609*	*1774*	*2054*	*2378*
17-18	*8.5*	*40*	*816*	*945*	*1042*	*1094*	*1149*	*1466*	*1539*	*1697*	*1964*	*2274*
18-19	*5.9*	*46*	*652*	*754*	*832*	*873*	*917*	*1170*	*1229*	*1355*	*1568*	*1815*
19-20	*3.9*	*48*	*449*	*520*	*574*	*602*	*632*	*807*	*847*	*934*	*1082*	*1252*
20-21	*3.3*	*47*	*372*	*431*	*475*	*499*	*524*	*669*	*702*	*774*	*896*	*1037*
21-22	*2.8*	*47*	*316*	*366*	*403*	*423*	*445*	*567*	*596*	*657*	*760*	*880*
22-23	*2.3*	*48*	*265*	*307*	*338*	*355*	*373*	*476*	*500*	*551*	*638*	*738*
23-24	*1.7*	*45*	*184*	*213*	*234*	*246*	*258*	*330*	*346*	*382*	*442*	*512*
Total			*11978*	*13866*	*15287*	*16052*	*16855*	*21511*	*22587*	*24902*	*28827*	*33370*

Step 4. Identify the User Cost Component

Table 44: work zone analysis matrix of the year 2020

Remark	AADT of Year 2020 = 21776			Queue Rate	№ of Queued Vehicles	Lanes Open	Operating Condition	Cost Factors
	Hour	Demand	Capacity					
	(a)	(b)	(c)	(d)	(e)	(f)		
Mid Night	12-1	138	1170	-1032	0	1	Free Flow. WZ in place. No Queue.	Free Flow Only Costs (3).
	1-2	99	1170	-1071	0	1		
	2-3	82	1170	-1088	0	1		
	3-4	57	1170	-1113	0	1		
	4-5	66	1170	-1104	0	1		
	5-6	155	1170	-1015	0	1		
Morning	6-7	411	1170	-759	0	1		
	7-8	679	1170	-491	0	1		
	8-9	562	1170	-608	0	1		
	9-10	510	1170	-660	0	1		
	10-11	553	1170	-617	0	1		
	11-12	589	1170	-581	0	1		
Mid-Day	12-13	610	1170	-560	0	1		
	13-14	621	1170	-549	0	1		
Afternoon	14-15	655	1170	-515	0	1		
	15-16	764	1170	-406	0	1		
	16-17	946	1170	-224	0	1		
	17-18	1111	1170	-59	0	1		
	18-19	694	1170	-476	0	1		
Night	19-20	442	1170	-728	0	1		
	20-21	381	1170	-789	0	1		
	21-22	323	1170	-847	0	1		
	22-23	260	1170	-910	0	1		
	23-24	204	1170	-966	0	1		

Table 45: work zone analysis matrix of the year 2038

AADT of year 2038 = 52406			Queue Rate	Num. of Queued Vehicles	Lanes Open	Operating Conditions	Cost Factors
hour	demand	capacity					
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
12-1	333	1170	-837	0	1	free flow work zone in place no queue	free flow only costs
1-2	239	1170	-931	0	1		
2-3	198	1170	-972	0	1		
3-4	136	1170	-1034	0	1		
4-5	158	1170	-1012	0	1		
5-6	374	1170	-796	0	1		

AADT of year 2038 = 52406			*Queue Rate*	*Num. of Queued Vehicles*	*Lanes Open*	*Operating Conditions*	*Cost Factors*
hour	*demand*	*capacity*					
6-7	*989*	*1170*	*-181*	*0*	*1*		
7-8	*1635*	*1170*	*465*	*465*	*1*	*Forced Flow WZ in place Queue Exists*	*WZ Delay and Queuing (5 costs)*
8-9	*1354*	*1170*	*184*	*649*	*1*		
9-10	*1226*	*1170*	*56*	*705*	*1*		
10-11	*1330*	*1170*	*160*	*865*	*1*		
11-12	*1417*	*1170*	*247*	*1112*	*1*		
12-13	*1467*	*1170*	*297*	*1409*	*1*		
13-14	*1494*	*1170*	*324*	*1733*	*1*		
14-15	*1577*	*1170*	*407*	*2139*	*1*		
15-16	*1839*	*1170*	*669*	*2809*	*1*		
16-17	*2277*	*1170*	*1107*	*3916*	*1*		
17-18	*2673*	*1170*	*1503*	*5419*	*1*		
18-19	*1670*	*1170*	*500*	*5918*	*1*		
19-20	*1063*	*1170*	*-107*	*0*	*1*	*free flow work zone in place no queue*	*free flow only costs*
20-21	*917*	*1170*	*-253*	*0*	*1*		
21-22	*778*	*1170*	*-392*	*0*	*1*		
22-23	*627*	*1170*	*-543*	*0*	*1*		
23-24	*490*	*1170*	*-680*	*0*	*1*		

Table 46: work zone analysis matrix of the year 2042

AADT of year 2042 = 63700			*Queue Rate*	*Num. of Queued Vehicles*	*Lanes Open*	*Operating Conditions*	*Cost Factors*
hour	*demand*	*capacity*					
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*
12-1	*405*	*1170*	*-765*	*0*	*1*	*free flow work zone in place no queue*	*free flow only costs*
1-2	*290*	*1170*	*-880*	*0*	*1*		
2-3	*241*	*1170*	*-929*	*0*	*1*		
3-4	*166*	*1170*	*-1004*	*0*	*1*		
4-5	*192*	*1170*	*-978*	*0*	*1*		
5-6	*455*	*1170*	*-715*	*0*	*1*		
6-7	*1202*	*1170*	*32*	32	*1*	*Forced Flow WZ in place Queue Exists*	*WZ Delay and Queuing (5 costs)*
7-8	*1987*	*1170*	*817*	*849*	*1*		
8-9	*1645*	*1170*	*475*	*1325*	*1*		
9-10	*1491*	*1170*	*321*	*1645*	*1*		
10-11	*1617*	*1170*	*447*	*2092*	*1*		
11-12	*1722*	*1170*	*552*	*2644*	*1*		
12-13	*1784*	*1170*	*614*	*3258*	*1*		

AADT of year 2042 = 63700			*Queue Rate*	*Num. of Queued Vehicles*	*Lanes Open*	*Operating Conditions*	*Cost Factors*
hour	*demand*	*capacity*					
13-14	*1815*	*1170*	*645*	*3903*	*1*	*Forced Flow, WZ in place, Queue Exists*	*WZ Delay & Queuing*
14-15	*1917*	*1170*	*747*	*4650*	*1*		
15-16	*2236*	*1170*	*1066*	*5716*	*1*	*Forced Flow WZ in place Queue Exists*	*WZ Delay and Queuing (5 costs)*
16-17	*2768*	*1170*	*1598*	*7313*	*1*		
17-18	*3249*	*1170*	*2079*	*9392*	*1*		
18-19	*2029*	*1170*	*859*	*10252*	*1*		
19-20	*1292*	*1170*	*122*	*10373*	*1*		
20-21	*1114*	*1170*	*-56*	*0*	*1*	*free flow work zone in place no queue*	*free flow only costs*
21-22	*945*	*1170*	*-225*	*0*	*1*		
22-23	*762*	*1170*	*-408*	*0*	*1*		
23-24	*596*	*1170*	*-574*	*0*	*1*		

Step 5. Quantify Traffic Affected by Each Cost Component

Table 47: Expanded Work Zone Matrix for the Year 2020

AADT of year 2020 = 21776			*Queue Rate*	*Num. of Queued Vehicles*	*Number of Vehicles that*			
hour	*demand*	*capacity*			*Traverse WZ*	*Traverse Queue*	*Stop 50-0-50 (km/hr)*	*Slow Down 50-30-50 (km/hr)*
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*
12-1	*138*	*1170*	*-1032*	*0*	*138*	*0*	*0*	*138*
1-2	*99*	*1170*	*-1071*	*0*	*99*	*0*	*0*	*99*
2-3	*82*	*1170*	*-1088*	*0*	*82*	*0*	*0*	*82*
3-4	*57*	*1170*	*-1113*	*0*	*57*	*0*	*0*	*57*
4-5	*66*	*1170*	*-1104*	*0*	*66*	*0*	*0*	*66*
5-6	*155*	*1170*	*-1015*	*0*	*155*	*0*	*0*	*155*
6-7	*411*	*1170*	*-759*	*0*	*411*	*0*	*0*	*411*
7-8	*679*	*1170*	*-491*	*0*	*679*	*0*	*0*	*679*
8-9	*562*	*1170*	*-608*	*0*	*562*	*0*	*0*	*562*
9-10	*510*	*1170*	*-660*	*0*	*510*	*0*	*0*	*510*
10-11	*553*	*1170*	*-617*	*0*	*553*	*0*	*0*	*553*
11-12	*589*	*1170*	*-581*	*0*	*589*	*0*	*0*	*589*
12-13	*610*	*1170*	*-560*	*0*	*610*	*0*	*0*	*610*
13-14	*621*	*1170*	*-549*	*0*	*621*	*0*	*0*	*621*
14-15	*655*	*1170*	*-515*	*0*	*655*	*0*	*0*	*655*
15-16	*764*	*1170*	*-406*	*0*	*764*	*0*	*0*	*764*
16-17	*946*	*1170*	*-224*	*0*	*946*	*0*	*0*	*946*
17-18	*1111*	*1170*	*-59*	*0*	*1111*	*0*	*0*	*1111*
18-19	*694*	*1170*	*-476*	*0*	*694*	*0*	*0*	*694*

AADT of year 2020 = 21776			*Queue Rate*	*Num. of Queued Vehicles*	*Number of Vehicles that*			
hour	*demand*	*capacity*			*Traverse WZ*	*Traverse Queue*	*Stop 50-0-50 (km/hr)*	*Slow Down 50-30-50 (km/hr)*
19-20	*442*	*1170*	*-728*	*0*	*442*	*0*	*0*	*442*
20-21	*381*	*1170*	*-789*	*0*	*381*	*0*	*0*	*381*
21-22	*323*	*1170*	*-847*	*0*	*323*	*0*	*0*	*323*
22-23	*260*	*1170*	*-910*	*0*	*260*	*0*	*0*	*260*
23-24	*204*	*1170*	*-966*	*0*	*204*	*0*	*0*	*204*
24-hrs	*10912*				*10912*	*0*	*0*	*10912*

Table 48: Expanded Work Zone Matrix for The Year 2038

AADT of year 2038 = 52406			*Queue Rate*	*Num. of Queued Vehicles*	*Number of Vehicles that*			
hour	*demand*	*capacity*			*Traverse WZ*	*Traverse Queue*	*Stop 50-0-50 (km/hr)*	*Slow Down 50-30-50 (km/hr)*
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*
12-1	*333*	*1170*	*-837*	*0*	*333*	*0*	*0*	*333*
1-2	*239*	*1170*	*-931*	*0*	*239*	*0*	*0*	*239*
2-3	*198*	*1170*	*-972*	*0*	*198*	*0*	*0*	*198*
3-4	*136*	*1170*	*-1034*	*0*	*136*	*0*	*0*	*136*
4-5	*158*	*1170*	*-1012*	*0*	*158*	*0*	*0*	*158*
5-6	*374*	*1170*	*-796*	*0*	*374*	*0*	*0*	*374*
6-7	*989*	*1170*	*-181*	*0*	*989*	*0*	*0*	*989*
7-8	*1635*	*1170*	*465*	*465*	*1170*	*1170*	*1635*	*0*
8-9	*1354*	*1170*	*184*	*649*	*1170*	*1170*	*1354*	*0*
9-10	*1226*	*1170*	*56*	*705*	*1170*	*1170*	*1226*	*0*
10-11	*1330*	*1170*	*160*	*865*	*1170*	*1170*	*1330*	*0*
11-12	*1417*	*1170*	*247*	*1112*	*1170*	*1170*	*1417*	*0*
12-13	*1467*	*1170*	*297*	*1409*	*1170*	*1170*	*1467*	*0*
13-14	*1494*	*1170*	*324*	*1733*	*1170*	*1170*	*1494*	*0*
14-15	*1577*	*1170*	*407*	*2139*	*1170*	*1170*	*1577*	*0*
15-16	*1839*	*1170*	*669*	*2809*	*1170*	*1170*	*1839*	*0*
16-17	*2277*	*1170*	*1107*	*3916*	*1170*	*1170*	*2277*	*0*
17-18	*2673*	*1170*	*1503*	*2953*	*3636*	*3636*	*2673*	*0*
18-19	*1670*	*1170*	*500*	*986*	*3636*	*3636*	*1670*	*0*
19-20	*1063*	*1170*	*-107*	*0*	*2049*	*1394*	*407*	*655*
20-21	*917*	*1170*	*-253*	*0*	*1170*	*0*	*0*	*917*
21-22	*778*	*1170*	*-392*	*0*	*1170*	*0*	*0*	*778*
22-23	*627*	*1170*	*-543*	*0*	*1170*	*0*	*0*	*627*
23-24	*490*	*1170*	*-680*	*0*	*1170*	*0*	*0*	*490*
24 hours	*26260*				*28129*	*20366*	*20366*	*5894*

Table 49: Expanded Work Zone Matrix for The Year 2042

AADT of year 2042 = 63700			*Queue Rate*	*Num. of Queued Vehicles*	*Number of Vehicles that*			
Hour	*Demand*	*Capacity*			*Traverse WZ*	*Traverse Queue*	*Stop 50-0-50 (km/hr)*	*Slow Down 50-30-50 (km/hr)*
(a)	*(b)*	*(c)*	*(d)*	*(e)*	*(f)*	*(g)*	*(h)*	*(i)*
12-1	*405*	*1170*	*-765*	*0*	*405*	*0*	*0*	*405*
1-2	*290*	*1170*	*-880*	*0*	*290*	*0*	*0*	*290*
2-3	*241*	*1170*	*-929*	*0*	*241*	*0*	*0*	*241*
3-4	*166*	*1170*	*-1004*	*0*	*166*	*0*	*0*	*166*
4-5	*192*	*1170*	*-978*	*0*	*192*	*0*	*0*	*192*
5-6	*455*	*1170*	*-715*	*0*	*455*	*0*	*0*	*455*
6-7	*1202*	*1170*	*32*	*32*	*1170*	*1170*	*1202*	*0*
7-8	*1987*	*1170*	*817*	*849*	*1170*	*1170*	*1987*	*0*
8-9	*1645*	*1170*	*475*	*1325*	*1170*	*1170*	*1645*	*0*
9-10	*1491*	*1170*	*321*	*1645*	*1170*	*1170*	*1491*	*0*
10-11	*1617*	*1170*	*447*	*2092*	*1170*	*1170*	*1617*	*0*
11-12	*1722*	*1170*	*552*	*2644*	*1170*	*1170*	*1722*	*0*
12-13	*1784*	*1170*	*614*	*3258*	*1170*	*1170*	*1784*	*0*
13-14	*1815*	*1170*	*645*	*3903*	*1170*	*1170*	*1815*	*0*
14-15	*1917*	*1170*	*747*	*4650*	*1170*	*1170*	*1917*	*0*
15-16	*2236*	*1170*	*1066*	*5716*	*1170*	*1170*	*2236*	*0*
16-17	*2768*	*1170*	*1598*	*7313*	*1170*	*1170*	*2768*	*0*
17-18	*3249*	*1170*	*2079*	*6926*	*3636*	*3636*	*3249*	*0*
18-19	*2029*	*1170*	*859*	*5320*	*3636*	*3636*	*2029*	*0*
19-20	*1292*	*1170*	*122*	*2975*	*3636*	*3636*	*1292*	*0*
20-21	*1114*	*1170*	*-56*	*453*	*3636*	*3636*	*1114*	*0*
21-22	*945*	*1170*	*-225*	*0*	*1399*	*613*	*159*	*786*
22-23	*762*	*1170*	*-408*	*0*	*1170*	*0*	*0*	*762*
23-24	*596*	*1170*	*-574*	*0*	*1170*	*0*	*0*	*596*
24 hours	*31919*				*32901*	*28027*	*28027*	*3892*

Table 50: Summary of Traffic Affected by Each Cost Component

year	*Number of Vehicles That*			
	Traverse WZ	*Traverse Queue*	*Stop 50-0-50*	*Slow 50-30-50*
2020	*10,912*	*-*	*-*	*10,912*
2021	*11,457*	*-*	*-*	*11,457*
2022	*12,030*	*-*	*-*	*12,030*

year	*Number of Vehicles That*			
	Traverse WZ	*Traverse Queue*	*Stop 50-0-50*	*Slow 50-30-50*
2023	*12,631*	*1,539*	*1,539*	*11,093*
2024	*13,263*	*1,814*	*1,814*	*11,449*
2025	*13,926*	*3,512*	*3,512*	*10,417*
2026	*14,623*	*3,866*	*3,866*	*10,756*
2027	*15,354*	*4,278*	*4,278*	*11,075*
2028	*16,426*	*4,926*	*4,926*	*11,500*
2029	*16,927*	*6,432*	*6,432*	*10,496*
2030	*17,774*	*7,102*	*7,102*	*10,672*
2031	*18,662*	*7,775*	*7,775*	*10,887*
2032	*19,595*	*11,207*	*11,207*	*8,388*
2033	*20,575*	*12,854*	*12,854*	*7,730*
2034	*21,567*	*13,795*	*13,795*	*8,128*
2035	*22,479*	*14,840*	*14,840*	*7,844*
2036	*23,818*	*20,438*	*20,438*	*3,380*
2037	*25,009*	*22,116*	*22,116*	*2,893*
2038	*28,129*	*20,366*	*20,366*	*5,894*
2039	*29,301*	*21,835*	*21,835*	*5,738*
2040	*28,951*	*25,645*	*25,645*	*3,306*
2041	*30,399*	*25,046*	*25,046*	*5,353*
2042	*32,901*	*28,027*	*28,027*	*3,892*
2043	*35550*	*30424*	*30424*	*3090*

Step 6. Compute Reduced Speed Delay

Work Zone Reduced Speed Delay

Table 51: work zone reduced speed delay

Year	*upstream speed (km/hr)*	*WZ length (km)*	*WZ speed (km/hr)*	*WZ length/upstream speed (hr)*	*WZ length/WZ speed (hr)*	*WZ delay/vehicle*	
						hours	*min*
2020	*55*	*1*	*30*	*0.018181818*	*0.03333333*	*0.015152*	*0.909091*

2021	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2022	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2023	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2024	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2025	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2026	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2027	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2028	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2029	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2030	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2031	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2032	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2033	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2034	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2035	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2036	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2037	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2038	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2039	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2040	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2041	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2042	55	1	30	0.018181818	0.03333333	0.015152	0.909091
2043	55	1	30	0.018181818	0.03333333	0.015152	0.909091

Table 52: Queue Speed Summary for Each Year

Year	Daily Time	Volume (Queue)	Capacity (Free Flow)	V/C	Speed (Mi/Hr)	Speed (Km/Hr)
2020	-	0	6141	0.0	0	0
2021	-	0	6141	0.0	0	0
2022	-	0	6141	0.0	0	0
2023	5pm-6pm	116	6141	0.0	0	0

Year	Daily Time	Volume (Queue)	Capacity (Free Flow)	V/C	Speed (Mi/Hr)	Speed (Km/Hr)
2024	4pm-6pm	180	6141	0.0	0	0
2025	5pm-6pm	285	6141	0.0	0	0
2026	6pm-6pm	416	6141	0.1	2	3.2184
2027	7pm-6pm	554	6141	0.1	2	3.2184
2028	8pm-6pm	756	6141	0.1	2	3.2184
2029	3pm-6pm	866	6141	0.1	2	3.2184
2030	4pm-6pm	1085	6141	0.2	3	4.8276
2031	3pm-7pm	1332	6141	0.2	3	4.8276
2032	2pm-7pm	1639	6141	0.3	5	8.0460
2033	7am-7pm	2124	6141	0.3	5	8.046
2034	6am-7pm	2503	6141	0.4	8	12.8736
2035	5am-7pm	3091	6141	0.5	10	16.092
2036	10am-7pm	4119	6141	0.7	15	24.138
2037	7am-7pm	4970	6141	0.8	18	28.9656
2038	8am-7pm	5919	6141	1.0	26	41.8392
2039	9am-7pm	6916	6141	1.1	26	41.8392
2040	7am-8pm	7966	6141	1.3	26	41.8392
2041	7am-8pm	6378	6141	1.0	26	41.8392
2042	6am-8pm	10374	6141	1.7	26	41.8392
2043	7am-8pm	10272	6141	1.7	26	41.8392

Table 53: Average Queue Length for The Year 2020

Time Hour	Volume		Speed		Density			№ Of Queued Vehicles	Average No. of Queued Vehicles	Average Queue Length (Km)(J/H)
	Through Queue	Up Stream Of Queue	In Queue	Up Stream Of Queue	In Queue (B/D)	Up Stream Of Queue (C/E)	Change (F-G)			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
Average for The Entire Period									0	0.000
Over All Queue Length for Entire Period										0.000

Table 54: Average Queue Length for The Year 2038

Time Hour	Volume		Speed		Density			№ of queued vehicles	Average No. of Queued Vehicles	average queue length (km)j/h
	through queue	up stream of queue (demand)	in queue	up stream of queue	in queue (b/d)	up stream of queue (c/e)	change (f-g)			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
7- 8	1170	1635	41.8392	50	28	33	-5	465	233	0
8-9	1170	1354	41.8392	50	28	27	1	649	557	625
9-10	1170	1226	41.8392	50	28	25	3	705	677	197
10-11	1170	1330	41.8392	50	28	27	1	865	785	576
11-12	1170	1417	41.8392	50	28	28	0	1112	988	0
12-13	1170	1467	41.8392	50	28	29	-1	1409	1260	0
13-14	1170	1494	41.8392	50	28	30	-2	1733	1571	0
14-15	1170	1577	41.8392	50	28	32	-4	2139	1936	0
15-16	1170	1839	41.8392	50	28	37	-9	2809	2474	0
16-17	1170	2277	41.8392	50	28	46	-18	3916	3362	0
Average for the 7-17 Period									1384	1398
Over All Queue Length For 7-17 Period										140

Table 55: Average Queue Length for The Year 2042

Time Hour	Volume		Speed		Density			№ of queued vehicle	Average No. of Queued Vehicle	average queue length (km)j/h
	through queue	up stream of queue (demand)	in queue	up stream of queue	in queue (b/d)	up stream of queue (c/e)	change (f-g)			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
6-7	1170	1202	41.8392	50	28	24	4	32	16	4
7-8	1170	1987	41.8392	50	28	40	-12	849	441	0
8-9	1170	1645	41.8392	50	28	33	-5	1325	1087	0
9-10	1170	1491	41.8392	50	28	30	-2	1645	1485	0
10-11	1170	1617	41.8392	50	28	32	-4	2092	1869	0
11-12	1170	1722	41.8392	50	28	34	-6	2644	2368	0
1213	1170	1784	41.8392	50	28	36	-8	3258	2951	0
13-14	1170	1815	41.8392	50	28	36	-8	3903	3580	0
14-15	1170	1917	41.8392	50	28	38	-10	4650	4276	0
15-16	1170	2236	41.8392	50	28	45	-17	5716	5183	0
16-17	1170	2768	41.8392	50	28	55	-27	7313	6514	0
Average for the 6-17 Period									2706	4
Over All Queue Length For 6-17 Period										0.371

Table 56: Summary of Average Queue Length for Each Year

Years	Average Queue Length	Years	Average Queue Length
2020	0.000000000	2032	4.539535988
2021	0.000000000	2033	5.000000000
2022	0.000000000	2034	15.05005846
2023	0.000000000	2035	27.85992574
2024	0.000000000	2036	18.77034142
2025	0.000000000	2037	46.58795933
2026	0.305040925	2038	141.4473897
2027	0.438649753	2039	76.93098119
2028	0.636811458	2040	243.1571647
2029	0.893893345	2041	283.987564
2030	1.897011338	2042	384.2773679
2031	2.4578965	2043	1013.437271

Then the average queue delay time is summarized in the following table.

