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Examination of Selected Public Transportation Modes in Addis Ababa City

IN A PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN CIVIL ENGINEERING (ROAD AND TRANSPORT ENGINEERING)

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Abstract

Addis Ababa is the capital city of Ethiopia with population of 5 million and the fastest growing economy in Africa. However, urban transportation system is one of emerging problem in Addis Ababa. The increasing public transportation demand, mobility, ridership, accessibility, capacity, congestion, affordability, health and safety problems need urgent solution. Currently the city's administration is on the way to introduce public transport like Bus rapid transit. Even though the Light Rail Transit has operational, maintenance, accessibility problems it caters more than 120,000 riders per day, on average. However, quantitative and qualitative benefits and costs are not well studied from the city`s context. The general objective of this study is to examine Addis Ababa Light Rail Transit and Bus Rapid Transit systems against multifaceted criteria. The first objective is the comparison of life cycle cost-benefit analysis among AA LRT and AA BRT. The second objective is to examine the effect of AA LRT infrastructure`s on the surrounding built-up activities using a selected line from Megenagna to Sealite-Mihiret.

The multifaceted LCCA is conducted for 30 years and using a discount rate of 10.23% to convert costs and benefits into present values (2019 USD. The result shows that that the NPV of AA BRT with trolley is 23,340,539.98USD/km which is greater than the other two alternatives. AA LRT has 12,752,547.77USD/km and AA BRT with diesel buses has 7,537,666.36USD/KM of NPV. The Benefit to Cost Ratio (BCR) of AA BRT is 2 and 1.5 per km for trolley and diesel buses which is higher than that of the LRT with 1.24 per km. Sensitivity analysis is also conducted by increasing selected costs and decreasing selected benefits resulting in a decreased value of NPV which is positive and BCR which is greater than one. To attain the second objective, 384 questionnaires were distributed for residents located around 500m distance from the both sides of the selected LRT corridor. The result shows for more than 71% and 68% of the respondents, there is a longer distance and time respectively whether they use walking and/or other public transportation modes after LRT is constructed. 82% of the residents reacted that the infrastructure increases the width of the roadway which inhibits their crossing movement and decreased their neighborhood interaction.

Finally it is concluded that the AA BRT with trolley buses the most cost effective option. But by enhancing the annual benefits of the MRTs through simple cost effective modifications to attract more passengers, their introduction and future expansion is more recommendable according to this study`s result. Additional recommendations from the result of sensitivity analysis proven that the agencies that manage these mass rapid transit systems should consider adding up more benefit categories and more benefit amounts to increase viability, efficiency, cost effectiveness and affordability. On the other hand, the result from the estimation of AALRT`s impact on non-users shows that the infrastructure has negative impact on them. But this can be solved by conducting proper planning through assessing its effect on surrounding users before expanding it.

Evaluating impacts only on the direct users of the mode and the agency is not a correct way of assessment. So, before implementation of any mass rapid transit systems within the city, it is recommendable to also examine their monetary and non-monetary impacts on external and internal users in order to reduce or alleviate the corresponding negative effects. It should be encouraged to attain a sustainable development in all public transportation modes in general. Therefore, this study can be used as an input for Policy and planning decisions which often involve economic analysis to determine whether a particular Mass Rapid Transit option is cost-effective or efficient, viable and which option provides the greatest overall benefits.

Key words: Addis Ababa, Bus Rapid Transit, Light Rail Transit, Life cycle cost, Life cycle benefit, Comprehensive examination