Table 57: Summary of Average Queue Delay Time for Each Year

Years	Average Queue Length	Queue Speed @		Time (Hours)@		Average Queue Delay Per Vehicles	
		Queue	Upstream	Queue	Upstream	Hours	Minute
a	b	c	d	e	f	e-f	(e-f) *60
2020	0.0000	0	50	-	-	-	-
2022	0.0000	0	50	-	-	-	-
2023	0.0000	0	50	-	-	-	-
2024	0.0000	0	50	-	-	-	-
2025	0.0000	0	50	-	-	-	-
2026	0.3050	3.2184	50	0.094780302	0.00610082	0.09	5.32
2027	0.4386	3.2184	50	0.136294355	0.008773	0.13	7.65
2028	0.6368	3.2184	50	0.197865852	0.01273623	0.19	11.11
2029	0.8939	3.2184	50	0.277744639	0.01787787	0.26	15.59
2030	1.8970	4.8276	50	0.392951226	0.03794023	0.36	21.30
2032	4.5395	8.0460	50	0.564197861	0.09079072	0.47	28.40
2034	15.0501	12.874	50	1.169063701	0.30100117	0.87	52.08
2035	27.8599	16.092	50	1.731290439	0.55719851	1.17	70.45
2036	18.7703	24.138	50	0.777626208	0.37540683	0.40	24.13
2037	46.5880	28.966	50	1.608389239	0.93175919	0.68	40.60
2038	141.447	41.839	50	3.380738392	2.82894779	0.55	33.11
2039	76.9310	41.839	50	1.838729737	1.53861962	0.30	18.01
2040	243.157	41.839	50	5.811706836	4.86314329	0.95	56.91
2042	384.277	41.839	50	9.184625134	7.68554736	1.50	89.94
2043	1013.44	41.839	50	24.22219525	20.2687454	3.95	237.21

Step 7. Select and Assign VOC Rates

Table 58 : Added time and vehicle running cost/1,000 stops and idling costs (2019).

Initial Speed (mi/h)	*Initial Speed (km/h)*	*Added Time (Hr/1,000 Stops) (Excludes Idling Time)*			*Added Cost (ETB/1,000 Stops) (Excludes Idling Time)*		
		Pass Cars	*Single-Unit Truck*	*Combination Truck*	*Pass Cars*	*Single-Unit Truck*	*Combination Truck*
5	*8*	*1.02*	*0.73*	*1.1*	*4.82*	*16.49*	*59.94*
10	*16*	*1.51*	*1.47*	*2.27*	*15.75*	*36.93*	*138.13*
15	*24*	*2*	*2.2*	*3.48*	*27.02*	*60.41*	*231.67*
20	*32*	*2.49*	*2.93*	*4.76*	*38.76*	*86.27*	*338.78*
25	*40*	*2.98*	*3.67*	*6.1*	*51.11*	*114.04*	*457.30*
30	*48*	*3.46*	*4.4*	*7.56*	*64.35*	*143.02*	*585.05*
35	*56*	*3.94*	*5.13*	*9.19*	*78.54*	*172.68*	*719.86*
40	*64*	*4.42*	*5.87*	*11.09*	*93.94*	*203.16*	*859.55*
45	*72*	*4.9*	*6.6*	*13.39*	*110.64*	*231.87*	*1002.03*
50	*80*	*5.37*	*7.33*	*16.37*	*128.90*	*260.18*	*1145.12*
55	*89*	*5.84*	*8.07*	*20.72*	*148.79*	*286.79*	*1286.58*
60	*97*	*6.31*	*8.8*	*27.94*	*170.58*	*319.03*	*1424.24*
65	*105*	*6.78*	*9.53*	*NA*	*194.34*	*349.10*	*NA*
70	*113*	*7.25*	*NA*	*NA*	*220.34*	*NA*	*NA*
75	*121*	*7.71*	*NA*	*NA*	*248.71*	*NA*	*NA*
80	*129*	*8.17*	*NA*	*NA*	*279.59*	*NA*	*NA*
Idling Cost (ETB/Veh-Hr)					*1.23*	*1.37*	*1.47*

Table 59 : Speed Change Computations

Initial Speed (mi/h)	*Initial speed (km/hr)*	*Added Time (Hr/1,000 Stops) (Excludes Idling Time)*			*Added Cost (ETB/1,000 Stops) (Excludes Idling Time)*		
		Pass Cars	*Single-Unit Truck*	*Combination Truck*	*Pass Cars*	*Single-Unit Truck*	*Combination Truck*
15	*24*	*2*	*2.2*	*3.48*	*27.02*	*60.41*	*231.67*
19	*30*	*2.36*	*2.73*	*4.41*	*35.57*	*79.25*	*309.71*
20	*32*	*2.49*	*2.93*	*4.76*	*38.76*	*86.27*	*338.78*
30	*48*	*3.46*	*4.4*	*7.56*	*64.35*	*143.02*	*585.05*
31	*50*	*3.56*	*4.56*	*7.91*	*67.39*	*149.38*	*613.93*
35	*56*	*3.94*	*5.13*	*9.19*	*78.54*	*172.68*	*719.86*
31-19-31	*50-30-50*	*1.21*	*1.82*	*3.50*	*31.82*	*70.12*	*304.22*
Idling Cost (ETB/Veh-Hr)					*1.23*	*1.37*	*1.47*

Step 8. Select and Assign Delay Cost Rates

Table 60: value of travel time (ETB/Veh-Hr, 2019)

Vehicle Class	*Wage Indicator*	*Value of time (ETB/Veh-Hr)*
Passenger Cars	*Real wage of medium skilled worker*	*18*
Single Unit Trucks	*Real wage of high skilled worker*	*42*
Combination Trucks	*Real wage of high skilled worker*	*50*

Step 9. Assign Traffic to Vehicle Classes

Table 61: Affected traffic by vehicle class and user cost component.

years	*cost component*	*Affected vehicles*	*Passenger vehicles 65%*	*Trucks*		*Total*
				Single-unit 20%	*Combination15%*	
2020	*speed change (50-30-50)*	*10912*	*7093*	*2182*	*1637*	*10912*
	Traverse WZ	*10912*	*7093*	*2182*	*1637*	*10912*
	Stopping (50-0-50)	*0*	*0*	*0*	*0*	*0*
	Queue Delay	*0*	*0*	*0*	*0*	*0*
2021	*speed change (50-30-50)*	*11457*	*7447*	*2291*	*1719*	*11457*
	Traverse WZ	*0*	*0*	*0*	*0*	*0*
	Stopping (50-0-50)	*0*	*0*	*0*	*0*	*0*
	Queue Delay	*11457*	*7447*	*2291*	*1719*	*11457*
2022	*speed change (50-30-50)*	*12030*	*7819*	*2406*	*1804*	*12030*
	Traverse WZ	*0*	*0*	*0*	*0*	*0*
	Stopping (50-0-50)	*0*	*0*	*0*	*0*	*0*
	Queue Delay	*12030*	*7819*	*2406*	*1804*	*12030*
2023	*speed change (50-30-50)*	*11093*	*7210*	*2219*	*1664*	*11093*
	Traverse WZ	*12631*	*8210*	*2526*	*1895*	*12631*
	Stopping (50-0-50)	*1539*	*1000*	*308*	*231*	*1539*
	Queue Delay	*1539*	*1000*	*308*	*231*	*1539*
2024	*speed change (50-30-50)*	*11449*	*7442*	*2290*	*1717*	*11449*
	Traverse WZ	*13263*	*8621*	*2653*	*1989*	*13263*
	Stopping (50-0-50)	*1814*	*1179*	*363*	*272*	*1814*
	Queue Delay	*1814*	*1179*	*363*	*272*	*1814*
2025	*speed change (50-30-50)*	*13926*	*9052*	*2785*	*2089*	*13926*
	Traverse WZ	*3512*	*2283*	*702*	*527*	*3512*
	Stopping (50-0-50)	*3512*	*2283*	*702*	*527*	*3512*
	Queue Delay	*10417*	*6771*	*2083*	*1563*	*10417*
2026	*speed change (50-30-50)*	*10756*	*6991*	*2151*	*1613*	*10756*
	Traverse WZ	*14623*	*9505*	*2925*	*2193*	*14623*
	Stopping (50-0-50)	*3866*	*2513*	*773*	*580*	*3866*
	Queue Delay	*3866*	*2513*	*773*	*580*	*3866*
2027	*speed change (50-30-50)*	*15354*	*9980*	*3071*	*2303*	*15354*
	Traverse WZ	*4278*	*2781*	*856*	*642*	*4278*

years	*cost component*	*Affected vehicles*	*Passenger vehicles 65%*	*Trucks*		*Total*
				Single-unit 20%	*Combination15%*	
	Stopping (50-0-50)	*4278*	*2781*	*856*	*642*	*4278*
	Queue Delay	*11075*	*7199*	*2215*	*1661*	*11075*
2028	*speed change (50-30-50)*	*16426*	*10677*	*3285*	*2464*	*16426*
	Traverse WZ	*4926*	*3202*	*985*	*739*	*4926*
	Stopping (50-0-50)	*4926*	*3202*	*985*	*739*	*4926*
	Queue Delay	*11500*	*7475*	*2300*	*1725*	*11500*
2029	*speed change (50-30-50)*	*16927*	*11003*	*3385*	*2539*	*16927*
	Traverse WZ	*6432*	*4180*	*1286*	*965*	*6432*
	Stopping (50-0-50)	*6432*	*4180*	*1286*	*965*	*6432*
	Queue Delay	*10496*	*6822*	*2099*	*1574*	*10496*
2030	*speed change (50-30-50)*	*10672*	*6937*	*2134*	*1601*	*10672*
	Traverse WZ	*17774*	*11553*	*3555*	*2666*	*17774*
	Stopping (50-0-50)	*7102*	*4616*	*1420*	*1065*	*7102*
	Queue Delay	*7102*	*4616*	*1420*	*1065*	*7102*
2031	*speed change (50-30-50)*	*18662*	*12130*	*3732*	*2799*	*18662*
	Traverse WZ	*7775*	*5054*	*1555*	*1166*	*7775*
	Stopping (50-0-50)	*7775*	*5054*	*1555*	*1166*	*7775*
	Queue Delay	*10887*	*7077*	*2177*	*1633*	*10887*
2032	*speed change (50-30-50)*	*8388*	*5452*	*1678*	*1258*	*8388*
	Traverse WZ	*19595*	*12737*	*3919*	*2939*	*19595*
	Stopping (50-0-50)	*11207*	*7285*	*2241*	*1681*	*11207*
	Queue Delay	*11207*	*7285*	*2241*	*1681*	*11207*
2033	*speed change (50-30-50)*	*20575*	*13374*	*4115*	*3086*	*20575*
	Traverse WZ	*12854*	*8355*	*2571*	*1928*	*12854*
	Stopping (50-0-50)	*12854*	*8355*	*2571*	*1928*	*12854*
	Queue Delay	*7730*	*5024*	*1546*	*1159*	*7730*
2034	*speed change (50-30-50)*	*21567*	*14018*	*4313*	*3235*	*21567*
	Traverse WZ	*13795*	*8967*	*2759*	*2069*	*13795*
	Stopping (50-0-50)	*13795*	*8967*	*2759*	*2069*	*13795*
	Queue Delay	*8128*	*5283*	*1626*	*1219*	*8128*
2035	*speed change (50-30-50)*	*22479*	*14612*	*4496*	*3372*	*22479*
	Traverse WZ	*14840*	*9646*	*2968*	*2226*	*14840*
	Stopping (50-0-50)	*14840*	*9646*	*2968*	*2226*	*14840*
	Queue Delay	*7844*	*5099*	*1569*	*1177*	*7844*
2036	*speed change (50-30-50)*	*3380*	*2197*	*676*	*507*	*3380*
	Traverse WZ	*23818*	*15482*	*4764*	*3573*	*23818*
	Stopping (50-0-50)	*20438*	*13285*	*4088*	*3066*	*20438*
	Queue Delay	*20438*	*13285*	*4088*	*3066*	*20438*

years	*cost component*	*Affected vehicles*	*Passenger vehicles 65%*	*Trucks*		*Total*
				Single-unit 20%	*Combination15%*	
2037	*speed change (50-30-50)*	*25009*	*16256*	*5002*	*3751*	*25009*
	Traverse WZ	*22116*	*14375*	*4423*	*3317*	*22116*
	Stopping (50-0-50)	*22116*	*14375*	*4423*	*3317*	*22116*
	Queue Delay	*2893*	*1881*	*579*	*434*	*2893*
2038	*speed change (50-30-50)*	*5894*	*3831*	*1179*	*884*	*5894*
	Traverse WZ	*28129*	*18284*	*5626*	*4219*	*28129*
	Stopping (50-0-50)	*20366*	*13238*	*4073*	*3055*	*20366*
	Queue Delay	*20366*	*13238*	*4073*	*3055*	*20366*
2039	*speed change (50-30-50)*	*5738*	*3730*	*1148*	*861*	*5738*
	Traverse WZ	*29301*	*19046*	*5860*	*4395*	*29301*
	Stopping (50-0-50)	*21835*	*14193*	*4367*	*3275*	*21835*
	Queue Delay	*21835*	*14193*	*4367*	*3275*	*21835*
2040	*speed change (50-30-50)*	*28951*	*18818*	*5790*	*4343*	*28951*
	Traverse WZ	*25645*	*16669*	*5129*	*3847*	*25645*
	Stopping (50-0-50)	*25645*	*16669*	*5129*	*3847*	*25645*
	Queue Delay	*3306*	*2149*	*661*	*496*	*3306*
2041	*speed change (50-30-50)*	*30399*	*19759*	*6080*	*4560*	*30399*
	Traverse WZ	*25046*	*16280*	*5009*	*3757*	*25046*
	Stopping (50-0-50)	*25046*	*16280*	*5009*	*3757*	*25046*
	Queue Delay	*5353*	*3479*	*1071*	*803*	*5353*
2042	*speed change (50-30-50)*	*3892*	*2530*	*778*	*584*	*3892*
	Traverse WZ	*32901*	*21386*	*6580*	*4935*	*32901*
	Stopping (50-0-50)	*28027*	*18218*	*5605*	*4204*	*28027*
	Queue Delay	*28027*	*18218*	*5605*	*4204*	*28027*
2043	*speed change (50-30-50)*	*35550*	*23108*	*7110*	*5333*	*35550*
	Traverse WZ	*30424*	*19776*	*6085*	*4564*	*30424*
	Stopping (50-0-50)	*30424*	*19776*	*6085*	*4564*	*30424*
	Queue Delay	*3090*	*2009*	*618*	*464*	*3090*

Step 10. Compute User Cost Components by Vehicle Class

Table 62: user cost component 1- speed change VOC (50-30-50) km/hr

Years	*Vehicle Class*	*Affected Vehicles*	*Added VOC (50-30-50), ETB/1000 Vehicles*	*Cost Per Day (ETB)*
2020	*Passenger Cars*	*7092.486752*	*31.82*	*226*
	Single Unit Truck	*2182.303616*	*70.12*	*153*
	Combination Truck	*1636.727712*	*304.22*	*498*
	Total Speed Change VOC	*10911.51808*		*877*

Years	*Vehicle Class*	*Affected Vehicles*	*Added VOC (50-30-50), ETB/1000 Vehicles*	*Cost Per Day (ETB)*
2021	*Passenger Cars*	*7447.17623*	*31.82*	*237*
	Single Unit Truck	*2291.43884*	*70.12*	*161*
	Combination Truck	*1718.57913*	*304.22*	*523*
	Total Speed Change VOC	*11457.1942*		*920*
2022	*Passenger Cars*	*7819.453616*	*31.82*	*249*
	Single Unit Truck	*2405.985728*	*70.12*	*169*
	Combination Truck	*1804.489296*	*304.22*	*549*
	Total Speed Change VOC	*12029.92864*		*966*
2023	*Passenger Cars*	*7210.149448*	*31.82*	*229*
	Single Unit Truck	*2218.507523*	*70.12*	*156*
	Combination Truck	*1663.880642*	*304.22*	*506*
	Total Speed Change VOC	*11092.53761*		*891*
2024	*Passenger Cars*	*7441.683527*	*31.82*	*237*
	Single Unit Truck	*2289.748778*	*70.12*	*161*
	Combination Truck	*1717.311583*	*304.22*	*522*
	Total Speed Change VOC	*11448.74389*		*920*
2025	*Passenger Cars*	*6770.969375*	*31.82*	*215*
	Single Unit Truck	*2083.375192*	*70.12*	*146*
	Combination Truck	*1562.531394*	*304.22*	*475*
	Total Speed Change VOC	*10416.87596*		*837*
2026	*Passenger Cars*	*6991.668927*	*31.82*	*222*
	Single Unit Truck	*2151.282747*	*70.12*	*151*
	Combination Truck	*1613.46206*	*304.22*	*491*
	Total Speed Change VOC	*10756.41373*		*864*

Years	*Vehicle Class*	*Affected Vehicles*	*Added VOC (50-30-50), ETB/1000 Vehicles*	*Cost Per Day (ETB)*
2027	*Passenger Cars*	*7198.916367*	*31.82*	*229*
	Single Unit Truck	*2215.05119*	*70.12*	*155*
	Combination Truck	*1661.288392*	*304.22*	*505*
	Total Speed Change VOC	*11075.25595*		*890*
2028	*Passenger Cars*	*7475.1796*	*31.82*	*238*
	Single Unit Truck	*2300.055262*	*70.12*	*161*
	Combination Truck	*1725.041446*	*304.22*	*525*
	Total Speed Change VOC	*11500.27631*		*924*
2029	*Passenger Cars*	*6822.379881*	*31.82*	*217*
	Single Unit Truck	*2099.19381*	*70.12*	*147*
	Combination Truck	*1574.395357*	*304.22*	*479*
	Total Speed Change VOC	*10495.96905*		*843*
2030	*Passenger Cars*	*6936.668499*	*31.82*	*221*
	Single Unit Truck	*2134.359538*	*70.12*	*150*
	Combination Truck	*1600.769654*	*304.22*	*487*
	Total Speed Change VOC	*10671.79769*		*857*
2031	*Passenger Cars*	*7076.797078*	*31.82*	*225*
	Single Unit Truck	*2177.476024*	*70.12*	*153*
	Combination Truck	*1633.107018*	*304.22*	*497*
	Total Speed Change VOC	*10887.38012*		*875*
2032	*Passenger Cars*	*5452.480245*	*31.82*	*173*
	Single Unit Truck	*1677.686229*	*70.12*	*118*
	Combination Truck	*1258.264672*	*304.22*	*383*
	Total Speed Change VOC	*8388.431146*		*674*
2033	*Passenger Cars*	*5024.414818*	*31.82*	*160*
	Single Unit Truck	*1545.97379*	*70.12*	*108*
	Combination Truck	*1159.480343*	*304.22*	*353*
	Total Speed Change VOC	*7729.868951*		*621*

Years	*Vehicle Class*	*Affected Vehicles*	*Added VOC (50-30-50), ETB/1000 Vehicles*	*Cost Per Day (ETB)*
2034	*Passenger Cars*	*5282.945623*	*31.82*	*168*
	Single Unit Truck	*1625.52173*	*70.12*	*114*
	Combination Truck	*1219.141298*	*304.22*	*371*
	Total Speed Change VOC	*8127.60865*		*653*
2035	*Passenger Cars*	*5098.546225*	*31.82*	*162*
	Single Unit Truck	*1568.783454*	*70.12*	*110*
	Combination Truck	*1176.58759*	*304.22*	*358*
	Total Speed Change VOC	*7843.917269*		*630*
2036	*Passenger Cars*	*2197.068324*	*31.82*	*70*
	Single Unit Truck	*676.0210228*	*70.12*	*47*
	Combination Truck	*507.0157671*	*304.22*	*154*
	Total Speed Change VOC	*3380.105114*		*272*
2037	*Passenger Cars*	*1880.767407*	*31.82*	*60*
	Single Unit Truck	*578.6976638*	*70.12*	*41*
	Combination Truck	*434.0232479*	*304.22*	*132*
	Total Speed Change VOC	*2893.488319*		*232*
2038	*Passenger Cars*	*3831.056005*	*31.82*	*122*
	Single Unit Truck	*1178.786463*	*70.12*	*83*
	Combination Truck	*884.0898474*	*304.22*	*269*
	Total Speed Change VOC	*5893.932316*		*474*
2039	*Passenger Cars*	*3729.481427*	*31.82*	*119*
	Single Unit Truck	*1147.532747*	*70.12*	*80*
	Combination Truck	*860.64956*	*304.22*	*262*
	Total Speed Change VOC	*5737.663733*		*461*
2040	*Passenger Cars*	*2149.1562*	*31.82*	*68*
	Single Unit Truck	*661.2788308*	*70.12*	*46*
	Combination Truck	*495.9591231*	*304.22*	*151*
	Total Speed Change VOC	*3306.394154*		*266*

Years	*Vehicle Class*	*Affected Vehicles*	*Added VOC (50-30-50), ETB/1000 Vehicles*	*Cost Per Day (ETB)*
2041	*Passenger Cars*	*3479.270695*	*31.82*	*111*
	Single Unit Truck	*1070.544829*	*70.12*	*75*
	Combination Truck	*802.9086219*	*304.22*	*244*
	Total Speed Change VOC	*5352.724146*		*430*
2042	*Passenger Cars*	*2529.801584*	*31.82*	*80*
	Single Unit Truck	*778.4004875*	*70.12*	*55*
	Combination Truck	*583.8003656*	*304.22*	*178*
	Total Speed Change VOC	*3892.002438*		*313*
2043	*Passenger Cars*	*2008.777342*	*31.82*	*64*
	Single Unit Truck	*618.0853361*	*70.12*	*43*
	Combination Truck	*463.5640021*	*304.22*	*141*
	Total Speed Change VOC	*3090.42668*		*248*

Table 63: user cost component 2 - speed change delay cost (50-30-50) km/hr

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-30-50), Hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2020	*Passenger Cars*	*7092.486752*	*1.21*	*14*	*120*
	Single Unit Truck	*2182.303616*	*1.82*	*42*	*167*
	Combination Truck	*1636.727712*	*3.50*	*50.4*	*288*
	Total Speed Change DC	*10911.51808*			*575*
2021	*Passenger Cars*	*7447.17623*	*1.21*	*14*	*126*
	Single Unit Truck	*2291.43884*	*1.82*	*42*	*176*
	Combination Truck	*1718.57913*	*3.50*	*50.4*	*303*
	Total Speed Change DC	*11457.1942*			*604*
2022	*Passenger Cars*	*7819.453616*	*1.21*	*14*	*132*
	Single Unit Truck	*2405.985728*	*1.82*	*42*	*184*
	Combination Truck	*1804.489296*	*3.50*	*50.4*	*318*
	Total Speed Change DC	*12029.92864*			*634*
2023	*Passenger Cars*	*7210.149448*	*1.21*	*14*	*122*
	Single Unit Truck	*2218.507523*	*1.82*	*42*	*170*
	Combination Truck	*1663.880642*	*3.50*	*50.4*	*293*
	Total Speed Change DC	*11092.53761*			*585*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-30-50), Hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2024	*Passenger Cars*	*7441.683527*	*1.21*	*14*	*126*
	Single Unit Truck	*2289.748778*	*1.82*	*42*	*175*
	Combination Truck	*1717.311583*	*3.50*	*50.4*	*303*
	Total Speed Change DC	*11448.74389*			*604*
2025	*Passenger Cars*	*6770.969375*	*1.21*	*14*	*114*
	Single Unit Truck	*2083.375192*	*1.82*	*42*	*160*
	Combination Truck	*1562.531394*	*3.50*	*50.4*	*275*
	Total Speed Change DC	*10416.87596*			*549*
2026	*Passenger Cars*	*6991.668927*	*1.21*	*14*	*118*
	Single Unit Truck	*2151.282747*	*1.82*	*42*	*165*
	Combination Truck	*1613.46206*	*3.50*	*50.4*	*284*
	Total Speed Change DC	*10756.41373*			*567*
2027	*Passenger Cars*	*7198.916367*	*1.21*	*14*	*122*
	Single Unit Truck	*2215.05119*	*1.82*	*42*	*170*
	Combination Truck	*1661.288392*	*3.50*	*50.4*	*293*
	Total Speed Change DC	*11075.25595*			*584*
2028	*Passenger Cars*	*7475.1796*	*1.21*	*14*	*126*
	Single Unit Truck	*2300.055262*	*1.82*	*42*	*176*
	Combination Truck	*1725.041446*	*3.50*	*50.4*	*304*
	Total Speed Change DC	*11500.27631*			*606*
2029	*Passenger Cars*	*6822.379881*	*1.21*	*14*	*115*
	Single Unit Truck	*2099.19381*	*1.82*	*42*	*161*
	Combination Truck	*1574.395357*	*3.50*	*50.4*	*277*
	Total Speed Change DC	*10495.96905*			*554*
2030	*Passenger Cars*	*6936.668499*	*1.21*	*14*	*117*
	Single Unit Truck	*2134.359538*	*1.82*	*42*	*164*
	Combination Truck	*1600.769654*	*3.50*	*50.4*	*282*
	Total Speed Change DC	*10671.79769*			*563*
2031	*Passenger Cars*	*7076.797078*	*1.21*	*14*	*119*
	Single Unit Truck	*2177.476024*	*1.82*	*42*	*167*
	Combination Truck	*1633.107018*	*3.50*	*50.4*	*288*
	Total Speed Change DC	*10887.38012*			*574*
2032	*Passenger Cars*	*5452.480245*	*1.21*	*14*	*92*
	Single Unit Truck	*1677.686229*	*1.82*	*42*	*129*
	Combination Truck	*1258.264672*	*3.50*	*50.4*	*222*
	Total Speed Change DC	*8388.431146*			*442*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-30-50), Hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2033	*Passenger Cars*	*5024.414818*	*1.21*	*14*	*85*
	Single Unit Truck	*1545.97379*	*1.82*	*42*	*118*
	Combination Truck	*1159.480343*	*3.50*	*50.4*	*204*
	Total Speed Change DC	*7729.868951*			*408*
2034	*Passenger Cars*	*5282.945623*	*1.21*	*14*	*89*
	Single Unit Truck	*1625.52173*	*1.82*	*42*	*125*
	Combination Truck	*1219.141298*	*3.50*	*50.4*	*215*
	Total Speed Change DC	*8127.60865*			*429*
2035	*Passenger Cars*	*5098.546225*	*1.21*	*14*	*86*
	Single Unit Truck	*1568.783454*	*1.82*	*42*	*120*
	Combination Truck	*1176.58759*	*3.50*	*50.4*	*207*
	Total Speed Change DC	*7843.917269*			*414*
2036	*Passenger Cars*	*2197.068324*	*1.21*	*14*	*37*
	Single Unit Truck	*676.0210228*	*1.82*	*42*	*52*
	Combination Truck	*507.0157671*	*3.50*	*50.4*	*89*
	Total Speed Change DC	*3380.105114*			*178*
2037	*Passenger Cars*	*1880.767407*	*1.21*	*14*	*32*
	Single Unit Truck	*578.6976638*	*1.82*	*42*	*44*
	Combination Truck	*434.0232479*	*3.50*	*50.4*	*76*
	Total Speed Change DC	*2893.488319*			*153*
2038	*Passenger Cars*	*3831.056005*	*1.21*	*14*	*65*
	Single Unit Truck	*1178.786463*	*1.82*	*42*	*90*
	Combination Truck	*884.0898474*	*3.50*	*50.4*	*156*
	Total Speed Change DC	*5893.932316*			*311*
2039	*Passenger Cars*	*3729.481427*	*1.21*	*14*	*63*
	Single Unit Truck	*1147.532747*	*1.82*	*42*	*88*
	Combination Truck	*860.64956*	*3.50*	*50.4*	*152*
	Total Speed Change DC	*5737.663733*			*303*
2040	*Passenger Cars*	*2149.1562*	*1.21*	*14*	*36*
	Single Unit Truck	*661.2788308*	*1.82*	*42*	*51*
	Combination Truck	*495.9591231*	*3.50*	*50.4*	*87*
	Total Speed Change DC	*3306.394154*			*174*
2041	*Passenger Cars*	*3479.270695*	*1.21*	*14*	*59*
	Single Unit Truck	*1070.544829*	*1.82*	*42*	*82*
	Combination Truck	*802.9086219*	*3.50*	*50.4*	*141*
	Total Speed Change DC	*5352.724146*			*282*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-30-50), Hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2042	*Passenger Cars*	*2529.801584*	*1.21*	*14*	*43*
	Single Unit Truck	*778.4004875*	*1.82*	*42*	*60*
	Combination Truck	*583.8003656*	*3.50*	*50.4*	*103*
	Total Speed Change DC	*3892.002438*			*205*
2043	*Passenger Cars*	*2008.777342*	*1.21*	*14*	*34*
	Single Unit Truck	*618.0853361*	*1.82*	*42*	*47*
	Combination Truck	*463.5640021*	*3.50*	*50.4*	*82*
	Total Speed Change DC	*3090.42668*			*163*

Table 64: user cost component 3 – work zone reduced speed delay cost (50-0-50) km/hr

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2020	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*
2021	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*
2022	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*
2023	*Passenger Cars*	*1000.146568*	*3.56*	*14*	*50*
	Single Unit Truck	*307.7374055*	*4.56*	*42*	*59*
	Combination Truck	*230.8030541*	*7.91*	*50.4*	*92*
	Total Reduced Speed DC	*1538.687027*			*201*
2024	*Passenger Cars*	*1179.322711*	*3.56*	*14*	*59*
	Single Unit Truck	*362.8685263*	*4.56*	*42*	*69*
	Combination Truck	*272.1513947*	*7.91*	*50.4*	*108*
	Total Reduced Speed DC	*1814.342632*			*237*
2025	*Passenger Cars*	*2282.589167*	*3.56*	*14*	*114*
	Single Unit Truck	*702.3351282*	*4.56*	*42*	*134*
	Combination Truck	*526.7513461*	*7.91*	*50.4*	*210*
	Total Reduced Speed DC	*3511.675641*			*458*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2026	*Passenger Cars*	*2512.966837*	*3.56*	*14*	*125*
	Single Unit Truck	*773.2205653*	*4.56*	*42*	*148*
	Combination Truck	*579.915424*	*7.91*	*50.4*	*231*
	Total Reduced Speed DC	*3866.102827*			*504*
2027	*Passenger Cars*	*2780.918615*	*3.56*	*14*	*139*
	Single Unit Truck	*855.6672662*	*4.56*	*42*	*164*
	Combination Truck	*641.7504496*	*7.91*	*50.4*	*256*
	Total Reduced Speed DC	*4278.336331*			*558*
2028	*Passenger Cars*	*3201.983364*	*3.56*	*14*	*160*
	Single Unit Truck	*985.2256505*	*4.56*	*42*	*189*
	Combination Truck	*738.9192379*	*7.91*	*50.4*	*295*
	Total Reduced Speed DC	*4926.128252*			*643*
2029	*Passenger Cars*	*4180.485083*	*3.56*	*14*	*209*
	Single Unit Truck	*1286.303102*	*4.56*	*42*	*246*
	Combination Truck	*964.7273268*	*7.91*	*50.4*	*385*
	Total Reduced Speed DC	*6431.515512*			*839*
2030	*Passenger Cars*	*4616.307143*	*3.56*	*14*	*230*
	Single Unit Truck	*1420.402198*	*4.56*	*42*	*272*
	Combination Truck	*1065.301648*	*7.91*	*50.4*	*425*
	Total Reduced Speed DC	*7102.01099*			*927*
2031	*Passenger Cars*	*5053.64821*	*3.56*	*14*	*252*
	Single Unit Truck	*1554.96868*	*4.56*	*42*	*298*
	Combination Truck	*1166.22651*	*7.91*	*50.4*	*465*
	Total Reduced Speed DC	*7774.8434*			*1015*
2032	*Passenger Cars*	*7284.400314*	*3.56*	*14*	*363*
	Single Unit Truck	*2241.353943*	*4.56*	*42*	*429*
	Combination Truck	*1681.015457*	*7.91*	*50.4*	*670*
	Total Reduced Speed DC	*11206.76971*			*1462*
2033	*Passenger Cars*	*8354.833847*	*3.56*	*14*	*417*
	Single Unit Truck	*2570.718107*	*4.56*	*42*	*492*
	Combination Truck	*1928.03858*	*7.91*	*50.4*	*769*
	Total Reduced Speed DC	*12853.59053*			*1677*
2034	*Passenger Cars*	*8966.914306*	*3.56*	*14*	*447*
	Single Unit Truck	*2759.050556*	*4.56*	*42*	*528*
	Combination Truck	*2069.287917*	*7.91*	*50.4*	*825*
	Total Reduced Speed DC	*13795.25278*			*1800*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2035	*Passenger Cars*	*9646.309017*	*3.56*	*14*	*481*
	Single Unit Truck	*2968.095082*	*4.56*	*42*	*568*
	Combination Truck	*2226.071312*	*7.91*	*50.4*	*887*
	Total Reduced Speed DC	*14840.47541*			*1937*
2036	*Passenger Cars*	*13284.85054*	*3.56*	*14*	*663*
	Single Unit Truck	*4087.646321*	*4.56*	*42*	*782*
	Combination Truck	*3065.734741*	*7.91*	*50.4*	*1222*
	Total Reduced Speed DC	*20438.23161*			*2667*
2037	*Passenger Cars*	*14375.34511*	*3.56*	*14*	*717*
	Single Unit Truck	*4423.183112*	*4.56*	*42*	*846*
	Combination Truck	*3317.387334*	*7.91*	*50.4*	*1322*
	Total Reduced Speed DC	*22115.91556*			*2886*
2038	*Passenger Cars*	*13237.68301*	*3.56*	*14*	*660*
	Single Unit Truck	*4073.133233*	*4.56*	*42*	*779*
	Combination Truck	*3054.849925*	*7.91*	*50.4*	*1218*
	Total Reduced Speed DC	*20365.66616*			*2658*
2039	*Passenger Cars*	*14192.92253*	*3.56*	*14*	*708*
	Single Unit Truck	*4367.053085*	*4.56*	*42*	*836*
	Combination Truck	*3275.289814*	*7.91*	*50.4*	*1306*
	Total Reduced Speed DC	*21835.26543*			*2849*
2040	*Passenger Cars*	*16669.25396*	*3.56*	*14*	*831*
	Single Unit Truck	*5129.001217*	*4.56*	*42*	*982*
	Combination Truck	*3846.750913*	*7.91*	*50.4*	*1533*
	Total Reduced Speed DC	*25645.00609*			*3346*
2041	*Passenger Cars*	*16280.09254*	*3.56*	*14*	*812*
	Single Unit Truck	*5009.259243*	*4.56*	*42*	*959*
	Combination Truck	*3756.944432*	*7.91*	*50.4*	*1498*
	Total Reduced Speed DC	*25046.29621*			*3268*
2042	*Passenger Cars*	*18217.41582*	*3.56*	*14*	*909*
	Single Unit Truck	*5605.358712*	*4.56*	*42*	*1073*
	Combination Truck	*4204.019034*	*7.91*	*50.4*	*1676*
	Total Reduced Speed DC	*28026.79356*			*3657*
2043	*Passenger Cars*	*19775.80093*	*3.56*	*14*	*986*
	Single Unit Truck	*6084.861824*	*4.56*	*42*	*1164*
	Combination Truck	*4563.646368*	*7.91*	*50.4*	*1819*
	Total Reduced Speed DC	*30424.30912*			*3970*

Table 65: user cost component 4 – stopping VOC (50-0-50) km/hr

Years	*Vehicle Class*	*Affected vehicles*	*Added VOC (50-0-50), ETB/1000 vehicles*	*Cost per day (ETB)*
2020	*Passenger Cars*	*0*	*67.39*	*-*
	Single Unit Truck	*0*	*149.38*	*-*
	Combination Truck	*0*	*613.93*	*-*
	Total Stopping VOC	*0*		*-*
2021	*Passenger Cars*	*0*	*67.39*	*-*
	Single Unit Truck	*0*	*149.38*	*-*
	Combination Truck	*0*	*613.93*	*-*
	Total Stopping VOC	*0*		*-*
2022	*Passenger Cars*	*0*	*67.39*	*-*
	Single Unit Truck	*0*	*149.38*	*-*
	Combination Truck	*0*	*613.93*	*-*
	Total Stopping VOC	*0*		*-*
2023	*Passenger Cars*	*1000.146568*	*67.39*	*67.40*
	Single Unit Truck	*307.7374055*	*149.38*	*45.97*
	Combination Truck	*230.8030541*	*613.93*	*141.70*
	Total Stopping VOC	*1538.687027*		*255.07*
2024	*Passenger Cars*	*1179.322711*	*67.39*	*79.47*
	Single Unit Truck	*362.8685263*	*149.38*	*54.20*
	Combination Truck	*272.1513947*	*613.93*	*167.08*
	Total Stopping VOC	*1814.342632*		*300.76*
2025	*Passenger Cars*	*2282.589167*	*67.39*	*153.82*
	Single Unit Truck	*702.3351282*	*149.38*	*104.91*
	Combination Truck	*526.7513461*	*613.93*	*323.39*
	Total Stopping VOC	*3511.675641*		*582.12*
2026	*Passenger Cars*	*2512.966837*	*67.39*	*169.35*
	Single Unit Truck	*773.2205653*	*149.38*	*115.50*
	Combination Truck	*579.915424*	*613.93*	*356.03*
	Total Stopping VOC	*3866.102827*		*640.88*
2027	*Passenger Cars*	*2780.918615*	*67.39*	*187.40*
	Single Unit Truck	*855.6672662*	*149.38*	*127.82*
	Combination Truck	*641.7504496*	*613.93*	*393.99*
	Total Stopping VOC	*4278.336331*		*709.21*

Years	*Vehicle Class*	*Affected vehicles*	*Added VOC (50-0-50), ETB/1000 vehicles*	*Cost per day (ETB)*
2028	*Passenger Cars*	*3201.983364*	*67.39*	*215.78*
	Single Unit Truck	*985.2256505*	*149.38*	*147.17*
	Combination Truck	*738.9192379*	*613.93*	*453.65*
	Total Stopping VOC	*4926.128252*		*816.60*
2029	*Passenger Cars*	*4180.485083*	*67.39*	*281.72*
	Single Unit Truck	*1286.303102*	*149.38*	*192.14*
	Combination Truck	*964.7273268*	*613.93*	*592.28*
	Total Stopping VOC	*6431.515512*		*1,066.14*
2030	*Passenger Cars*	*4616.307143*	*67.39*	*311.09*
	Single Unit Truck	*1420.402198*	*149.38*	*212.18*
	Combination Truck	*1065.301648*	*613.93*	*654.02*
	Total Stopping VOC	*7102.01099*		*1,177.29*
2031	*Passenger Cars*	*5053.64821*	*67.39*	*340.56*
	Single Unit Truck	*1554.96868*	*149.38*	*232.28*
	Combination Truck	*1166.22651*	*613.93*	*715.99*
	Total Stopping VOC	*7774.8434*		*1,288.82*
2032	*Passenger Cars*	*7284.400314*	*67.39*	*490.89*
	Single Unit Truck	*2241.353943*	*149.38*	*334.81*
	Combination Truck	*1681.015457*	*613.93*	*1,032.03*
	Total Stopping VOC	*11206.76971*		*1,857.73*
2033	*Passenger Cars*	*8354.833847*	*67.39*	*563.02*
	Single Unit Truck	*2570.718107*	*149.38*	*384.01*
	Combination Truck	*1928.03858*	*613.93*	*1,183.69*
	Total Stopping VOC	*12853.59053*		*2,130.72*
2034	*Passenger Cars*	*8966.914306*	*67.39*	*604.27*
	Single Unit Truck	*2759.050556*	*149.38*	*412.14*
	Combination Truck	*2069.287917*	*613.93*	*1,270.41*
	Total Stopping VOC	*13795.25278*		*2,286.82*
2035	*Passenger Cars*	*9646.309017*	*67.39*	*650.06*
	Single Unit Truck	*2968.095082*	*149.38*	*443.36*
	Combination Truck	*2226.071312*	*613.93*	*1,366.66*
	Total Stopping VOC	*14840.47541*		*2,460.08*
2036	*Passenger Cars*	*13284.85054*	*67.39*	*895.25*
	Single Unit Truck	*4087.646321*	*149.38*	*610.60*
	Combination Truck	*3065.734741*	*613.93*	*1,882.16*
	Total Stopping VOC	*20438.23161*		*3,388.01*

Years	*Vehicle Class*	*Affected vehicles*	*Added VOC (50-0-50), ETB/1000 vehicles*	*Cost per day (ETB)*
2037	*Passenger Cars*	*14375.34511*	*67.39*	*968.74*
	Single Unit Truck	*4423.183112*	*149.38*	*660.72*
	Combination Truck	*3317.387334*	*613.93*	*2,036.66*
	Total Stopping VOC	*22115.91556*		*3,666.12*
2038	*Passenger Cars*	*13237.68301*	*67.39*	*892.07*
	Single Unit Truck	*4073.133233*	*149.38*	*608.43*
	Combination Truck	*3054.849925*	*613.93*	*1,875.48*
	Total Stopping VOC	*20365.66616*		*3,375.98*
2039	*Passenger Cars*	*14192.92253*	*67.39*	*956.45*
	Single Unit Truck	*4367.053085*	*149.38*	*652.34*
	Combination Truck	*3275.289814*	*613.93*	*2,010.81*
	Total Stopping VOC	*21835.26543*		*3,619.59*
2040	*Passenger Cars*	*16669.25396*	*67.39*	*1,123.32*
	Single Unit Truck	*5129.001217*	*149.38*	*766.15*
	Combination Truck	*3846.750913*	*613.93*	*2,361.65*
	Total Stopping VOC	*25645.00609*		*4,251.13*
2041	*Passenger Cars*	*16280.09254*	*67.39*	*1,097.10*
	Single Unit Truck	*5009.259243*	*149.38*	*748.27*
	Combination Truck	*3756.944432*	*613.93*	*2,306.52*
	Total Stopping VOC	*25046.29621*		*4,151.88*
2042	*Passenger Cars*	*18217.41582*	*67.39*	*1,227.65*
	Single Unit Truck	*5605.358712*	*149.38*	*837.31*
	Combination Truck	*4204.019034*	*613.93*	*2,580.99*
	Total Stopping VOC	*28026.79356*		*4,645.95*
2043	*Passenger Cars*	*19775.80093*	*67.39*	*1,332.67*
	Single Unit Truck	*6084.861824*	*149.38*	*908.94*
	Combination Truck	*4563.646368*	*613.93*	*2,801.78*
	Total Stopping VOC	*30424.30912*		*5,043.39*

Table 66: user cost component 5 – stopping delay cost (50-0-50) km/hr

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2020	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2021	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*
2022	*Passenger Cars*	*0*	*3.56*	*14*	*0*
	Single Unit Truck	*0*	*4.56*	*42*	*0*
	Combination Truck	*0*	*7.91*	*50.4*	*0*
	Total Reduced Speed DC	*0*			*0*
2023	*Passenger Cars*	*1000.146568*	*3.56*	*14*	*50*
	Single Unit Truck	*307.7374055*	*4.56*	*42*	*59*
	Combination Truck	*230.8030541*	*7.91*	*50.4*	*92*
	Total Reduced Speed DC	*1538.687027*			*201*
2024	*Passenger Cars*	*1179.322711*	*3.56*	*14*	*59*
	Single Unit Truck	*362.8685263*	*4.56*	*42*	*69*
	Combination Truck	*272.1513947*	*7.91*	*50.4*	*108*
	Total Reduced Speed DC	*1814.342632*			*237*
2025	*Passenger Cars*	*2282.589167*	*3.56*	*14*	*114*
	Single Unit Truck	*702.3351282*	*4.56*	*42*	*134*
	Combination Truck	*526.7513461*	*7.91*	*50.4*	*210*
	Total Reduced Speed DC	*3511.675641*			*458*
2026	*Passenger Cars*	*2512.966837*	*3.56*	*14*	*125*
	Single Unit Truck	*773.2205653*	*4.56*	*42*	*148*
	Combination Truck	*579.915424*	*7.91*	*50.4*	*231*
	Total Reduced Speed DC	*3866.102827*			*504*
2027	*Passenger Cars*	*2780.918615*	*3.56*	*14*	*139*
	Single Unit Truck	*855.6672662*	*4.56*	*42*	*164*
	Combination Truck	*641.7504496*	*7.91*	*50.4*	*256*
	Total Reduced Speed DC	*4278.336331*			*558*
2028	*Passenger Cars*	*3201.983364*	*3.56*	*14*	*160*
	Single Unit Truck	*985.2256505*	*4.56*	*42*	*189*
	Combination Truck	*738.9192379*	*7.91*	*50.4*	*295*
	Total Reduced Speed DC	*4926.128252*			*643*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2029	*Passenger Cars*	*4180.485083*	*3.56*	*14*	*209*
	Single Unit Truck	*1286.303102*	*4.56*	*42*	*246*
	Combination Truck	*964.7273268*	*7.91*	*50.4*	*385*
	Total Reduced Speed DC	*6431.515512*			*839*
2030	*Passenger Cars*	*4616.307143*	*3.56*	*14*	*230*
	Single Unit Truck	*1420.402198*	*4.56*	*42*	*272*
	Combination Truck	*1065.301648*	*7.91*	*50.4*	*425*
	Total Reduced Speed DC	*7102.01099*			*927*
2031	*Passenger Cars*	*5053.64821*	*3.56*	*14*	*252*
	Single Unit Truck	*1554.96868*	*4.56*	*42*	*298*
	Combination Truck	*1166.22651*	*7.91*	*50.4*	*465*
	Total Reduced Speed DC	*7774.8434*			*1015*
2032	*Passenger Cars*	*7284.400314*	*3.56*	*14*	*363*
	Single Unit Truck	*2241.353943*	*4.56*	*42*	*429*
	Combination Truck	*1681.015457*	*7.91*	*50.4*	*670*
	Total Reduced Speed DC	*11206.76971*			*1462*
2033	*Passenger Cars*	*8354.833847*	*3.56*	*14*	*417*
	Single Unit Truck	*2570.718107*	*4.56*	*42*	*492*
	Combination Truck	*1928.03858*	*7.91*	*50.4*	*769*
	Total Reduced Speed DC	*12853.59053*			*1677*
2034	*Passenger Cars*	*8966.914306*	*3.56*	*14*	*447*
	Single Unit Truck	*2759.050556*	*4.56*	*42*	*528*
	Combination Truck	*2069.287917*	*7.91*	*50.4*	*825*
	Total Reduced Speed DC	*13795.25278*			*1800*
2035	*Passenger Cars*	*9646.309017*	*3.56*	*14*	*481*
	Single Unit Truck	*2968.095082*	*4.56*	*42*	*568*
	Combination Truck	*2226.071312*	*7.91*	*50.4*	*887*
	Total Reduced Speed DC	*14840.47541*			*1937*
2036	*Passenger Cars*	*13284.85054*	*3.56*	*14*	*663*
	Single Unit Truck	*4087.646321*	*4.56*	*42*	*782*
	Combination Truck	*3065.734741*	*7.91*	*50.4*	*1222*
	Total Reduced Speed DC	*20438.23161*			*2667*
2037	*Passenger Cars*	*14375.34511*	*3.56*	*14*	*717*
	Single Unit Truck	*4423.183112*	*4.56*	*42*	*846*
	Combination Truck	*3317.387334*	*7.91*	*50.4*	*1322*
	Total Reduced Speed DC	*22115.91556*			*2886*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (50-0-50), hrs./1000 vehicles*	*Delay cost rate (ETB/Veh-Hr)*	*Cost per day (ETB)*
2038	*Passenger Cars*	*13237.68301*	*3.56*	*14*	*660*
	Single Unit Truck	*4073.133233*	*4.56*	*42*	*779*
	Combination Truck	*3054.849925*	*7.91*	*50.4*	*1218*
	Total Reduced Speed DC	*20365.66616*			*2658*
2039	*Passenger Cars*	*14192.92253*	*3.56*	*14*	*708*
	Single Unit Truck	*4367.053085*	*4.56*	*42*	*836*
	Combination Truck	*3275.289814*	*7.91*	*50.4*	*1306*
	Total Reduced Speed DC	*21835.26543*			*2849*
2040	*Passenger Cars*	*16669.25396*	*3.56*	*14*	*831*
	Single Unit Truck	*5129.001217*	*4.56*	*42*	*982*
	Combination Truck	*3846.750913*	*7.91*	*50.4*	*1533*
	Total Reduced Speed DC	*25645.00609*			*3346*
2041	*Passenger Cars*	*16280.09254*	*3.56*	*14*	*812*
	Single Unit Truck	*5009.259243*	*4.56*	*42*	*959*
	Combination Truck	*3756.944432*	*7.91*	*50.4*	*1498*
	Total Reduced Speed DC	*25046.29621*			*3268*
2042	*Passenger Cars*	*18217.41582*	*3.56*	*14*	*909*
	Single Unit Truck	*5605.358712*	*4.56*	*42*	*1073*
	Combination Truck	*4204.019034*	*7.91*	*50.4*	*1676*
	Total Reduced Speed DC	*28026.79356*			*3657*
2043	*Passenger Cars*	*19775.80093*	*3.56*	*14*	*986*
	Single Unit Truck	*6084.861824*	*4.56*	*42*	*1164*
	Combination Truck	*4563.646368*	*7.91*	*50.4*	*1819*
	Total Reduced Speed DC	*30424.30912*			*3970*

Table 67: user cost component 6 – Idling VOC

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Idle VOC rates (ETB/1000 Veh-Hr)*	*Cost per day (ETB)*
2020	*Passenger Cars*	*0*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*0*	*0.000*	*1369.12*	*0*
	Combination Truck	*0*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*0*			*0*
2021	*Passenger Cars*	*0*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*0*	*0.000*	*1369.12*	*0*
	Combination Truck	*0*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*0*			*0*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Idle VOC rates (ETB/1000 Veh-Hr)*	*Cost per day (ETB)*
2022	*Passenger Cars*	*0*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*0*	*0.000*	*1369.12*	*0*
	Combination Truck	*0*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*0*			*0*
2023	*Passenger Cars*	*1000*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*308*	*0.000*	*1369.12*	*0*
	Combination Truck	*231*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*1,539*			*0*
2024	*Passenger Cars*	*1179*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*363*	*0.000*	*1369.12*	*0*
	Combination Truck	*272*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*1,814*			*0*
2025	*Passenger Cars*	*2,283*	*0.000*	*1234.72*	*0*
	Single Unit Truck	*702*	*0.000*	*1369.12*	*0*
	Combination Truck	*527*	*0.000*	*1470.26*	*0*
	Total Idling VOC	*3512*			*0*
2026	*Passenger Cars*	*2513*	*0.09*	*1234.72*	*275*
	Single Unit Truck	*773*	*0.09*	*1369.12*	*94*
	Combination Truck	*580*	*0.09*	*1470.26*	*76*
	Total Idling VOC	*3,866*			*445*
2027	*Passenger Cars*	*2,781*	*0.13*	*1234.72*	*438*
	Single Unit Truck	*856*	*0.13*	*1369.12*	*149*
	Combination Truck	*642*	*0.13*	*1470.26*	*120*
	Total Idling VOC	*4278*			*708*
2028	*Passenger Cars*	*3,202*	*0.19*	*1234.72*	*732*
	Single Unit Truck	*985*	*0.19*	*1369.12*	*250*
	Combination Truck	*739*	*0.19*	*1470.26*	*201*
	Total Idling VOC	*4926*			*1183*
2029	*Passenger Cars*	*4,181*	*0.26*	*1234.72*	*1341*
	Single Unit Truck	*1,286*	*0.26*	*1369.12*	*458*
	Combination Truck	*965*	*0.26*	*1470.26*	*369*
	Total Idling VOC	*6432*			*2168*
2030	*Passenger Cars*	*4616*	*0.36*	*1234.72*	*2024*
	Single Unit Truck	*1420*	*0.36*	*1369.12*	*690*
	Combination Truck	*1065*	*0.36*	*1470.26*	*556*
	Total Idling VOC	*7,102*			*3270*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Idle VOC rates (ETB/1000 Veh-Hr)*	*Cost per day (ETB)*
2031	*Passenger Cars*	*5054*	*0.48*	*1234.72*	*3024*
	Single Unit Truck	*1555*	*0.48*	*1369.12*	*1032*
	Combination Truck	*1166*	*0.48*	*1470.26*	*831*
	Total Idling VOC	*7775*			*4887*
2032	*Passenger Cars*	*7285*	*0.47*	*1234.72*	*4258*
	Single Unit Truck	*2241*	*0.47*	*1369.12*	*1453*
	Combination Truck	*1681*	*0.47*	*1470.26*	*1170*
	Total Idling VOC	*11,207*			*6881*
2033	*Passenger Cars*	*8355*	*0.52*	*1234.72*	*5379*
	Single Unit Truck	*2571*	*0.52*	*1369.12*	*1835*
	Combination Truck	*1928*	*0.52*	*1470.26*	*1478*
	Total Idling VOC	*12854*			*8692*
2034	*Passenger Cars*	*8,967*	*0.87*	*1234.72*	*9611*
	Single Unit Truck	*2,759*	*0.87*	*1369.12*	*3279*
	Combination Truck	*2,069*	*0.87*	*1470.26*	*2641*
	Total Idling VOC	*13795*			*15531*
2035	*Passenger Cars*	*9,646*	*1.17*	*1234.72*	*13984*
	Single Unit Truck	*2,968*	*1.17*	*1369.12*	*4771*
	Combination Truck	*2,226*	*1.17*	*1470.26*	*3843*
	Total Idling VOC	*14840*			*22597*
2036	*Passenger Cars*	*13285*	*0.40*	*1234.72*	*6598*
	Single Unit Truck	*4088*	*0.40*	*1369.12*	*2251*
	Combination Truck	*3066*	*0.40*	*1470.26*	*1813*
	Total Idling VOC	*20,438*			*10661*
2037	*Passenger Cars*	*14,375*	*0.68*	*1234.72*	*12010*
	Single Unit Truck	*4,423*	*0.68*	*1369.12*	*4098*
	Combination Truck	*3,317*	*0.68*	*1470.26*	*3300*
	Total Idling VOC	*22116*			*19408*
2038	*Passenger Cars*	*13238*	*0.55*	*1234.72*	*9019*
	Single Unit Truck	*4073*	*0.55*	*1234.72*	*2775*
	Combination Truck	*3055*	*0.55*	*1234.72*	*2081*
	Total Idling VOC	*20,366*			*13875*
2039	*Passenger Cars*	*14193*	*0.30*	*1234.72*	*5259*
	Single Unit Truck	*4367*	*0.30*	*1234.72*	*1618*
	Combination Truck	*3275*	*0.30*	*1234.72*	*1214*
	Total Idling VOC	*21,835*			*8091*

Years	Vehicle Class	Affected vehicles	Added time (Hours)	Idle VOC rates (ETB/1000 Veh-Hr)	Cost per day (ETB)
2040	Passenger Cars	16,669	0.95	1234.72	19523
	Single Unit Truck	5,129	0.95	1369.12	6661
	Combination Truck	3,847	0.95	1470.26	5365
	Total Idling VOC	25645			31549
2041	Passenger Cars	16280	1.12	1234.72	22581
	Single Unit Truck	5009	1.12	1369.12	7704
	Combination Truck	3757	1.12	1470.26	6205
	Total Idling VOC	25046			36490
2042	Passenger Cars	18218	1.50	1234.72	33720
	Single Unit Truck	5605	1.50	1234.72	10375
	Combination Truck	4204	1.50	1234.72	7781
	Total Idling VOC	28,027			51876
2043	Passenger Cars	19775.6	3.95	1234.72	96533
	Single Unit Truck	6084.8	3.95	1369.12	32935
	Combination Truck	4563.6	3.95	1470.26	26526
	Total Idling VOC	30424			155994

Table 68: user cost component 7 – Queue reduced speed delay cost

Years	Vehicle Class	Affected vehicles	Added time (Hours)	Delay cost rate (ETB/Veh- Hr)	Cost per day (ETB)
2020	Passenger Cars	0	0.000	14	0
	Single Unit Truck	0	0.000	42	0
	Combination Truck	0	0.000	50.4	0
	Total Queue RSDC	0			0
2021	Passenger Cars	0	0.000	14	0
	Single Unit Truck	0	0.000	42	0
	Combination Truck	0	0.000	50.4	0
	Total Queue RSDC	0			0
2022	Passenger Cars	0	0.000	14	0
	Single Unit Truck	0	0.000	42	0
	Combination Truck	0	0.000	50.4	0
	Total Queue RSDC	0			0
2023	Passenger Cars	1000	0.000	14	0
	Single Unit Truck	308	0.000	42	0
	Combination Truck	231	0.000	50.4	0
	Total Queue RSDC	1,539			0

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Delay cost rate (ETB/Veh- Hr)*	*Cost per day (ETB)*
2024	*Passenger Cars*	*1179*	*0.000*	*14*	*0*
	Single Unit Truck	*363*	*0.000*	*42*	*0*
	Combination Truck	*272*	*0.000*	*50.4*	*0*
	Total Queue RSDC	*1,814*			*0*
2025	*Passenger Cars*	*2,283*	*0.000*	*14*	*0*
	Single Unit Truck	*702*	*0.000*	*42*	*0*
	Combination Truck	*527*	*0.000*	*50.4*	*0*
	Total Queue RSDC	*3512*			*0*
2026	*Passenger Cars*	*2513*	*0.09*	*14*	*3*
	Single Unit Truck	*773*	*0.09*	*42*	*3*
	Combination Truck	*580*	*0.09*	*50.4*	*3*
	Total Queue RSDC	*3,866*			*9*
2027	*Passenger Cars*	*2,781*	*0.13*	*14*	*5*
	Single Unit Truck	*856*	*0.13*	*42*	*5*
	Combination Truck	*642*	*0.13*	*50.4*	*4*
	Total Queue RSDC	*4278*			*14*
2028	*Passenger Cars*	*3,202*	*0.19*	*14*	*8*
	Single Unit Truck	*985*	*0.19*	*42*	*8*
	Combination Truck	*739*	*0.19*	*50.4*	*7*
	Total Queue RSDC	*4926*			*23*
2029	*Passenger Cars*	*4,181*	*0.26*	*14*	*15*
	Single Unit Truck	*1,286*	*0.26*	*42*	*14*
	Combination Truck	*965*	*0.26*	*50.4*	*13*
	Total Queue RSDC	*6432*			*42*
2030	*Passenger Cars*	*4616*	*0.36*	*14*	*23*
	Single Unit Truck	*1420*	*0.36*	*42*	*21*
	Combination Truck	*1065*	*0.36*	*50.4*	*19*
	Total Queue RSDC	*7,102*			*63*
2031	*Passenger Cars*	*5054*	*0.485*	*14*	*34*
	Single Unit Truck	*1555*	*0.485*	*42*	*32*
	Combination Truck	*1166*	*0.485*	*50.4*	*28*
	Total Queue RSDC	*7775*			*94*
2032	*Passenger Cars*	*7285*	*0.47*	*14*	*48*
	Single Unit Truck	*2241*	*0.47*	*42*	*45*
	Combination Truck	*1681*	*0.47*	*50.4*	*40*
	Total Queue RSDC	*11,207*			*133*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Delay cost rate (ETB/Veh- Hr)*	*Cost per day (ETB)*
2033	*Passenger Cars*	*8355*	*0.521*	*14*	*61*
	Single Unit Truck	*2571*	*0.521*	*42*	*56*
	Combination Truck	*1928*	*0.521*	*50.4*	*51*
	Total Queue RSDC	*12854*			*168*
2034	*Passenger Cars*	*8,967*	*0.87*	*14*	*109*
	Single Unit Truck	*2,759*	*0.87*	*42*	*101*
	Combination Truck	*2,069*	*0.87*	*50.4*	*91*
	Total Queue RSDC	*13795*			*300*
2035	*Passenger Cars*	*9,646*	*1.17*	*14*	*159*
	Single Unit Truck	*2,968*	*1.17*	*42*	*146*
	Combination Truck	*2,226*	*1.17*	*50.4*	*132*
	Total Queue RSDC	*14840*			*437*
2036	*Passenger Cars*	*13285*	*0.40*	*14*	*75*
	Single Unit Truck	*4088*	*0.40*	*42*	*69*
	Combination Truck	*3066*	*0.40*	*50.4*	*62*
	Total Queue RSDC	*20,438*			*206*
2037	*Passenger Cars*	*14,375*	*0.68*	*14*	*136*
	Single Unit Truck	*4,423*	*0.68*	*42*	*126*
	Combination Truck	*3,317*	*0.68*	*50.4*	*113*
	Total Queue RSDC	*22116*			*375*
2038	*Passenger Cars*	*13238*	*0.55*	*14*	*102*
	Single Unit Truck	*4073*	*0.55*	*42*	*94*
	Combination Truck	*3055*	*0.55*	*50.4*	*85*
	Total Queue RSDC	*20,366*			*282*
2039	*Passenger Cars*	*14193*	*0.30*	*14*	*60*
	Single Unit Truck	*4367*	*0.30*	*42*	*55*
	Combination Truck	*3275*	*0.30*	*50.4*	*50*
	Total Queue RSDC	*21,835*			*164*
2040	*Passenger Cars*	*16,669*	*0.95*	*14*	*221*
	Single Unit Truck	*5,129*	*0.95*	*42*	*204*
	Combination Truck	*3,847*	*0.95*	*50.4*	*184*
	Total Queue RSDC	*25645*			*610*
2041	*Passenger Cars*	*16280*	*1.123*	*14*	*256*
	Single Unit Truck	*5009*	*1.123*	*42*	*236*
	Combination Truck	*3757*	*1.123*	*50.4*	*213*
	Total Queue RSDC	*25046*			*705*

Years	*Vehicle Class*	*Affected vehicles*	*Added time (Hours)*	*Delay cost rate (ETB/Veh- Hr)*	*Cost per day (ETB)*
2042	*Passenger Cars*	*18218*	*1.50*	*14*	*382*
	Single Unit Truck	*5605*	*1.50*	*42*	*353*
	Combination Truck	*4204*	*1.50*	*50.4*	*318*
	Total Queue RSDC	*28,027*			*1053*
2043	*Passenger Cars*	*19775.6*	*3.95*	*14*	*1095*
	Single Unit Truck	*6084.8*	*3.95*	*42*	*1010*
	Combination Truck	*4563.6*	*3.95*	*50.4*	*909*
	Total Queue RSDC	*30424*			*3014*

Step 11. Total Work Zone User Costs

Table 69: Master summary of present user cost components during routine maintenance for CFP

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2021	*Speed Change VOC*	*236.969*	*160.676*	*522.826*	*920.471*
	Speed Change Delay Cost	*125.723*	*175.597*	*302.871*	*604.191*
	Work Zone Reduced Speed Delay	*0.000*	*0.000*	*0.000*	*0.000*
	Stopping VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Stopping Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	*362.692*	*336.273*	*825.698*	*1524.662*
2023	*Speed Change VOC*	*229.437*	*155.568*	*506.207*	*891.212*
	Speed Change Delay Cost	*121.726*	*170.015*	*293.244*	*584.986*
	Work Zone Reduced Speed Delay	*49.897*	*58.904*	*92.023*	*200.824*
	Stopping VOC	*67.413*	*45.978*	*141.727*	*255.117*
	Stopping Delay Cost	*49.897*	*58.904*	*92.023*	*200.824*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	*518.370*	*489.369*	*1125.223*	*2132.962*
2024	*Speed Change VOC*	*236.800*	*160.561*	*522.452*	*919.813*
	Speed Change Delay Cost	*125.633*	*175.471*	*302.655*	*603.759*
	Work Zone Reduced Speed Delay	*58.813*	*69.429*	*108.466*	*236.708*
	Stopping VOC	*79.458*	*54.194*	*167.051*	*300.704*
	Stopping Delay Cost	*58.813*	*69.429*	*108.466*	*236.708*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	*559.518*	*529.084*	*1209.091*	*2297.693*

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2026	*Speed Change VOC*	*222.466*	*150.842*	*490.829*	*864.137*
	Speed Change Delay Cost	*118.028*	*164.850*	*284.335*	*567.214*
	Work Zone Reduced Speed Delay	*125.343*	*147.967*	*231.164*	*504.474*
	Stopping VOC	*169.342*	*115.498*	*356.020*	*640.860*
	Stopping Delay Cost	*125.343*	*147.967*	*231.164*	*504.474*
	Idling VOC	*412.722*	*140.815*	*113.413*	*666.949*
	Queue Reduced Speed Delay Cost	*4.680*	*4.320*	*3.888*	*12.887*
	Total	*1177.925*	*872.259*	*1710.811*	*3760.995*
2029	*Speed Change VOC*	*217.089*	*147.196*	*478.964*	*843.249*
	Speed Change Delay Cost	*115.175*	*160.865*	*277.462*	*553.503*
	Work Zone Reduced Speed Delay	*208.538*	*246.178*	*384.595*	*839.310*
	Stopping VOC	*281.740*	*192.158*	*592.323*	*1066.222*
	Stopping Delay Cost	*208.538*	*246.178*	*384.595*	*839.310*
	Idling VOC	*731.900*	*249.713*	*201.120*	*1182.733*
	Queue Reduced Speed Delay Cost	*15.210*	*14.040*	*12.636*	*41.887*
	Total	*1778.190*	*1256.329*	*2331.696*	*5366.214*
2030	*Speed Change VOC*	*220.729*	*149.664*	*486.995*	*857.388*
	Speed Change Delay Cost	*117.107*	*163.563*	*282.115*	*562.784*
	Work Zone Reduced Speed Delay	*230.260*	*271.821*	*424.657*	*926.739*
	Stopping VOC	*311.088*	*212.175*	*654.024*	*1177.287*
	Stopping Delay Cost	*230.260*	*271.821*	*424.657*	*926.739*
	Idling VOC	*1820.029*	*620.966*	*500.129*	*2941.124*
	Queue Reduced Speed Delay Cost	*20.637*	*19.049*	*17.144*	*56.830*
	Total	*2950.110*	*1709.060*	*2789.721*	*7448.890*
2032	*Speed Change VOC*	*173.489*	*117.633*	*382.770*	*673.892*
	Speed Change Delay Cost	*92.044*	*128.557*	*221.737*	*442.338*
	Work Zone Reduced Speed Delay	*363.352*	*428.935*	*670.111*	*1462.399*
	Stopping VOC	*490.899*	*334.813*	*1032.053*	*1857.765*
	Stopping Delay Cost	*363.352*	*428.935*	*670.111*	*1462.399*
	Idling VOC	*4658.371*	*1589.366*	*1280.082*	*7527.818*
	Queue Reduced Speed Delay Cost	*52.819*	*48.756*	*43.881*	*145.457*
	Total	*6194.327*	*3076.997*	*4300.745*	*13572.069*
2033	*Speed Change VOC*	*159.877*	*108.404*	*352.737*	*621.018*
	Speed Change Delay Cost	*84.822*	*118.471*	*204.339*	*407.632*
	Work Zone Reduced Speed Delay	*416.738*	*491.957*	*768.567*	*1677.262*
	Stopping VOC	*563.024*	*384.006*	*1183.688*	*2130.718*
	Stopping Delay Cost	*416.738*	*491.957*	*768.567*	*1677.262*
	Idling VOC	*5378.970*	*1835.223*	*1478.096*	*8692.290*

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
	Queue Reduced Speed Delay Cost	*60.990*	*56.299*	*50.669*	*167.957*
	Total	*7081.159*	*3486.316*	*4806.664*	*15374.140*
2036	*Speed Change VOC*	*69.909*	*47.401*	*154.240*	*271.549*
	Speed Change Delay Cost	*37.090*	*51.803*	*89.350*	*178.243*
	Work Zone Reduced Speed Delay	*662.639*	*782.242*	*1222.069*	*2666.950*
	Stopping VOC	*895.243*	*610.593*	*1882.137*	*3387.973*
	Stopping Delay Cost	*662.639*	*782.242*	*1222.069*	*2666.950*
	Idling VOC	*26069.025*	*8894.358*	*7163.552*	*42126.936*
	Queue Reduced Speed Delay Cost	*295.587*	*272.849*	*245.564*	*814.000*
	Total	*28692.131*	*11441.488*	*11978.982*	*52112.602*
2038	*Speed Change VOC*	*121.906*	*82.657*	*268.961*	*473.524*
	Speed Change Delay Cost	*64.676*	*90.334*	*155.808*	*310.818*
	Work Zone Reduced Speed Delay	*660.305*	*779.486*	*1217.764*	*2657.555*
	Stopping VOC	*892.089*	*608.442*	*1875.506*	*3376.037*
	Stopping Delay Cost	*660.305*	*779.486*	*1217.764*	*2657.555*
	Idling VOC	*8912.109*	*2742.187*	*2056.641*	*13710.937*
	Queue Reduced Speed Delay Cost	*101.051*	*93.278*	*83.950*	*278.279*
	Total	*11412.441*	*5175.870*	*6876.395*	*23464.706*
2039	*Speed Change VOC*	*118.679*	*80.470*	*261.842*	*460.991*
	Speed Change Delay Cost	*62.965*	*87.943*	*151.684*	*302.592*
	Work Zone Reduced Speed Delay	*707.933*	*835.710*	*1305.602*	*2849.245*
	Stopping VOC	*956.436*	*652.329*	*2010.787*	*3619.551*
	Stopping Delay Cost	*707.933*	*835.710*	*1305.602*	*2849.245*
	Idling VOC	*2649.091*	*815.105*	*611.329*	*4075.525*
	Queue Reduced Speed Delay Cost	*30.037*	*27.726*	*24.954*	*82.717*
	Total	*5233.073*	*3334.993*	*5671.799*	*14239.865*
2041	*Speed Change VOC*	*110.710*	*75.067*	*244.261*	*430.038*
	Speed Change Delay Cost	*58.737*	*82.038*	*141.499*	*282.274*
	Work Zone Reduced Speed Delay	*812.049*	*958.619*	*1497.618*	*3268.286*
	Stopping VOC	*1097.100*	*748.267*	*2306.515*	*4151.882*
	Stopping Delay Cost	*812.049*	*958.619*	*1497.618*	*3268.286*
	Idling VOC	*22580.548*	*7704.143*	*6204.948*	*36489.638*
	Queue Reduced Speed Delay Cost	*256.032*	*236.337*	*212.704*	*705.073*
	Total	*25727.225*	*10763.090*	*12105.163*	*48595.478*
2042	*Speed Change VOC*	*80.498*	*54.581*	*177.604*	*312.683*
	Speed Change Delay Cost	*42.708*	*59.650*	*102.885*	*205.243*
	Work Zone Reduced Speed Delay	*908.689*	*1072.702*	*1675.846*	*3657.237*
	Stopping VOC	*1227.663*	*837.317*	*2581.008*	*4645.988*

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
	Stopping Delay Cost	*908.689*	*1072.702*	*1675.846*	*3657.237*
	Idling VOC	*32.547*	*10.015*	*7.511*	*50.073*
	Queue Reduced Speed Delay Cost	*382.333*	*352.923*	*317.631*	*1052.887*
	Total	*3583.128*	*3459.891*	*6538.331*	*13581.350*

Table 70: Grand summary of user cost components during routine maintenance for conventional FP.

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV = e*b*
	a	***b***	***c***	***d***	***e***	***f***
2021	*Speed Change VOC*	*920.471*	***2***	*1.274*	*1.624019*	*1494.862269*
	Speed Change Delay Cost	*604.191*	***2***	*1.274*	*1.624*	*981.218*
	Work Zone Reduced Speed Delay	*0.000*	***2***	*1.274*	*1.624*	*0.000*
	Stopping VOC	*0.000*	***2***	*1.274*	*1.624*	*0.000*
	Stopping Delay Cost	*0.000*	***2***	*1.274*	*1.624*	*0.000*
	Idling VOC	*0.000*	***2***	*1.274*	*1.624*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	***2***	*1.274*	*1.624*	*0.000*
	Total	***1524.662***	***2***	***1.274***	***1.624***	***2476.080***
2023	*Speed Change VOC*	*891.212*	*4*	*1.274*	*2.637*	*2350.515*
	Speed Change Delay Cost	*584.986*	*4*	*1.274*	*2.637*	*1542.863*
	Work Zone Reduced Speed Delay	*200.824*	*4*	*1.274*	*2.637*	*529.660*
	Stopping VOC	*255.117*	*4*	*1.274*	*2.637*	*672.856*
	Stopping Delay Cost	*200.824*	*4*	*1.274*	*2.637*	*529.660*
	Idling VOC	*0.000*	*4*	*1.274*	*2.637*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*4*	*1.274*	*2.637*	*0.000*
	Total	***2132.962***	***4***	***1.274***	***2.637***	***5625.555***
2024	*Speed Change VOC*	*919.813*	*5*	*1.274*	*3.361*	*3091.556*
	Speed Change Delay Cost	*603.759*	*5*	*1.274*	*3.361*	*2029.278*
	Work Zone Reduced Speed Delay	*236.708*	*5*	*1.274*	*3.361*	*795.594*
	Stopping VOC	*300.704*	*5*	*1.274*	*3.361*	*1010.687*
	Stopping Delay Cost	*236.708*	*5*	*1.274*	*3.361*	*795.594*
	Idling VOC	*0.000*	*5*	*1.274*	*3.361*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*5*	*1.274*	*3.361*	*0.000*
	Total	***2297.693***	***5***	***1.274***	***3.361***	***7722.708***
2026	*Speed Change VOC*	*864.137*	*7*	*1.274*	*5.458*	*4716.843*
	Speed Change Delay Cost	*567.214*	*7*	*1.274*	*5.458*	*3096.106*
	Work Zone Reduced Speed Delay	*504.474*	*7*	*1.274*	*5.458*	*2753.640*
	Stopping VOC	*640.860*	*7*	*1.274*	*5.458*	*3498.099*
	Stopping Delay Cost	*504.474*	*7*	*1.274*	*5.458*	*2753.640*

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV = e*b*
	a	***b***	***c***	***d***	***e***	***f***
	Idling VOC	*666.949*	*7*	*1.274*	*5.458*	*3640.503*
	Queue Reduced Speed Delay Cost	*12.887*	*7*	*1.274*	*5.458*	*70.344*
	Total	***3760.995***	***7***	***1.274***	***5.458***	***20529.175***
2029	*Speed Change VOC*	*843.249*	*10*	*1.274*	*11.297*	*9526.010*
	Speed Change Delay Cost	*553.503*	*10*	*1.274*	*11.297*	*6252.813*
	Work Zone Reduced Speed Delay	*839.310*	*10*	*1.274*	*11.297*	*9481.520*
	Stopping VOC	*1066.222*	*10*	*1.274*	*11.297*	*12044.892*
	Stopping Delay Cost	*839.310*	*10*	*1.274*	*11.297*	*9481.520*
	Idling VOC	*1182.733*	*10*	*1.274*	*11.297*	*13361.097*
	Queue Reduced Speed Delay Cost	*41.887*	*10*	*1.274*	*11.297*	*473.187*
	Total	***5366.214***	***10***	***1.274***	***11.297***	***60621.041***
2030	*Speed Change VOC*	*857.388*	*11*	*1.274*	*14.396*	*12343.223*
	Speed Change Delay Cost	*562.784*	*11*	*1.274*	*14.396*	*8102.014*
	Work Zone Reduced Speed Delay	*926.739*	*11*	*1.274*	*14.396*	*13341.607*
	Stopping VOC	*1177.287*	*11*	*1.274*	*14.396*	*16948.571*
	Stopping Delay Cost	*926.739*	*11*	*1.274*	*14.396*	*13341.607*
	Idling VOC	*2941.124*	*11*	*1.274*	*14.396*	*42341.302*
	Queue Reduced Speed Delay Cost	*56.830*	*11*	*1.274*	*14.396*	*818.142*
	Total	***7448.890***	***11***	***1.274***	***14.396***	***107236.467***
2032	*Speed Change VOC*	*673.892*	*13*	*1.274*	*23.380*	*15755.502*
	Speed Change Delay Cost	*442.338*	*13*	*1.274*	*23.380*	*10341.813*
	Work Zone Reduced Speed Delay	*1462.399*	*13*	*1.274*	*23.380*	*34190.695*
	Stopping VOC	*1857.765*	*13*	*1.274*	*23.380*	*43434.305*
	Stopping Delay Cost	*1462.399*	*13*	*1.274*	*23.380*	*34190.695*
	Idling VOC	*7527.818*	*13*	*1.274*	*23.380*	*175999.381*
	Queue Reduced Speed Delay Cost	*145.457*	*13*	*1.274*	*23.380*	*3400.759*
	Total	***13572.069***	***13***	***1.274***	***23.380***	***317313.151***
2033	*Speed Change VOC*	*621.018*	*14*	*1.274*	*29.795*	*18502.973*
	Speed Change Delay Cost	*407.632*	*14*	*1.274*	*29.795*	*12145.235*
	Work Zone Reduced Speed Delay	*1677.262*	*14*	*1.274*	*29.795*	*49973.361*
	Stopping VOC	*2130.718*	*14*	*1.274*	*29.795*	*63483.887*
	Stopping Delay Cost	*1677.262*	*14*	*1.274*	*29.795*	*49973.361*
	Idling VOC	*8692.290*	*14*	*1.274*	*29.795*	*258983.294*
	Queue Reduced Speed Delay Cost	*167.957*	*14*	*1.274*	*29.795*	*5004.220*
	Total	***15374.140***	*14*	***1.274***	***29.795***	***458066.330***
2036	*Speed Change VOC*	*271.549*	*17*	*1.274*	*61.663*	*16744.520*

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV = e*b*
	a	***b***	***c***	***d***	***e***	***f***
	Speed Change Delay Cost	*178.243*	*17*	*1.274*	*61.663*	*10990.997*
	Work Zone Reduced Speed Delay	*2666.950*	*17*	*1.274*	*61.663*	*164451.981*
	Stopping VOC	*3387.973*	*17*	*1.274*	*61.663*	*208912.324*
	Stopping Delay Cost	*2666.950*	*17*	*1.274*	*61.663*	*164451.981*
	Idling VOC	*42126.936*	*17*	*1.274*	*61.663*	*2597670.348*
	Queue Reduced Speed Delay Cost	*814.000*	*17*	*1.274*	*61.663*	*50193.642*
	Total	***52112.602***	***17***	***1.274***	***61.663***	***3213415.793***
2038	*Speed Change VOC*	*473.524*	*19*	*1.274*	*100.142*	*47419.525*
	Speed Change Delay Cost	*310.818*	*19*	*1.274*	*100.142*	*31125.878*
	Work Zone Reduced Speed Delay	*2657.555*	*19*	*1.274*	*100.142*	*266132.266*
	Stopping VOC	*3376.037*	*19*	*1.274*	*100.142*	*338082.339*
	Stopping Delay Cost	*2657.555*	*19*	*1.274*	*100.142*	*266132.266*
	Idling VOC	*13710.937*	*19*	*1.274*	*100.142*	*1373037.451*
	Queue Reduced Speed Delay Cost	*278.279*	*19*	*1.274*	*100.142*	*27867.339*
	Total	***23464.706***	***19***	***1.274***	***100.142***	***2349797.064***
2039	*Speed Change VOC*	*460.991*	*20*	*1.274*	*127.618*	*58830.583*
	Speed Change Delay Cost	*302.592*	*20*	*1.274*	*127.618*	*38616.025*
	Work Zone Reduced Speed Delay	*2849.245*	*20*	*1.274*	*127.618*	*363613.943*
	Stopping VOC	*3619.551*	*20*	*1.274*	*127.618*	*461918.632*
	Stopping Delay Cost	*2849.245*	*20*	*1.274*	*127.618*	*363613.943*
	Idling VOC	*4075.525*	*20*	*1.274*	*127.618*	*520108.983*
	Queue Reduced Speed Delay Cost	*82.717*	*20*	*1.274*	*127.618*	*10556.197*
	Total	***14239.865***	***20***	***1.274***	***127.618***	***1817258.305***
041	*Speed Change VOC*	*430.038*	*22*	*1.274*	*207.253*	*89126.849*
	Speed Change Delay Cost	*282.274*	*22*	*1.274*	*207.253*	*58502.303*
	Work Zone Reduced Speed Delay	*3268.286*	*22*	*1.274*	*207.253*	*677363.705*
	Stopping VOC	*4151.882*	*22*	*1.274*	*207.253*	*860492.075*
	Stopping Delay Cost	*3268.286*	*22*	*1.274*	*207.253*	*677363.705*
	Idling VOC	*36489.638*	*22*	*1.274*	*207.253*	*7562605.086*
	Queue Reduced Speed Delay Cost	*705.073*	*22*	*1.274*	*207.253*	*146128.893*
	Total	***48595.478***	***22***	***1.274***	***207.253***	***10071582.616***
2042	*Speed Change VOC*	*312.683*	*23*	*1.274*	*264.118*	*82585.169*
	Speed Change Delay Cost	*205.243*	*23*	*1.274*	*264.118*	*54208.385*
	Work Zone Reduced Speed Delay	*3657.237*	*23*	*1.274*	*264.118*	*965940.916*
	Stopping VOC	*4645.988*	*23*	*1.274*	*264.118*	*1227087.451*
	Stopping Delay Cost	*3657.237*	*23*	*1.274*	*264.118*	*965940.916*
	Idling VOC	*50.073*	*23*	*1.274*	*264.118*	*13225.031*

	Queue Reduced Speed Delay Cost	*1052.887*	*23*	*1.274*	*264.118*	*278086.078*
	Total	***13581.350***	***23***	***1.274***	***264.118***	***3587073.945***
	Grand Total (ETB)					***22,018,718.23***

Appendix C.1.1.2 Work zone operation user cost for CFP during periodic maintenance

Table 71 : Master summary of user cost components during periodic maintenance for CFP.

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2022	*Speed Change VOC*	*248.816*	*168.709*	*548.965*	*966.490*
	Speed Change Delay Cost	*132.008*	*184.376*	*318.014*	*634.398*
	Work Zone Reduced Speed Delay	*0.000*	*0.000*	*0.000*	*0.000*
	Stopping VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Stopping Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	***380.825***	***353.085***	***866.979***	***1600.888***
2025	*Speed Change VOC*	*215.455*	*146.088*	*475.359*	*836.902*
	Speed Change Delay Cost	*114.309*	*159.655*	*275.374*	*549.337*
	Work Zone Reduced Speed Delay	*113.866*	*134.418*	*209.996*	*458.280*
	Stopping VOC	*153.836*	*104.922*	*323.420*	*582.178*
	Stopping Delay Cost	*113.866*	*134.418*	*209.996*	*458.280*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	***711.331***	***679.501***	***1494.146***	***2884.977***
2028	*Speed Change VOC*	*237.855*	*161.276*	*524.780*	*923.910*
	Speed Change Delay Cost	*126.193*	*176.253*	*304.003*	*606.449*
	Work Zone Reduced Speed Delay	*159.710*	*188.537*	*294.545*	*642.793*
	Stopping VOC	*215.773*	*147.166*	*453.636*	*816.575*
	Stopping Delay Cost	*159.710*	*188.537*	*294.545*	*642.793*
	Idling VOC	*731.900*	*249.713*	*201.120*	*1182.733*
	Queue Reduced Speed Delay Cost	*8.299*	*7.660*	*6.894*	*22.853*
	Total	***1639.439***	***1119.143***	***2079.523***	***4838.105***
2031	*Speed Change VOC*	*225.184*	*152.685*	*496.824*	*874.692*
	Speed Change Delay Cost	*119.470*	*166.864*	*287.808*	*574.142*
	Work Zone Reduced Speed Delay	*252.075*	*297.574*	*464.889*	*1014.538*
	Stopping VOC	*340.560*	*232.276*	*715.986*	*1288.823*
	Stopping Delay Cost	*252.075*	*297.574*	*464.889*	*1014.538*
	Idling VOC	*3024.029*	*1031.753*	*830.978*	*4886.760*
	Queue Reduced Speed Delay Cost	*34.288*	*31.651*	*28.486*	*94.425*
	Total	***4247.682***	***2210.376***	***3289.860***	***9747.917***

2034	*Speed Change VOC*	*168.111*	*113.987*	*370.905*	*653.004*
	Speed Change Delay Cost	*89.191*	*124.573*	*214.864*	*428.627*
	Work Zone Reduced Speed Delay	*447.260*	*527.988*	*824.858*	*1800.107*
	Stopping VOC	*604.261*	*412.131*	*1270.383*	*2286.774*
	Stopping Delay Cost	*447.260*	*527.988*	*824.858*	*1800.107*
	Idling VOC	*9610.678*	*3279.018*	*2640.935*	*15530.631*
	Queue Reduced Speed Delay Cost	*108.972*	*100.589*	*90.530*	*300.092*
	Total	***11475.73***	***5086.275***	***6237.333***	***22799.341***
2037	*Speed Change VOC*	*59.836*	*40.571*	*132.016*	*232.424*
	Speed Change Delay Cost	*31.746*	*44.339*	*76.477*	*152.561*
	Work Zone Reduced Speed Delay	*717.043*	*846.465*	*1322.404*	*2885.912*
	Stopping VOC	*968.744*	*660.724*	*2036.664*	*3666.132*
	Stopping Delay Cost	*717.043*	*846.465*	*1322.404*	*2885.912*
	Idling VOC	*7170.432*	*8464.654*	*13224.037*	*28859.123*
	Queue Reduced Speed Delay Cost	*136.176*	*125.701*	*113.130*	*375.007*
	Total	***9801.020***	***11028.919***	***18227.132***	***39057.071***
2040	*Speed Change VOC*	*68.378*	*46.363*	*150.863*	*265.604*
	Speed Change Delay Cost	*36.278*	*50.669*	*87.394*	*174.341*
	Work Zone Reduced Speed Delay	*831.460*	*981.534*	*1533.417*	*3346.411*
	Stopping VOC	*1123.324*	*766.154*	*2361.650*	*4251.128*
	Stopping Delay Cost	*831.460*	*981.534*	*1533.417*	*3346.411*
	Idling VOC	*19523.175*	*6661.013*	*5364.807*	*31548.995*
	Queue Reduced Speed Delay Cost	*221.366*	*204.338*	*183.904*	*609.607*
	Total	***22635.44***	***9691.605***	***11215.451***	***43542.497***

Table 72: Grand summary of user cost components during periodic maintenance for CFP.

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV= b*e*
	A	*b*	*c*	*d*	*e*	*f*
2022	*Speed Change VOC*	*966.490*	*3*	*1.27437*	*2.069601*	*2000.249047*
	Speed Change Delay Cost	*634.398*	*3*	*1.27437*	*2.069601*	*1312.950894*
	Work Zone Reduced Speed Delay	*0.000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Stopping VOC	*0.000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Stopping Delay Cost	*0.000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Idling VOC	*0.000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Queue Reduced Speed Delay Cost	*0.000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Total	***1600.888***	***3***	***1.27437***	***2.0696***	***3313.199941***
2025	*Speed Change VOC*	*836.902*	*6*	*1.27437*	*4.283248*	*3584.657993*
	Speed Change Delay Cost	*549.337*	*6*	*1.27437*	*4.283248*	*2352.94696*
	Work Zone Reduced Speed Delay	*458.280*	*6*	*1.27437*	*4.283248*	*1962.92764*

	Stopping VOC	*582.178*	*6*	*1.27437*	*4.283248*	*2493.614087*
	Stopping Delay Cost	*458.280*	*6*	*1.27437*	*4.283248*	*1962.92764*
	Idling VOC	*0.000*	*6*	*1.27437*	*4.283248*	*0.000000*
	Queue Reduced Speed Delay Cost	*0.000*	*6*	*1.27437*	*4.283248*	*0.000000*
	Total	***2884.977***	***6***	***1.27437***	***4.28325***	***12357.07432***
2028	*Speed Change VOC*	*923.910*	*9*	*1.27437*	*8.864614*	*8190.105955*
	Speed Change Delay Cost	*606.449*	*9*	*1.27437*	*8.864614*	*5375.934037*
	Work Zone Reduced Speed Delay	*642.793*	*9*	*1.27437*	*8.864614*	*5698.109728*
	Stopping VOC	*816.575*	*9*	*1.27437*	*8.864614*	*7238.619701*
	Stopping Delay Cost	*642.793*	*9*	*1.27437*	*8.864614*	*5698.109728*
	Idling VOC	*1182.733*	*9*	*1.27437*	*8.864614*	*10484.47218*
	Queue Reduced Speed Delay Cost	*22.853*	*9*	*1.27437*	*8.864614*	*202.5868461*
	Total	***4838.105***	***9***	***1.27437***	***8.86461***	***42887.93818***
2031	*Speed Change VOC*	*874.692*	*12*	*1.27437*	*18.34621*	*16047.28935*
	Speed Change Delay Cost	*574.142*	*12*	*1.27437*	*18.34621*	*10533.3398*
	Work Zone Reduced Speed Delay	*1014.538*	*12*	*1.27437*	*18.34621*	*18612.92676*
	Stopping VOC	*1288.823*	*12*	*1.27437*	*18.34621*	*23645.01647*
	Stopping Delay Cost	*1014.538*	*12*	*1.27437*	*18.34621*	*18612.92676*
	Idling VOC	*4886.760*	*12*	*1.27437*	*18.34621*	*89653.54554*
	Queue Reduced Speed Delay Cost	*94.425*	*12*	*1.27437*	*18.34621*	*1732.336041*
	Total	***9747.917***	***12***	***1.27437***	***18.3462***	***178837.3807***
2034	*Speed Change VOC*	*653.004*	*15*	*1.27437*	*37.96934*	*24794.11492*
	Speed Change Delay Cost	*428.627*	*15*	*1.27437*	*37.96934*	*16274.70109*
	Work Zone Reduced Speed Delay	*1800.107*	*15*	*1.27437*	*37.96934*	*68348.87025*
	Stopping VOC	*2286.774*	*15*	*1.27437*	*37.96934*	*86827.2993*
	Stopping Delay Cost	*1800.107*	*15*	*1.27437*	*37.96934*	*68348.87025*
	Idling VOC	*15530.631*	*15*	*1.27437*	*37.96934*	*589687.8759*
	Queue Reduced Speed Delay Cost	*300.092*	*15*	*1.27437*	*37.96934*	*11394.27955*
	Total	***22799.341***	***15***	***1.27437***	***37.9693***	***865676.0112***
2037	*Speed Change VOC*	*232.424*	*18*	*1.27437*	*78.58139*	*18264.17106*
	Speed Change Delay Cost	*152.561*	*18*	*1.27437*	*78.58139*	*11988.48701*
	Work Zone Reduced Speed Delay	*2885.912*	*18*	*1.27437*	*78.58139*	*226778.9992*
	Stopping VOC	*3666.132*	*18*	*1.27437*	*78.58139*	*288089.7368*
	Stopping Delay Cost	*2885.912*	*18*	*1.27437*	*78.58139*	*226778.9992*
	Idling VOC	*28859.123*	*18*	*1.27437*	*78.58139*	*2267789.992*
	Queue Reduced Speed Delay Cost	*375.007*	*18*	*1.27437*	*78.58139*	*29468.5411*
	Total	***39057.071***	***18***	***1.27437***	***78.5814***	***3069158.927***
2040	*Speed Change VOC*	*265.604*	*21*	*1.27437*	*162.6321*	*43195.74803*
	Speed Change Delay Cost	*174.341*	*21*	*1.27437*	*162.6321*	*28353.41732*
	Work Zone Reduced Speed Delay	*3346.411*	*21*	*1.27437*	*162.6321*	*544233.8797*

	Stopping VOC	*4251.128*	*21*	*1.27437*	*162.6321*	*691369.9932*
	Stopping Delay Cost	*3346.411*	*21*	*1.27437*	*162.6321*	*544233.8797*
	Idling VOC	*31548.995*	*21*	*1.27437*	*162.6321*	*5130879.911*
	Queue Reduced Speed Delay Cost	*609.607*	*21*	*1.27437*	*162.6321*	*99141.73653*
	Total	***43542.497***	***21***	***1.27437***	***162.632***	***7081408.566***
	Total (ETB)					***11,253,639.10***

Appendix C.1.1.3 Work zone operation user cost for conventional flexible pavement during rehabilitation

Table 73: Master summary of user cost components during rehabilitation for CFP.

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2027	*Speed Change VOC*	*229.084908*	*155.329824*	*505.431108*	*889.8458*
	Speed Change Delay Cost	*121.539938*	*169.754724*	*292.7945506*	*584.0892*
	Work Zone Reduced Speed Delay	*138.700984*	*163.7357062*	*255.7986516*	*558.2353*
	Stopping VOC	*187.388653*	*127.8068313*	*393.9613305*	*709.1568*
	Stopping Delay Cost	*138.700984*	*163.7357062*	*255.7986516*	*558.2353*
	Idling VOC	*437.829509*	*149.3808298*	*120.3119276*	*707.5223*
	Queue Reduced Speed Delay Cost	*4.96438105*	*4.582505587*	*4.124255029*	*13.6711*
	Total	***1258.20936***	***934.3261272***	***1828.220475***	*4020.7560*
2035	*Speed Change VOC*	*162.237452*	*110.004256*	*357.945252*	*630.1870*
	Speed Change Delay Cost	*86.0743295*	*120.21994*	*207.3564875*	*413.6508*
	Work Zone Reduced Speed Delay	*481.141329*	*567.9845443*	*887.3426811*	*1936.4686*
	Stopping VOC	*650.034504*	*443.3504855*	*1366.616677*	*2460.0017*
	Stopping Delay Cost	*481.141329*	*567.9845443*	*887.3426811*	*1936.4686*
	Idling VOC	*13983.546*	*4770.975124*	*3842.562761*	*22597.0838*
	Queue Reduced Speed Delay Cost	*158.55407*	*146.3576029*	*131.7218426*	*436.6335*
	Total	***16002.729***	***6726.876497***	***7680.888382***	*30410.4938*
2043	*Speed Change VOC*	*63.9104700*	*43.33416000*	*141.0059700*	*248.2506*
	Speed Change Delay Cost	*33.9074041*	*47.35844143*	*81.68428687*	*162.9501*
	Work Zone Reduced Speed Delay	*986.404568*	*1164.444864*	*1819.172084*	*3970.0215*
	Stopping VOC	*1332.65834*	*908.928246*	*2801.748368*	*5043.3350*
	Stopping Delay Cost	*986.404568*	*1164.444864*	*1819.172084*	*3970.0215*
	Idling VOC	*96532.5671*	*32935.45697*	*26526.35094*	*155994.375*
	Queue Reduced Speed Delay Cost	*1094.54579*	*1010.349961*	*909.3149653*	*3014.2107*
	Total	***101030.398***	***37274.31751***	***34098.4487***	*172403.164*

Table 74: Grand summary of user cost components during rehabilitation for CFP.

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV = b*e*
	A	***b***	***c***	***d***	***e***	***f***
2027	*Speed Change VOC*	*889.8458*	*8*	*1.27437*	*6.956076*	*6189.83522*

	Speed Change Delay Cost	*584.0892*	*8*	*1.27437*	*6.956076*	*4062.968907*
	Work Zone Reduced Speed Delay	*558.2353*	*8*	*1.27437*	*6.956076*	*3883.127421*
	Stopping VOC	*709.1568*	*8*	*1.27437*	*6.956076*	*4932.948643*
	Stopping Delay Cost	*558.2353*	*8*	*1.27437*	*6.956076*	*3883.127421*
	Idling VOC	*707.5223*	*8*	*1.27437*	*6.956076*	*4921.578602*
	Queue Reduced Speed Delay Cost	*13.6711*	*8*	*1.27437*	*6.956076*	*95.09749936*
	Total	***4020.7560***	***8***	***1.27437***	***6.95608***	***27968.68371***
2035	*Speed Change VOC*	*630.1870*	*16*	*1.27437*	*48.38699*	*30492.85152*
	Speed Change Delay Cost	*413.6508*	*16*	*1.27437*	*48.38699*	*20015.31595*
	Work Zone Reduced Speed Delay	*1936.4686*	*16*	*1.27437*	*48.38699*	*93699.88886*
	Stopping VOC	*2460.0017*	*16*	*1.27437*	*48.38699*	*119032.0815*
	Stopping Delay Cost	*1936.4686*	*16*	*1.27437*	*48.38699*	*93699.88886*
	Idling VOC	*22597.0838*	*16*	*1.27437*	*48.38699*	*1093404.92*
	Queue Reduced Speed Delay Cost	*436.6335*	*16*	*1.27437*	*48.38699*	*21127.3825*
	Total	***30410.4938***	***16***	***1.27437***	***48.387***	***1471472.329***
2043	*Speed Change VOC*	*248.2506*	*24*	*1.27437*	*336.5836*	*83557.0785*
	Speed Change Delay Cost	*162.9501*	*24*	*1.27437*	*336.5836*	*54846.34079*
	Work Zone Reduced Speed Delay	*3970.0215*	*24*	*1.27437*	*336.5836*	*1336244.1*
	Stopping VOC	*5043.3350*	*24*	*1.27437*	*336.5836*	*1697503.791*
	Stopping Delay Cost	*3970.0215*	*24*	*1.27437*	*336.5836*	*1336244.1*
	Idling VOC	*155994.3750*	*24*	*1.27437*	*336.5836*	*52505146.96*
	Queue Reduced Speed Delay Cost	*3014.2107*	*24*	*1.27437*	*336.5836*	*1014533.869*
	Total	***172403.1644***	***24***	***1.27437***	***336.584***	***58028076.23***
	Total (ETB)					***59,527,517.25***

Table 75: Future Value User Cost Summary for conventional flexible pavement in the analysis period

№	***Description***	***Total Cost (ETB)***
1	*Routine maintenance*	***22,018,718.23***
2	*Periodic maintenance*	***11,253,639.10***
3	*Rehabilitation (upgrading)*	***59,527,517.2***
Total (ETB)		***82,024,516.03***

Appendix C 1.2 WZ operation user cost for flexible pavement with geosynthetic materials

Appendix C.1.2.1 WZ operation user cost for FP with geosynthetic material during routine maintenance

Table 76: Master summary of user cost components during routine maintenance for Flexible Pavement with geosynthetic materials

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	

2020	Speed Change VOC	225.6929	153.0299	497.9473	876.6701
	Speed Change Delay Cost	119.7403	167.2412	288.4592	575.4407
	Work Zone Reduced Speed Delay	0.0000	0.0000	0.0000	0.0000
	Stopping VOC	0.0000	0.0000	0.0000	0.0000
	Stopping Delay Cost	0.0000	0.0000	0.0000	0.0000
	Idling VOC	0.0000	0.0000	0.0000	0.0000
	Queue Reduced Speed Delay Cost	0.0000	0.0000	0.0000	0.0000
	Total	**345.4332**	**320.2711**	**786.4065**	**1452.1108**
2021	Speed Change VOC	236.9691	160.6757	522.8261	920.4710
	Speed Change Delay Cost	125.7229	175.5970	302.8714	604.1914
	Work Zone Reduced Speed Delay	0.0000	0.0000	0.0000	0.0000
	Stopping VOC	0.0000	0.0000	0.0000	0.0000
	Stopping Delay Cost	0.0000	0.0000	0.0000	0.0000
	Idling VOC	0.0000	0.0000	0.0000	0.0000
	Queue Reduced Speed Delay Cost	0.0000	0.0000	0.0000	0.0000
	Total	**362.6920**	**336.2727**	**825.6976**	**1524.6623**
2022	Speed Change VOC	248.8165	168.7087	548.9650	966.4902
	Speed Change Delay Cost	132.0084	184.3761	318.0136	634.3981
	Work Zone Reduced Speed Delay	0.0000	0.0000	0.0000	0.0000
	Stopping VOC	0.0000	0.0000	0.0000	0.0000
	Stopping Delay Cost	0.0000	0.0000	0.0000	0.0000
	Idling VOC	0.0000	0.0000	0.0000	0.0000
	Queue Reduced Speed Delay Cost	0.0000	0.0000	0.0000	0.0000
	Total	**380.8249**	**353.0848**	**866.9786**	**1600.8883**
2024	Speed Change VOC	236.7997	160.5608	522.4522	919.8127
	Speed Change Delay Cost	125.6330	175.4715	302.6548	603.7592
	Work Zone Reduced Speed Delay	58.8134	69.4288	108.4663	236.7085
	Stopping VOC	79.4584	54.1939	167.0514	300.7037
	Stopping Delay Cost	58.8134	69.4288	108.4663	236.7085
	Idling VOC	0.0000	0.0000	0.0000	0.0000
	Queue Reduced Speed Delay Cost	0.0000	0.0000	0.0000	0.0000
	Total	**559.5178**	**529.0838**	**1209.0910**	**2297.6926**
2025	Speed Change VOC	215.4548	146.0880	475.3590	836.9018
	Speed Change Delay Cost	114.3086	159.6547	275.3739	549.3371
	Work Zone Reduced Speed Delay	113.8658	134.4179	209.9965	458.2802
	Stopping VOC	153.8357	104.9223	323.4203	582.1783
	Stopping Delay Cost	113.8658	134.4179	209.9965	458.2802
	Idling VOC	0.0000	0.0000	0.0000	0.0000
	Queue Reduced Speed Delay Cost	0.0000	0.0000	0.0000	0.0000
	Total	**711.3306**	**679.5008**	**1494.1461**	**2884.9775**

2026	*Speed Change VOC*	*222.4663*	*150.8421*	*490.8285*	*864.1370*
	Speed Change Delay Cost	*118.0285*	*164.8503*	*284.3353*	*567.2141*
	Work Zone Reduced Speed Delay	*125.3432*	*147.9669*	*231.1635*	*504.4735*
	Stopping VOC	*169.3419*	*115.4982*	*356.0202*	*640.8603*
	Stopping Delay Cost	*125.3432*	*147.9669*	*231.1635*	*504.4735*
	Idling VOC	*412.7220*	*140.8145*	*113.4126*	*666.9491*
	Queue Reduced Speed Delay Cost	*4.6797*	*4.3197*	*3.8877*	*12.8872*
	Total	***1177.9247***	***872.2586***	***1710.8115***	***3760.9947***
2028	*Speed Change VOC*	*237.8545*	*161.2760*	*524.7795*	*923.9100*
	Speed Change Delay Cost	*126.1926*	*176.2531*	*304.0030*	*606.4487*
	Work Zone Reduced Speed Delay	*159.7104*	*188.5372*	*294.5452*	*642.7927*
	Stopping VOC	*215.7729*	*147.1661*	*453.6357*	*816.5747*
	Stopping Delay Cost	*159.7104*	*188.5372*	*294.5452*	*642.7927*
	Idling VOC	*731.8998*	*249.7132*	*201.1200*	*1182.7330*
	Queue Reduced Speed Delay Cost	*8.2987*	*7.6604*	*6.8943*	*22.8534*
	Total	***1639.4393***	***1119.1431***	***2079.5229***	***4838.1053***
2030	*Speed Change VOC*	*220.7290*	*149.6641*	*486.9954*	*857.3885*
	Speed Change Delay Cost	*117.1067*	*163.5629*	*282.1148*	*562.7844*
	Work Zone Reduced Speed Delay	*230.2605*	*271.8212*	*424.6569*	*926.7385*
	Stopping VOC	*311.0879*	*212.1749*	*654.0237*	*1177.2865*
	Stopping Delay Cost	*230.2605*	*271.8212*	*424.6569*	*926.7385*
	Idling VOC	*1820.0285*	*620.9663*	*500.1288*	*2941.1236*
	Queue Reduced Speed Delay Cost	*20.6366*	*19.0492*	*17.1443*	*56.8300*
	Total	***2950.1098***	***1709.0597***	***2789.7206***	***7448.8901***
2032	*Speed Change VOC*	*173.4890*	*117.6333*	*382.7696*	*673.8919*
	Speed Change Delay Cost	*92.0438*	*128.5575*	*221.7372*	*442.3384*
	Work Zone Reduced Speed Delay	*363.3525*	*428.9355*	*670.1111*	*1462.3991*
	Stopping VOC	*490.8987*	*334.8133*	*1032.0534*	*1857.7654*
	Stopping Delay Cost	*363.3525*	*428.9355*	*670.1111*	*1462.3991*
	Idling VOC	*4658.3707*	*1589.3659*	*1280.0817*	*7527.8184*
	Queue Reduced Speed Delay Cost	*52.8195*	*48.7564*	*43.8808*	*145.4567*
	Total	***6194.3267***	***3076.9974***	***4300.7450***	***13572.069***
2033	*Speed Change VOC*	*159.8769*	*108.4037*	*352.7371*	*621.0177*
	Speed Change Delay Cost	*84.8219*	*118.4707*	*204.3394*	*407.6321*
	Work Zone Reduced Speed Delay	*416.7381*	*491.9569*	*768.5674*	*1677.2624*
	Stopping VOC	*563.0241*	*384.0058*	*1183.6881*	*2130.7179*
	Stopping Delay Cost	*416.7381*	*491.9569*	*768.5674*	*1677.2624*
	Idling VOC	*5378.9700*	*1835.2235*	*1478.0965*	*8692.2899*
	Queue Reduced Speed Delay Cost	*60.9901*	*56.2985*	*50.6687*	*167.9573*
	Total	***7081.1592***	***3486.3160***	***4806.6645***	***15374.139***

2034	*Speed Change VOC*	*168.1114*	*113.9871*	*370.9050*	*653.0035*
	Speed Change Delay Cost	*89.1907*	*124.5726*	*214.8640*	*428.6274*
	Work Zone Reduced Speed Delay	*447.2604*	*527.9883*	*824.8580*	*1800.1067*
	Stopping VOC	*604.2605*	*412.1307*	*1270.3826*	*2286.7738*
	Stopping Delay Cost	*447.2604*	*527.9883*	*824.8580*	*1800.1067*
	Idling VOC	*9610.6780*	*3279.0185*	*2640.9348*	*15530.631*
	Queue Reduced Speed Delay Cost	*108.9718*	*100.5894*	*90.5304*	*300.0916*
	Total	***11475.7333***	***5086.2749***	***6237.3328***	***22799.341***
2036	*Speed Change VOC*	*69.9085*	*47.4011*	*154.2395*	*271.5492*
	Speed Change Delay Cost	*37.0897*	*51.8031*	*89.3504*	*178.2432*
	Work Zone Reduced Speed Delay	*662.6393*	*782.2418*	*1222.0694*	*2666.9504*
	Stopping VOC	*895.2429*	*610.5928*	*1882.1369*	*3387.9726*
	Stopping Delay Cost	*662.6393*	*782.2418*	*1222.0694*	*2666.9504*
	Idling VOC	*26069.0250*	*8894.3584*	*7163.5524*	*42126.935*
	Queue Reduced Speed Delay Cost	*295.5867*	*272.8492*	*245.5643*	*814.0003*
	Total	***28692.1313***	***11441.488***	***11978.9824***	***52112.602***
2037	*Speed Change VOC*	*59.8359*	*40.5714*	*132.0163*	*232.4236*
	Speed Change Delay Cost	*31.7457*	*44.3391*	*76.4766*	*152.5614*
	Work Zone Reduced Speed Delay	*717.0432*	*846.4654*	*1322.4037*	*2885.9123*
	Stopping VOC	*968.7441*	*660.7237*	*2036.6640*	*3666.1319*
	Stopping Delay Cost	*717.0432*	*846.4654*	*1322.4037*	*2885.9123*
	Idling VOC	*7170.4324*	*8464.6538*	*13224.0369*	*28859.123*
	Queue Reduced Speed Delay Cost	*136.1756*	*125.7005*	*113.1305*	*375.0066*
	Total	***9801.0202***	***11028.919***	***18227.1316***	***39057.071***
2038	*Speed Change VOC*	*121.9056*	*82.6575*	*268.9609*	*473.5240*
	Speed Change Delay Cost	*64.6765*	*90.3335*	*155.8082*	*310.8181*
	Work Zone Reduced Speed Delay	*660.3049*	*779.4861*	*1217.7642*	*2657.5552*
	Stopping VOC	*892.0891*	*608.4418*	*1875.5064*	*3376.0373*
	Stopping Delay Cost	*660.3049*	*779.4861*	*1217.7642*	*2657.5552*
	Idling VOC	*8912.1091*	*2742.1874*	*2056.6406*	*13710.937*
	Queue Reduced Speed Delay Cost	*101.0510*	*93.2778*	*83.9501*	*278.2789*
	Total	***11412.4410***	***5175.8702***	***6876.3945***	***23464.705***
2040	*Speed Change VOC*	*68.3780*	*46.3633*	*150.8627*	*265.6040*
	Speed Change Delay Cost	*36.2776*	*50.6689*	*87.3943*	*174.3408*
	Work Zone Reduced Speed Delay	*831.4602*	*981.5339*	*1533.4166*	*3346.4108*
	Stopping VOC	*1123.3245*	*766.1539*	*2361.6499*	*4251.1282*
	Stopping Delay Cost	*831.4602*	*981.5339*	*1533.4166*	*3346.4108*
	Idling VOC	*19523.1749*	*6661.0130*	*5364.8070*	*31548.994*
	Queue Reduced Speed Delay Cost	*221.3658*	*204.3377*	*183.9039*	*609.6074*
	Total	***22635.4412***	***9691.6047***	***11215.4510***	***43542.496***

2041	Speed Change VOC	110.7104	75.0666	244.2609	430.0379
	Speed Change Delay Cost	58.7369	82.0378	141.4995	282.2741
	Work Zone Reduced Speed Delay	812.0491	958.6192	1497.6178	3268.2861
	Stopping VOC	1097.0995	748.2674	2306.5152	4151.8821
	Stopping Delay Cost	812.0491	958.6192	1497.6178	3268.2861
	Idling VOC	22580.5480	7704.1427	6204.9478	36489.638
	Queue Reduced Speed Delay Cost	256.0322	236.3374	212.7037	705.0732
	Total	**25727.2251**	**10763.090**	**12105.1626**	**48595.477**
2042	Speed Change VOC	80.4982	54.5814	177.6036	312.6833
	Speed Change Delay Cost	42.7080	59.6502	102.8852	205.2433
	Work Zone Reduced Speed Delay	908.6892	1072.7023	1675.8459	3657.2375
	Stopping VOC	1227.6629	837.3170	2581.0085	4645.9883
	Stopping Delay Cost	908.6892	1072.7023	1675.8459	3657.2375
	Idling VOC	32.5471	10.0145	7.5109	50.0725
	Queue Reduced Speed Delay Cost	382.3333	352.9231	317.6308	1052.8872
	Total	**3583.1280**	**3459.8908**	**6538.3308**	**13581.349**

Table 77: Grand summary of user cost components during routine maintenance for FP with geosynthetic material.

Years	User Cost Components	Total (ETB)	n	1+If	(1+If) ^n	FV= b*e
	a	**b**	**c**	**d**	**e**	**f**
2020	Speed Change VOC	876.6701	1	1.27437	1.27437	1117.20205
	Speed Change Delay Cost	575.4407	1	1.27437	1.27437	733.3243988
	Work Zone Reduced Speed Delay	0.0000	1	1.27437	1.27437	0.00000
	Stopping VOC	0.0000	1	1.27437	1.27437	0.00000
	Stopping Delay Cost	0.0000	1	1.27437	1.27437	0.00000
	Idling VOC	0.0000	1	1.27437	1.27437	0.00000
	Queue Reduced Speed Delay Cost	0.0000	1	1.27437	1.27437	0.00000
	Total	**1452.1108**	**1**	1.27437	**1.27437**	**1850.526449**
2021	Speed Change VOC	920.4710	**2**	1.27437	1.624019	1494.862269
	Speed Change Delay Cost	604.1914	**2**	1.27437	1.624019	981.2181912
	Work Zone Reduced Speed Delay	0.0000	**2**	1.27437	1.624019	0.00000
	Stopping VOC	0.0000	**2**	1.27437	1.624019	0.00000
	Stopping Delay Cost	0.0000	**2**	1.27437	1.624019	0.00000
	Idling VOC	0.0000	**2**	1.27437	1.624019	0.00000
	Queue Reduced Speed Delay Cost	0.0000	**2**	1.27437	1.624019	0.00000
	Total	**1524.6623**	**2**	**1.27437**	**1.62402**	**2476.08046**
2022	Speed Change VOC	966.4902	3	1.27437	2.069601	2000.249047

	Speed Change Delay Cost	*634.3981*	*3*	*1.27437*	*2.069601*	*1312.950894*
	Work Zone Reduced Speed Delay	*0.0000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Stopping VOC	*0.0000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Stopping Delay Cost	*0.0000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Idling VOC	*0.0000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Queue Reduced Speed Delay Cost	*0.0000*	*3*	*1.27437*	*2.069601*	*0.00000*
	Total	***1600.8883***	***3***	***1.27437***	***2.0696***	***3313.199941***
2024	*Speed Change VOC*	*919.8127*	*5*	*1.27437*	*3.361071*	*3091.555722*
	Speed Change Delay Cost	*603.7592*	*5*	*1.27437*	*3.361071*	*2029.277731*
	Work Zone Reduced Speed Delay	*236.7085*	*5*	*1.27437*	*3.361071*	*795.5940503*
	Stopping VOC	*300.7037*	*5*	*1.27437*	*3.361071*	*1010.686533*
	Stopping Delay Cost	*236.7085*	*5*	*1.27437*	*3.361071*	*795.5940503*
	Idling VOC	*0.0000*	*5*	*1.27437*	*3.361071*	*0.000000*
	Queue Reduced Speed Delay Cost	*0.0000*	*5*	*1.27437*	*3.361071*	*0.000000*
	Total	***2297.6926***	***5***	***1.27437***	***3.36107***	***7722.708087***
2025	*Speed Change VOC*	*836.9018*	*6*	*1.27437*	*4.283248*	*3584.657993*
	Speed Change Delay Cost	*549.3371*	*6*	*1.27437*	*4.283248*	*2352.94696*
	Work Zone Reduced Speed Delay	*458.2802*	*6*	*1.27437*	*4.283248*	*1962.92764*
	Stopping VOC	*582.1783*	*6*	*1.27437*	*4.283248*	*2493.614087*
	Stopping Delay Cost	*458.2802*	*6*	*1.27437*	*4.283248*	*1962.92764*
	Idling VOC	*0.0000*	*6*	*1.27437*	*4.283248*	*0.000000*
	Queue Reduced Speed Delay Cost	*0.0000*	*6*	*1.27437*	*4.283248*	*0.000000*
	Total	***2884.9775***	***6***	***1.27437***	***4.28325***	***12357.07432***
2026	*Speed Change VOC*	*864.1370*	*7*	*1.27437*	*5.458443*	*4716.842719*
	Speed Change Delay Cost	*567.2141*	*7*	*1.27437*	*5.458443*	*3096.105894*
	Work Zone Reduced Speed Delay	*504.4735*	*7*	*1.27437*	*5.458443*	*2753.640065*
	Stopping VOC	*640.8603*	*7*	*1.27437*	*5.458443*	*3498.099226*
	Stopping Delay Cost	*504.4735*	*7*	*1.27437*	*5.458443*	*2753.640065*
	Idling VOC	*666.9491*	*7*	*1.27437*	*5.458443*	*3640.503349*
	Queue Reduced Speed Delay Cost	*12.8872*	*7*	*1.27437*	*5.458443*	*70.34384553*
	Total	***3760.9947***	***7***	***1.27437***	***5.45844***	***20529.17516***
2028	*Speed Change VOC*	*923.9100*	*9*	*1.27437*	*8.864614*	*8190.105955*
	Speed Change Delay Cost	*606.4487*	*9*	*1.27437*	*8.864614*	*5375.934037*
	Work Zone Reduced Speed Delay	*642.7927*	*9*	*1.27437*	*8.864614*	*5698.109728*
	Stopping VOC	*816.5747*	*9*	*1.27437*	*8.864614*	*7238.619701*
	Stopping Delay Cost	*642.7927*	*9*	*1.27437*	*8.864614*	*5698.109728*
	Idling VOC	*1182.7330*	*9*	*1.27437*	*8.864614*	*10484.47218*
	Queue Reduced Speed Delay Cost	*22.8534*	*9*	*1.27437*	*8.864614*	*202.5868461*
	Total	***4838.1053***	***9***	***1.27437***	***8.86461***	***42887.93818***
2030	*Speed Change VOC*	*857.3885*	*11*	*1.27437*	*14.3963*	*12343.22299*

	Speed Change Delay Cost	562.7844	11	1.27437	14.3963	8102.013935
	Work Zone Reduced Speed Delay	926.7385	11	1.27437	14.3963	13341.6071
	Stopping VOC	1177.2865	11	1.27437	14.3963	16948.57148
	Stopping Delay Cost	926.7385	11	1.27437	14.3963	13341.6071
	Idling VOC	2941.1236	11	1.27437	14.3963	42341.30194
	Queue Reduced Speed Delay Cost	56.8300	11	1.27437	14.3963	818.1423604
	Total	**7448.8901**	**11**	**1.27437**	**14.3963**	**107236.4669**
2032	Speed Change VOC	673.8919	13	1.27437	23.37987	15755.50248
	Speed Change Delay Cost	442.3384	13	1.27437	23.37987	10341.81273
	Work Zone Reduced Speed Delay	1462.3991	13	1.27437	23.37987	34190.69503
	Stopping VOC	1857.7654	13	1.27437	23.37987	43434.30549
	Stopping Delay Cost	1462.3991	13	1.27437	23.37987	34190.69503
	Idling VOC	7527.8184	13	1.27437	23.37987	175999.3811
	Queue Reduced Speed Delay Cost	145.4567	13	1.27437	23.37987	3400.758657
	Total	**13572.0691**	**13**	**1.27437**	**23.3799**	**317313.1506**
2033	Speed Change VOC	621.0177	14	1.27437	29.7946	18502.97265
	Speed Change Delay Cost	407.6321	14	1.27437	29.7946	12145.23487
	Work Zone Reduced Speed Delay	1677.2624	14	1.27437	29.7946	49973.36077
	Stopping VOC	2130.7179	14	1.27437	29.7946	63483.88696
	Stopping Delay Cost	1677.2624	14	1.27437	29.7946	49973.36077
	Idling VOC	8692.2899	14	1.27437	29.7946	258983.2938
	Queue Reduced Speed Delay Cost	167.9573	14	1.27437	29.7946	5004.220313
	Total	**15374.1397**	14	**1.27437**	**29.7946**	**458066.3301**
2034	Speed Change VOC	653.0035	15	1.27437	37.96934	24794.11492
	Speed Change Delay Cost	428.6274	15	1.27437	37.96934	16274.70109
	Work Zone Reduced Speed Delay	1800.1067	15	1.27437	37.96934	68348.87025
	Stopping VOC	2286.7738	15	1.27437	37.96934	86827.2993
	Stopping Delay Cost	1800.1067	15	1.27437	37.96934	68348.87025
	Idling VOC	15530.6314	15	1.27437	37.96934	589687.8759
	Queue Reduced Speed Delay Cost	300.0916	15	1.27437	37.96934	11394.27955
	Total	**22799.3411**	**15**	**1.27437**	**37.9693**	**865676.0112**
2036	Speed Change VOC	271.5492	17	1.27437	61.66293	16744.51965
	Speed Change Delay Cost	178.2432	17	1.27437	61.66293	10990.99738
	Work Zone Reduced Speed Delay	2666.9504	17	1.27437	61.66293	164451.9808
	Stopping VOC	3387.9726	17	1.27437	61.66293	208912.3244
	Stopping Delay Cost	2666.9504	17	1.27437	61.66293	164451.9808
	Idling VOC	42126.9358	17	1.27437	61.66293	2597670.348
	Queue Reduced Speed Delay Cost	814.0003	17	1.27437	61.66293	50193.64197
	Total	**52112.6020**	**17**	**1.27437**	**61.6629**	**3213415.793**
2037	Speed Change VOC	232.4236	18	1.27437	78.58139	18264.17106

	Speed Change Delay Cost	*152.5614*	*18*	*1.27437*	*78.58139*	*11988.48701*
	Work Zone Reduced Speed Delay	*2885.9123*	*18*	*1.27437*	*78.58139*	*226778.9992*
	Stopping VOC	*3666.1319*	*18*	*1.27437*	*78.58139*	*288089.7368*
	Stopping Delay Cost	*2885.9123*	*18*	*1.27437*	*78.58139*	*226778.9992*
	Idling VOC	*28859.1230*	*18*	*1.27437*	*78.58139*	*2267789.992*
	Queue Reduced Speed Delay Cost	*375.0066*	*18*	*1.27437*	*78.58139*	*29468.5411*
	Total	***39057.0711***	***18***	***1.27437***	***78.5814***	***3069158.927***
2038	*Speed Change VOC*	*473.5240*	*19*	*1.27437*	*100.1418*	*47419.52541*
	Speed Change Delay Cost	*310.8181*	*19*	*1.27437*	*100.1418*	*31125.87823*
	Work Zone Reduced Speed Delay	*2657.5552*	*19*	*1.27437*	*100.1418*	*266132.266*
	Stopping VOC	*3376.0373*	*19*	*1.27437*	*100.1418*	*338082.3388*
	Stopping Delay Cost	*2657.5552*	*19*	*1.27437*	*100.1418*	*266132.266*
	Idling VOC	*13710.9371*	*19*	*1.27437*	*100.1418*	*1373037.451*
	Queue Reduced Speed Delay Cost	*278.2789*	*19*	*1.27437*	*100.1418*	*27867.33859*
	Total	***23464.7058***	***19***	***1.27437***	***100.142***	***2349797.064***
2040	*Speed Change VOC*	*265.6040*	*21*	*1.27437*	*162.6321*	*43195.74803*
	Speed Change Delay Cost	*174.3408*	*21*	*1.27437*	*162.6321*	*28353.41732*
	Work Zone Reduced Speed Delay	*3346.4108*	*21*	*1.27437*	*162.6321*	*544233.8797*
	Stopping VOC	*4251.1282*	*21*	*1.27437*	*162.6321*	*691369.9932*
	Stopping Delay Cost	*3346.4108*	*21*	*1.27437*	*162.6321*	*544233.8797*
	Idling VOC	*31548.9949*	*21*	*1.27437*	*162.6321*	*5130879.911*
	Queue Reduced Speed Delay Cost	*609.6074*	*21*	*1.27437*	*162.6321*	*99141.73653*
	Total	***43542.4969***	***21***	***1.27437***	***162.632***	***7081408.566***
2041	*Speed Change VOC*	*430.0379*	*22*	*1.27437*	*207.2535*	*89126.84877*
	Speed Change Delay Cost	*282.2741*	*22*	*1.27437*	*207.2535*	*58502.30296*
	Work Zone Reduced Speed Delay	*3268.2861*	*22*	*1.27437*	*207.2535*	*677363.7051*
	Stopping VOC	*4151.8821*	*22*	*1.27437*	*207.2535*	*860492.0746*
	Stopping Delay Cost	*3268.2861*	*22*	*1.27437*	*207.2535*	*677363.7051*
	Idling VOC	*36489.6385*	*22*	*1.27437*	*207.2535*	*7562605.086*
	Queue Reduced Speed Delay Cost	*705.0732*	*22*	*1.27437*	*207.2535*	*146128.8929*
	Total	***48595.4779***	***22***	***1.27437***	***207.253***	***10071582.62***
2042	*Speed Change VOC*	*312.6833*	*23*	*1.27437000*	*264.1176*	*82585.17*
	Speed Change Delay Cost	*205.2433*	*23*	*1.27437*	*264.1176*	*54208.38525*
	Work Zone Reduced Speed Delay	*3657.2375*	*23*	*1.27437*	*264.1176*	*965940.9158*
	Stopping VOC	*4645.9883*	*23*	*1.27437*	*264.1176*	*1227087.451*
	Stopping Delay Cost	*3657.2375*	*23*	*1.27437*	*264.1176*	*965940.9158*
	Idling VOC	*50.0725*	*23*	*1.27437*	*264.1176*	*13225.03078*
	Queue Reduced Speed Delay Cost	*1052.8872*	*23*	*1.27437*	*264.1176*	*278086.0778*
	Total	***13581.3496***	***23***	***1.27437***	***264.118***	***3587073.945***

	Grand Total (ETB)	***31211865.57***

Appendix C.1.2.2Work zone operation user cost for flexible pavement with geosynthetic material during periodic maintenance

Table 78: master summary of user cost components during periodic maintenance for FP with geosynthetic materials

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2023	*Speed Change VOC*	*229.437*	*155.568*	*506.207*	*891.212*
	Speed Change Delay Cost	*121.726*	*170.015*	*293.244*	*584.986*
	Work Zone Reduced Speed Delay	*49.897*	*58.904*	*92.023*	*200.824*
	Stopping VOC	*67.413*	*45.978*	*141.727*	*255.117*
	Stopping Delay Cost	*49.897*	*58.904*	*92.023*	*200.824*
	Idling VOC	*0.000*	*0.000*	*0.000*	*0.000*
	Queue Reduced Speed Delay Cost	*0.000*	*0.000*	*0.000*	*0.000*
	Total	***518.370***	***489.369***	***1125.223***	***2132.962***
2027	*Speed Change VOC*	*229.085*	*155.330*	*505.431*	*889.846*
	Speed Change Delay Cost	*121.540*	*169.755*	*292.795*	*584.089*
	Work Zone Reduced Speed Delay	*138.701*	*163.736*	*255.799*	*558.235*
	Stopping VOC	*187.389*	*127.807*	*393.961*	*709.157*
	Stopping Delay Cost	*138.701*	*163.736*	*255.799*	*558.235*
	Idling VOC	*437.830*	*149.381*	*120.312*	*707.522*
	Queue Reduced Speed Delay Cost	*4.964*	*4.583*	*4.124*	*13.671*
	Total	***1258.209***	***934.326***	***1828.220***	***4020.756***
2031	*Speed Change VOC*	*225.184*	*152.685*	*496.824*	*874.692*
	Speed Change Delay Cost	*119.470*	*166.864*	*287.808*	*574.142*
	Work Zone Reduced Speed Delay	*252.075*	*297.574*	*464.889*	*1014.538*
	Stopping VOC	*340.560*	*232.276*	*715.986*	*1288.823*
	Stopping Delay Cost	*252.075*	*297.574*	*464.889*	*1014.538*
	Idling VOC	*3024.029*	*1031.753*	*830.978*	*4886.760*
	Queue Reduced Speed Delay Cost	*34.288*	*31.651*	*28.486*	*94.425*
	Total	***4247.682***	***2210.376***	***3289.860***	***9747.917***
2035	*Speed Change VOC*	*162.237*	*110.004*	*357.945*	*630.187*
	Speed Change Delay Cost	*86.074*	*120.220*	*207.356*	*413.651*
	Work Zone Reduced Speed Delay	*481.141*	*567.985*	*887.343*	*1936.469*
	Stopping VOC	*650.035*	*443.350*	*1366.617*	*2460.002*
	Stopping Delay Cost	*481.141*	*567.985*	*887.343*	*1936.469*
	Idling VOC	*13983.546*	*4770.975*	*3842.563*	*22597.084*
	Queue Reduced Speed Delay Cost	*158.554*	*146.358*	*131.722*	*436.634*

	Total	***16002.729***	***6726.876***	***7680.888***	***30410.494***
2043	*Speed Change VOC*	*63.910*	*43.334*	*141.006*	*248.251*
	Speed Change Delay Cost	*33.907*	*47.358*	*81.684*	*162.950*
	Work Zone Reduced Speed Delay	*986.405*	*1164.445*	*1819.172*	*3970.022*
	Stopping VOC	*1332.658*	*908.928*	*2801.748*	*5043.335*
	Stopping Delay Cost	*986.405*	*1164.445*	*1819.172*	*3970.022*
	Idling VOC	*96532.567*	*32935.457*	*26526.351*	*155994.375*
	Queue Reduced Speed Delay Cost	*1094.546*	*1010.350*	*909.315*	*3014.211*
	Total	***101030.398***	***37274.318***	***34098.449***	***172403.164***

Table 79: Grand summary of user cost components during periodic maintenance for FP with geosynthetic materials

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+If*	*(1+If) ^n*	*FV = b*e*
	a	***b***	***c***	***d***	***e***	***f***
2023	*Speed Change VOC*	*891.212*	*4*	*1.27437*	*2.637437*	*2350.514838*
	Speed Change Delay Cost	*584.986*	*4*	*1.27437*	*2.637437*	*1542.863156*
	Work Zone Reduced Speed Delay	*200.824*	*4*	*1.27437*	*2.637437*	*529.660181*
	Stopping VOC	*255.117*	*4*	*1.27437*	*2.637437*	*672.8562286*
	Stopping Delay Cost	*200.824*	*4*	*1.27437*	*2.637437*	*529.660181*
	Idling VOC	*0.000*	*4*	*1.27437*	*2.637437*	*0.000000*
	Queue Reduced Speed Delay Cost	*0.000*	*4*	*1.27437*	*2.637437*	*0.000000*
	Total	***2132.962***	***4***	***1.27437***	***2.63744***	***5625.554584***
2027	*Speed Change VOC*	*889.846*	*8*	*1.27437*	*6.956076*	*6189.83522*
	Speed Change Delay Cost	*584.089*	*8*	*1.27437*	*6.956076*	*4062.968907*
	Work Zone Reduced Speed Delay	*558.235*	*8*	*1.27437*	*6.956076*	*3883.127421*
	Stopping VOC	*709.157*	*8*	*1.27437*	*6.956076*	*4932.948643*
	Stopping Delay Cost	*558.235*	*8*	*1.27437*	*6.956076*	*3883.127421*
	Idling VOC	*707.522*	*8*	*1.27437*	*6.956076*	*4921.578602*
	Queue Reduced Speed Delay Cost	*13.671*	*8*	*1.27437*	*6.956076*	*95.09749936*
	Total	***4020.756***	***8***	***1.27437***	***6.95608***	***27968.68371***
2031	*Speed Change VOC*	*874.692*	*12*	*1.27437*	*18.34621*	*16047.28935*
	Speed Change Delay Cost	*574.142*	*12*	*1.27437*	*18.34621*	*10533.3398*
	Work Zone Reduced Speed Delay	*1014.538*	*12*	*1.27437*	*18.34621*	*18612.92676*
	Stopping VOC	*1288.823*	*12*	*1.27437*	*18.34621*	*23645.01647*
	Stopping Delay Cost	*1014.538*	*12*	*1.27437*	*18.34621*	*18612.92676*
	Idling VOC	*4886.760*	*12*	*1.27437*	*18.34621*	*89653.54554*
	Queue Reduced Speed Delay Cost	*94.425*	*12*	*1.27437*	*18.34621*	*1732.336041*

	Total	***9747.917***	***12***	***1.27437***	***18.3462***	***178837.3807***
2035	*Speed Change VOC*	*630.187*	*16*	*1.27437*	*48.38699*	*30492.85152*
	Speed Change Delay Cost	*413.651*	*16*	*1.27437*	*48.38699*	*20015.31595*
	Work Zone Reduced Speed Delay	*1936.469*	*16*	*1.27437*	*48.38699*	*93699.88886*
	Stopping VOC	*2460.002*	*16*	*1.27437*	*48.38699*	*119032.0815*
	Stopping Delay Cost	*1936.469*	*16*	*1.27437*	*48.38699*	*93699.88886*
	Idling VOC	*22597.084*	*16*	*1.27437*	*48.38699*	*1093404.92*
	Queue Reduced Speed Delay Cost	*436.634*	*16*	*1.27437*	*48.38699*	*21127.3825*
	Total	***30410.494***	***16***	***1.27437***	***48.387***	***1471472.329***
2043	*Speed Change VOC*	*248.251*	*24*	*1.27437*	*336.5836*	*83557.0785*
	Speed Change Delay Cost	*162.950*	*24*	*1.27437*	*336.5836*	*54846.34079*
	Work Zone Reduced Speed Delay	*3970.022*	*24*	*1.27437*	*336.5836*	*1336244.1*
	Stopping VOC	*5043.335*	*24*	*1.27437*	*336.5836*	*1697503.791*
	Stopping Delay Cost	*3970.022*	*24*	*1.27437*	*336.5836*	*1336244.1*
	Idling VOC	*155994.375*	*24*	*1.27437*	*336.5836*	*52505146.96*
	Queue Reduced Speed Delay Cost	*3014.211*	*24*	*1.27437*	*336.5836*	*1014533.869*
	Total	***172403.164***	***24***	***1.27437***	***336.584***	***58028076.23***
						59,711,980.18

Appendix C.1.2.3 Work zone operation user cost for flexible pavement with geosynthetic material during rehabilitation

Table 80: Master summary of user cost components during rehabilitation for FP with geosynthetic materials

Years	*User Cost Components*	*Passenger Cars*	*Trucks*		*Total (ETB)*
			Single Unit	*Combination*	
2029	*Speed Change VOC*	*217.0888*	*147.1959*	*478.9640*	*843.2486*
	Speed Change Delay Cost	*115.1754*	*160.8654*	*277.4622*	*553.5031*
	Work Zone Reduced Speed Delay	*208.5378*	*246.1777*	*384.5949*	*839.3104*
	Stopping VOC	*281.7400*	*192.1584*	*592.3233*	*1066.2217*
	Stopping Delay Cost	*208.5378*	*246.1777*	*384.5949*	*839.3104*
	Idling VOC	*731.8998*	*249.7132*	*201.1200*	*1182.7330*
	Queue Reduced Speed Delay Cost	*15.2103*	*14.0403*	*12.6363*	*41.8869*
	Total	***1778.1900***	***1256.3285***	***2331.6956***	***5366.2141***
2039	*Speed Change VOC*	*118.6791*	*80.4697*	*261.8422*	*460.9909*
	Speed Change Delay Cost	*62.9646*	*87.9426*	*151.6843*	*302.5915*
	Work Zone Reduced Speed Delay	*707.9327*	*835.7104*	*1305.6016*	*2849.2447*
	Stopping VOC	*956.4355*	*652.3287*	*2010.7867*	*3619.5510*
	Stopping Delay Cost	*707.9327*	*835.7104*	*1305.6016*	*2849.2447*

	Idling VOC	*2649.0913*	*815.1050*	*611.3288*	*4075.5251*
	Queue Reduced Speed Delay Cost	*30.0370*	*27.7265*	*24.9538*	*82.7174*
	Total	***5233.0729***	***3334.9934***	***5671.7989***	***14239.8652***

Table 81: Grand summary of user cost components during rehabilitation for FP with geosynthetic materials

Years	*User Cost Components*	*Total (ETB)*	*n*	*1+if*	*(1+if) ^n*	*FV = b*e*
	a	***b***	***c***	***d***	***e***	***f***
2029	*Speed Change VOC*	*843.2486*	*10*	*1.27437*	*11.2968*	*9526.010176*
	Speed Change Delay Cost	*553.5031*	*10*	*1.27437*	*11.2968*	*6252.813165*
	Work Zone Reduced Speed Delay	*839.3104*	*10*	*1.27437*	*11.2968*	*9481.52022*
	Stopping VOC	*1066.2217*	*10*	*1.27437*	*11.2968*	*12044.89249*
	Stopping Delay Cost	*839.3104*	*10*	*1.27437*	*11.2968*	*9481.52022*
	Idling VOC	*1182.7330*	*10*	*1.27437*	*11.2968*	*13361.09682*
	Queue Reduced Speed Delay Cost	*41.8869*	*10*	*1.27437*	*11.2968*	*473.18748*
	Total	***5366.2141***	***10***	***1.27437***	***11.2968***	***60621.04056***
2039	*Speed Change VOC*	*460.9909*	*20*	*1.27437*	*127.6177*	*58830.58334*
	Speed Change Delay Cost	*302.5915*	*20*	*1.27437*	*127.6177*	*38616.02488*
	Work Zone Reduced Speed Delay	*2849.2447*	*20*	*1.27437*	*127.6177*	*363613.9426*
	Stopping VOC	*3619.5510*	*20*	*1.27437*	*127.6177*	*461918.6317*
	Stopping Delay Cost	*2849.2447*	*20*	*1.27437*	*127.6177*	*363613.9426*
	Idling VOC	*4075.5251*	*20*	*1.27437*	*127.6177*	*520108.9833*
	Queue Reduced Speed Delay Cost	*82.7174*	*20*	*1.27437*	*127.6177*	*10556.19651*
	Total	***14239.8652***	***20***	***1.27437***	***127.618***	***1817258.305***
	Grand Total (ETB)					***1,877,879.35***

Table 82: user cost summary for FP with geosynthetic materials in the analysis period.

№	*Description*	*Total Cost (ETB)*
1	*Routine maintenance*	*3081516.001*
2	*Periodic maintenance*	*59533142.8*
3	*Rehabilitation (upgrading)*	*1877879.346*
Total (ETB)		***64492538.15***

Appendix D Net Present Value (NPV)

Appendix E.1 Net Present Value for Conventional Flexible Pavement.

Table 83: Discounting Factors for Each Year in the Analysis Period for conventional FP.

Year	*Activities*	*nk*	*Activity Cost*	*User Cost*	*1+Dr*	*(1/(1+Dr)) ^nk*
2019	*Construction*	*0*	*4,248,120.00*	*0.000*	*1.035*	*1*
2020	*Routine Maintenance*	*1*	*987,916.46*	*1850.526*	*1.035*	*0.966183575*
2021	*Routine Maintenance*	*2*	*1,258,971.10*	*0.00000*	*1.035*	*0.9335107*

2022	*Periodic Maintenance*	*3*	*2,920,261.76*	*3313.200*	*1.035*	*0.901942706*
2023	*Routine Maintenance*	*4*	*2,044,592.86*	*5625.555*	*1.035*	*0.871442228*
2024	*Routine Maintenance*	*5*	*2,605,567.80*	*7722.708*	*1.035*	*0.841973167*
2025	*Periodic Maintenance*	*6*	*6,043,776.55*	*12357.074*	*1.035*	*0.813500644*
2026	*Routine Maintenance*	*7*	*4,231,491.34*	*20529.175*	*1.035*	*0.785990961*
2027	*Rehabilitation*	*8*	*36,829,055.53*	*27968.684*	*1.035*	*0.759411556*
2028	*Periodic Maintenance*	*9*	*12,508,205.75*	*42887.938*	*1.035*	*0.733730972*
2029	*Routine Maintenance*	*10*	*8,757,498.55*	*60621.041*	*1.035*	*0.708918814*
2030	*Routine Maintenance*	*11*	*11,160,293.42*	*107236.467*	*1.035*	*0.684945714*
2031	*Periodic Maintenance*	*12*	*25,886,994.65*	*0.000*	*1.035*	*0.661783298*
2032	*Routine Maintenance*	*13*	*18,124,527.42*	*317313.151*	*1.035*	*0.639404153*
2033	*Routine Maintenance*	*14*	*23,097,354.00*	*0.000*	*1.035*	*0.61778179*
2034	*Periodic Maintenance*	*15*	*53,575,749.03*	*865676.011*	*1.035*	*0.596890619*
2035	*Rehabilitation*	*16*	*256,185,706.37*	*1471472.329*	*1.035*	*0.576705912*
2036	*Routine Maintenance*	*17*	*47,802,306.05*	*3213415.793*	*1.035*	*0.557203779*
2037	*Periodic Maintenance*	*18*	*110,880,421.71*	*3069158.927*	*1.035*	*0.53836114*
2038	*Routine Maintenance*	*19*	*77,631,848.35*	*2349797.064*	*1.035*	*0.52015569*
2039	*Routine Maintenance*	*20*	*98,931,698.58*	*1817258.305*	*1.035*	*0.502565884*
2040	*Periodic Maintenance*	*21*	*229,478,227.41*	*7081408.566*	*1.035*	*0.485570903*
2041	*Routine Maintenance*	*22*	*160,666,948.00*	*0.000*	*1.035*	*0.469150631*
2042	*Routine Maintenance*	*23*	*204,749,138.52*	*3587073.945*	*1.035*	*0.453285634*
2043	*Rehabilitation*	*24*	*1,782,047,223.16*	*58028076.23*	*1.035*	*0.437957134*
2044	*Salvage Value*	*25*	*222,755,902.90*	*0.000*	*1.035*	*0.423146989*

Table 84: Discounted Costs for Each Year in the Analysis Period for conventional FP

Years	*Activity Cost*	*User Cost*	*(1/(1+dr)) ^nk*	*cost* ((1/(1+dr)) ^nk)*	*user cost * ((1/(1+dr)) ^nk)*
2019	*4312620*	*0*	*1*	*4312620*	*0*
2020	*987916.4601*	*1452.111*	*0.966183575*	*954508.6571*	*1403.005797*
2021	*1258971.099*	*1524.662*	*0.9335107*	*1175262.993*	*1423.288291*
2022	*1604395*	*1600.888*	*0.901942706*	*1447072.367*	*1443.909254*
2023	*3721493.979*	*2132.962*	*0.871442228*	*3243067.003*	*1858.753157*
2024	*2605567.798*	*2297.693*	*0.841973167*	*2193818.17*	*1934.595852*
2025	*3320457.434*	*2884.977*	*0.813500644*	*2701194.262*	*2346.930648*
2026	*4231491.34*	*3760.995*	*0.785990961*	*3325913.944*	*2956.108073*
2027	*9815207.32*	*4020.756*	*0.759411556*	*7453781.866*	*3053.408571*
2028	*6872021.899*	*4838.105*	*0.733730972*	*5042215.309*	*3549.867485*
2029	*59811082.14*	*5366.214*	*0.708918814*	*42401201.4*	*3804.210063*
2030	*11160293.42*	*7448.89*	*0.684945714*	*7644195.145*	*5102.085278*

2031	25886994.65	9747.917	0.661783298	17131580.71	6451.008664
2032	18124527.42	13572.07	0.639404153	11588898.1	8678.037922
2033	23097354	15374.14	0.61778179	14269124.71	9497.863733
2034	29434575.02	22799.34	0.596890619	17569221.69	13608.71216
2035	68275327.29	30410.49	0.576705912	39374784.87	17537.90936
2036	47802306.05	52112.6	0.557203779	26635625.6	29037.33768
2037	60917824.77	39057.07	0.53836114	32795789.56	21026.80871
2038	77631848.35	23464.71	0.52015569	40380647.67	12205.30243
2039	675673757.6	14239.87	0.502565884	339570579.6	7156.472861
2040	77631848.35	43542.5	0.485570903	37695766.69	21142.97104
2041	77631848.35	48595.48	0.469150631	36421030.62	22798.60009
2042	77631848.35	13581.35	0.453285634	35189401.56	6156.23084
2043	474928360.1	172403.2	0.437957134	207998263.4	75505.21135
2044	337836878.8	0	0.423146989	142954658.1	0

Appendix E.2 Net Present Value for Flexible Pavement with Geosynthetic Materials

Table 85: Discounting Factors for Each Year in the Analysis Period for FP with geosynthetic materials

Age in years	activity	nk	activity cost	user cost	1+Dr	1/(1+Dr) ^nk
2019	Initial Construction	0	**4,312,620**	0.0000	1.035	1
2020	Routine Maintenance	1	987916.4601	1452.111	1.035	0.96618357
2021	Routine Maintenance	2	1258971.099	1524.662	1.035	0.9335107
2022	Routine Maintenance	3	1604395.000	1600.888	1.035	0.90194271
2023	Periodic Maintenance	4	3721493.979	2132.962	1.035	0.87144223
2024	Routine Maintenance	5	2605567.798	2297.693	1.035	0.84197317
2025	Routine Maintenance	6	3320457.434	2884.977	1.035	0.81350064
2026	Routine Maintenance	7	4231491.340	3760.995	1.035	0.78599096
2027	Periodic Maintenance	8	9815207.32	4020.756	1.035	0.75941156
2028	Routine Maintenance	9	6872021.899	4838.105	1.035	0.73373097
2029	Rehabilitation	10	59811082.14	5366.214	1.035	0.70891881
2030	Routine Maintenance	11	11160293.42	7448.89	1.035	0.68494571
2031	Periodic Maintenance	12	25886994.65	9747.917	1.035	0.6617833
2032	Routine Maintenance	13	18124527.42	13572.07	1.035	0.63940415
2033	Routine Maintenance	14	23097354	15374.14	1.035	0.61778179
2034	Routine Maintenance	15	29434575.02	22799.34	1.035	0.59689062
2035	Periodic Maintenance	16	68275327.29	30410.49	1.035	0.57670591
2036	Routine Maintenance	17	47802306.05	52112.6	1.035	0.55720378
2037	Routine Maintenance	18	60917824.77	39057.07	1.035	0.53836114
2038	Routine Maintenance	19	77631848.35	23464.71	1.035	0.52015569
2039	Rehabilitation	20	675673757.6	14239.87	1.035	0.50256588
2040	Routine Maintenance	21	77631848.35	43542.5	1.035	0.4855709

2041	*Routine Maintenance*	*22*	*77631848.35*	*48595.48*	*1.035*	*0.46915063*
2042	*Routine Maintenance*	*23*	*77631848.35*	*13581.35*	*1.035*	*0.45328563*
2043	*Periodic Maintenance*	*24*	*474928360.1*	*172403.2*	*1.035*	*0.43795713*
2044	*Salvage Value*	*25*	*337,836,878.78*	*0.00000*	*1.035*	*0.42314699*

Table 86: Discounted Costs for Each Year in The Analysis Period for FP with geosynthetic materials

Years	*Activity Cost*	*User Cost*	*(1/(1+dr)) ^nk*	*Activity Cost* ((1/(1+dr)) ^nk)*	*User Cost * ((1/(1+dr)) ^nk)*
2019	***4,312,620***	*0.0000*	*1*	*4,312,620.00*	*0*
2020	*987916.4601*	*1452.111*	*0.966183575*	*954,508.66*	*1403.0058*
2021	*1258971.099*	*1524.662*	*0.9335107*	*1,175,262.99*	*1423.28829*
2022	*1604395.000*	*1600.888*	*0.901942706*	*1,447,072.37*	*1443.90925*
2023	*3721493.979*	*2132.962*	*0.871442228*	*3,243,067.00*	*1858.75316*
2024	*2605567.798*	*2297.693*	*0.841973167*	*2,193,818.17*	*1934.59585*
2025	*3320457.434*	*2884.977*	*0.813500644*	*2,701,194.26*	*2346.93065*
2026	*4231491.340*	*3760.995*	*0.785990961*	*3,325,913.94*	*2956.10807*
2027	*9815207.32*	*4020.756*	*0.759411556*	*7,453,781.86*	*3053.40857*
2028	*6872021.899*	*4838.105*	*0.733730972*	*5,042,215.31*	*3549.86748*
2029	*59811082.14*	*5366.214*	*0.708918814*	*42,401,201.41*	*3804.21006*
2030	*11160293.42*	*7448.89*	*0.684945714*	*7,644,195.15*	*5102.08528*
2031	*25886994.65*	*9747.917*	*0.661783298*	*17,131,580.69*	*6451.00866*
2032	*18124527.42*	*13572.07*	*0.639404153*	*11,588,898.10*	*8678.03792*
2033	*23097354*	*15374.14*	*0.61778179*	*14,269,124.70*	*9497.86373*
2034	*29434575.02*	*22799.34*	*0.596890619*	*17,569,221.70*	*13608.7122*
2035	*68275327.29*	*30410.49*	*0.576705912*	*39,374,784.89*	*17537.9094*
2036	*47802306.05*	*52112.6*	*0.557203779*	*26,635,625.58*	*29037.3377*
2037	*60917824.77*	*39057.07*	*0.53836114*	*32,795,789.59*	*21026.8087*
2038	*77631848.35*	*23464.71*	*0.52015569*	*40,380,647.64*	*12205.3024*
2039	*675673757.6*	*14239.87*	*0.502565884*	*339,570,579.28*	*7156.47285*
2040	*77631848.35*	*43542.5*	*0.485570903*	*37,695,766.70*	*21142.971*
2041	*77631848.35*	*48595.48*	*0.469150631*	*36,421,030.64*	*22798.6001*
2042	*77631848.35*	*13581.35*	*0.453285634*	*35,189,401.60*	*6156.23085*
2043	*474928360.1*	*172403.2*	*0.437957134*	*207,998,263.44*	*75505.2114*
2044	*337,836,878.78*	*0.00000*	*0.423146989*	*142,954,658.03*	*0*

Appendix F Glossary

- Analysis Period- The analysis period is the time period used when evaluating projects economically. For example, in pavement projects, the Federal Highway Administration (FHWA) recommends that the analysis period chosen should contain at least one rehabilitation project, but may or may not contain maintenance activities during the life cycle of the evaluated pavement. The analysis period should be of sufficient time for predicting future costs so as to capture all the significant costs. One important note is that the analysis period must be the same for all alternatives under evaluation when LCCA is used for comparing various design alternatives.
- Constant Dollars or Real Dollars—Economic units measured in terms of constant purchasing power. The constant dollars are un-inflated and represent the prevailing price for all elements at the base year for the analysis. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product (GDP) or the Consumer Price Index (CPI).
- Cost-Effectiveness – A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits for a given objective.
- Current Dollars or Nominal Dollars—Economic units measured in terms of purchasing power of the date in question. Current dollars are inflated and represent the price levels that may exist at some future date when costs are incurred. The uncertainty associated with predicting future rates of inflation, and incorporating price changes into the economic analysis, is extremely complex. An accepted approach of dealing with this issue is using constant dollars and a discount rate.
- Deterministic Approach – The deterministic approach considers applying procedures and methodologies without regard for the variability or uncertainty of the input parameters.
- Discount Factor—The factor that translates expected costs and benefits in any given future year into the present terms. The discount factor is equal to $1/(1 + i)t$ where i is the interest rate and t is the number of years from the date of commencement for the project until the given year.
- Discount rates -- A value in percent used in calculating the present value of future costs and benefits when comparing the alternative uses of funds over a period of time. A detailed discussion about discount rates is presented in Chapter 4.
- Inflation – The proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price. Inflation is usually measured by a broad-based price index, such as the Consumer Price Index (CPI) or the implicit deflator for Gross Domestic Product.
- Initial Cost—The total investment required to construct a project. For example, in highway projects

the initial cost will include the estimated cost of pavement construction and may include other costs such as preliminary engineering, traffic control, and construction engineering. The initial costs used in the analysis should be the most current and accurate data available. If costs for the same project elements are identical in different alternatives, it should be noted and these costs may not be included in the analysis.

- Maintenance Costs—The cost of preserving an existing facility and keeping it functioning above the minimum acceptable level of service. These costs include the unavoidable routine maintenance costs that are incurred annually.
- Net Present Value (NPV) -- It is the net cumulative present worth of difference between a series of benefits and costs that are encountered in the life time (analysis period) of a project. The PV method involves the conversion of all present and future expenses and benefits to a base of today's costs. The present worth of planned future funds is equivalent to the amount of money needed to be invested now at a given compound interest rate for the original investment plus interest, to equal the expected cost at the time needed.
- Nominal Interest Rate—An interest rate that is not adjusted to remove the effects of actual or expected inflation. Market interest rates are generally nominal interest rates.
- Probabilistic Approach – This approach applies the recognized procedures but taking into account the uncertainty of the input variables. The results of this approach will be an entire range of outcomes with probability distribution.
- Real Interest Rate – An interest rate that has been adjusted to remove the effect of expected or actual inflation.
- Rehabilitation Costs—The cost for the activities associated with restoring or rehabilitating the facility to function at an acceptable level of service.
- Sunk Cost – A cost incurred in the past that will not be affected by any present or future decision. Sunk costs should be ignored in determining whether a new investment is worthwhile.
- Treasury Rates – Rates of interest on marketable Treasury debt. Such debt is issued in maturities ranging from ninety-one days to thirty years.
- Unit Value of Time—In transportation projects this term refers of the cost of time attributed to one hour of travel, which is usually different for cars and trucks.
- User Costs—Indirect or non-agency (soft) costs which are accrued by the facility user and the excess costs incurred by those who cannot use the facility because of some agency requirement. In highway project, these costs should include time delays, vehicle operating and crash costs associated with using a

facility under normal and forced operation.

- Value of Travel Time—Vehicle travel time multiplied by the average unit value of time.
- Vehicle Operating Cost—The mileage-dependent cost of driving cars, trucks, and other motor vehicles on the highway. This includes the expense of fuel, oil, tires, maintenance, and vehicle depreciation attributable to highway miles.
- Vehicle Travel Time—The total hours traveled by a specific vehicle.
- Accident or crash costs – costs associated with damage to the user's vehicle and/or other vehicles and/or public or private property, as well as injury to the user and others.
- Activity – a specific action performed by the highway agency or the contractor, such as initial construction or a preservation/rehabilitation.
- Administrative Costs – cost incurred in contract management administration overhead expenses.
- Agency – a government organization responsible for initiating and carrying forward a highway program for the general public. May be federal, state department of transportation (DOT), metropolitan planning organization, local government, etc.
- Agency costs – costs incurred by the agency over the analysis period.
- Alternatives – the complete set of initial and future activities that will satisfy established pavement performance objectives of a project.
- Analysis period – the timeframe over which the strategy alternatives are compared.
- Annual worth or equivalent uniform annual cost (EUAC) – all costs over the analysis period expressed in terms of an equivalent annual value that is the same for every year of the analysis period.
- Benefit-cost analysis – an analysis in which all consequences of the investment are measured in or converted to economic terms.
- Benefit-cost ratio (B/C) – the ratio of a project's benefits (to the public) to its costs (to the government).
- Concrete pavement preservation (CPP) – a set of non-overlay techniques that repair isolated sections of deteriorated pavement, or prevent or slow overall deterioration, as well as reduce the impact of traffic loadings on the pavement; also known as preservation.
- Constant dollars – costs of items as if they were incurred in the year in which the life-cycle cost analysis is conducted.
- Consumer Price Index (CPI) – An inflation index compiled by the U.S. Department of Labor's Bureau of Labor Statistics (BLS) to reflect the change in retail prices for a selected set, or "market

basket," of purchases of clothing, food, housing, transportation, medical care, entertainment, education, and other items.

- Delay costs – costs to motorists due to reduced speeds and/or the use of alternate routes.
- Design period **(design life)**– the period of time for which either a new pavement or a rehabilitation treatment is designed to serve. It is the time from original construction to a terminal condition for a pavement structure. A terminal condition refers to a state where the pavement needs reconstruction.
- Discount rate – in banking, the rate that commercial banks and other depository institutions are charged on loans from the Federal Reserve. In life-cycle cost analysis, the rate that reflects both the time value of money (interest rate) and the decrease in purchasing power (inflation rate) over time; also called the real discount rate.
- Equivalent Uniform Annual Cost (EUAC) – see Annual worth.
- Future costs – costs incurred after the beginning of the analysis period.
- Incremental benefit-cost analysis – process by which a project is judged more favorable than another if the additional increment of benefit to be gained exceeds the incremental increase in cost.
- Inflation rate – the rate of increase in prices; a measure of the decline of purchasing power.
- Initial costs – costs incurred at the beginning of the analysis period.
- Interest rate – the rate of return on an investment.
- Life-cycle cost analysis – a procedure for evaluating the economic consequences of mutually exclusive project alternatives over a period of time.
- Maintenance and operation costs – the daily costs associated with keeping the pavement at a given level of service.
- Net present value (NPV) - The net value of all present and future costs and benefits converted to a single point in time using a real discount rate factor.
- Network-level analysis – analysis of the condition and needs of an entire network of roadway sections.
- Performance period – The best estimate of the expected life of a pavement or a rehabilitation treatment. For a newly constructed or reconstructed pavement, the performance period is the design period. For some rehabilitation treatments that are not designed for a specific time period or number of traffic loadings, the performance period must be estimated from field performance observations or empirical models developed from field performance data.
- Present worth (PW) – the equivalent value at the present, based on the time value of money; the

monetary sum equivalent to a future sum or sums when interest is compounded at a given rate; the discounted value of future sums.

- Preservation – see Rehabilitation.
- Private entity – a private owner of a roadway, such as a concessionaire.
- Probabilistic analysis – an analysis in which the variability of each input is taken into account and used to generate a probability distribution for the calculated life-cycle cost.
- Producer Price Index (PPI) – a family of Bureau of Labor Statistics indices that reflect changes over time in the prices received by domestic producers for a variety of goods and services.
- Project-level analysis – analysis of the condition and needs of a single roadway section.
- Public entity – a government (local, State, or Federal) owner of a roadway.
- Real discount rate – see Discount rate.
- Rehabilitation – the act of restoring a pavement to former condition. To restore to near original condition.
- **Reconstruction** – to comprehensively rebuild to a new condition with current criteria.
- Residual value – the cost recovered or that could be recovered from a used property when removed, sold, scrapped, or reused. It refers to the net value from recycling the pavement. The differential residual value between pavement design strategies is generally not very large, and, when discounted over 35 years, tends to have little effect on LCCA results.
- Salvage Value represents value of an investment alternative at the end of the analysis period. The two fundamental components associated with salvage value are residual value and serviceable life.
- Serviceable Life represents the more significant salvage value component and is the remaining life in a pavement alternative at the end of the analysis period. It is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period. For example, over a 35-year analysis, Alternative A reaches terminal serviceability at year 35, while Alternative B requires a 10-year design rehabilitation at year 30. In this case, the serviceable life of Alternative A at year 35 would be 0, as it has reached its terminal serviceability. Conversely, Alternative B receives a 10-year design rehabilitation at year 30 and will have 5 years of serviceable life at year 35, the year the analysis terminates. The value of the serviceable life of Alternative B at year 35 could be calculated as a percent of design life remaining at the end of the analysis period (5 of 10 yrs or 50%) multiplied by the cost of Alternative B’s Rehablitation.