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List of Abbreviations

AA BRT – Addis Ababa Bus Rapid Transit

AACRA - Addis Ababa City Road Authority

AACTA - Addis Ababa City Transport Authority

AA LRT - Addis Ababa Light Rail Transit

AARTB - Addis Ababa Road and Transport Bureau

ACB - Anbesa City Bus

ATAP - Australian Transport Assessment and Planning

BCR – Benefit to Cost Ratio

BRT – Bus Rapid Transit

CO2 – Carbon di Oxide

CO – Carbon Mono Oxide

CSA – Central Statistical Agency

DFID - Department for International Development

ERC – Ethiopian Railway Cooperation

ERCD - Economic Research and Regional Cooperation Department

GDP – Gross Domestic Product

HC – Hydrocarbons

iRAP – International Road Assessment Program

ITDP - Institute for Transportation & Development Institute

LCB – Life Cycle Benefit

LCC – Life Cycle Cost

LCCA – Life Cycle Cost Analysis

LOS - Level of Service

LRT – Light Rail Transit

MoFED - Ministry of Finance and Economic Development

MRTS – Mass Rapid Transit System

NPV – Net Present Value

PM10 – Particulate Matter

PPH - Passengers per Hour

TCRP - Transit Cooperative Research Program

TDM – Transportation Demand Management

TRB – Transportation Research Board

UATP – African Association of Public Transport

UITP - International association of Public Transport

VOT – Value of Time

VTPI – Victoria Transport Policy Institute

WHO – World Health Organization

Chapter One
1. Introduction

1.1. General Background

The urban population in Ethiopia is estimated at only 16.1 percent in 2007, which makes it one of the lowest in the world. But this is forecasted to change radically to 31.1 percent on 2037 (Central Statistical Agency (CSA) Ethiopia, 2013; World Bank, 2015). As one of the fast growing urban centers in East Africa, the capital of Ethiopia, Addis Ababa is also subjected to the above mentioned rapid population growth. By using Central Statistical Agency survey of 2007 as baseline, the capital`s Population is estimated as 4.2 million on the year of 2017 and projected to increase up to 5 million in 2019 with 3.8 percent of annual growth rate (World Bank, 2018b). This leads to greater demand in every infrastructure and service within the city which mainly includes transportation.

The city's approach to address urban transport problems over the past years was predominantly through expanding the transport infrastructure. The total length of the road network in Addis 3761.1 km in the year 2018, but this could not make the desired improvements by fulfilling the increased demand (Addis Ababa City Road Authority, 2019). The increase in road length is also not balanced with the growth in the number of vehicles on these roads. According to Addis Ababa City Administration Driver and Vehicle Licensing and Control Authority data of 2018/19, the current vehicle number in the city is around 567,000. Figures show that the car ownership rate is low when compared to most global cities (Addis Ababa City Administration Driver and Vehicle Licensing and Control Authority, 2019). However, the rapid economic growth in recent years is expected to lead to a strong increase in vehicle ownership in the coming years which leads to a negative impact on mobility, traffic congestion and delay. The delay caused due to congestion will result in long total travel time from place to place. In addition, the majorities of vehicles in the city are aged and poor in quality especially minibusses, taxis, kitkit buses, higer buses, automobiles and so on. This situation coupled with road traffic crash, air pollution, high energy emission and health related problems leaves the city`s transportation planning mechanism in question. Generally, the lack of consistent combined efforts from the various traffic, transport and road stakeholders and policy makers is the core reason for Problems regarding transportation management within the city.

The modal split in Addis Ababa shows 54% of walking, 31% of Public transportation (buses and mini-buses) and 15% of personal vehicles coverage (Addis Ababa City Adminstrarion Road and Transport Bureau, 2018). Public transportation system is one of the most common transportation modes used in Addis Ababa due to the low economic status of most people in the city who cannot afford to buy a private vehicle and to pay for most public transportation modes. The majority of public transportation users prefer Anbessa City Bus and mini-bus taxis which serves about 16.17% and 46.65% of the total passengers respectively (Addis Ababa City Transport Authority, 2018a). Public transport needs to be more attractive for people to shift to it from their personal cars and other vehicles. It is in this respect the government has constructed the two lines of Addis Ababa Light Rail Transit (LRT) System totaling 34 km with 39 stations which was opened on September 20, 2015 (Addis Ababa

Light Rail Transit Operator, 2018). In addition to this, one bus rapid transit (BRT) corridor of 23 stations with a total length of 17.7km is on its bidding stage along with a further possible lines identified by the City`s transport authority and other stakeholders (Addis Ababa Road and Transport Bureau, 2018a).

Cities with rapid increase of urban population have been implementing mass rapid transits (MRTs) as an effective solution for sustainable mobility. There have been a total number of 53 billion passengers carried by mass rapid transits in 2017 as surveyed from cities mainly from Asia, Europe, Latin America, North America, and Middle-East North Africa (International Association of Public Transportation, 2018). In densely populated urban areas MRT provide higher levels of passenger capacity than standard bus services, along with faster and more reliable journey times. The capacity and journey time benefits are achieved by a combination of the use of high capacity vehicles, increased service frequency, and high levels of priority and segregation over other modes, particularly general traffic (Fox, 2000; Y.P.Singh and Kashyap, 2016). On other hand, MRTs serve as an affordable means of public transport in developing cities populated with low income societies. As a policy brief report of International Association of Public Transportation (UITP) on 2016 dictates, without public transport, other sustainable and innovative mobility services cannot offer an affordable alternative to car ownership. So, promoting and improving mass rapid transit delivers a substantial benefit to the economic, social and environmental system of cities.

Choices of transit options are choices on the city`s future (Wright and Karl Fjellschaft, 2003). Among the rapid transit systems, choosing between Light Rail Transit (LRT) and Bus Rapid Transit (BRT) has become most cities` struggle. Cities especially densely populated ones have been implementing one of the two using mechanisms that answer questions like which is more economical, affordable, and clean (Lyndon Henry & Todd Alexander Litman, 2014).

A comprehensive study of transportation benefit and costing method can be used to evaluate the social, economic and environmental impacts of MRTs. These impacts can be internal (user) or external (others) or social costs, fixed or variable, market or nonmarket. Using the best available data, this method provides monetized estimates of public transits (Litman, 2012). Therefore, it provides costs values in a format designed to help users easily apply this information to policy analysis and planning situations. It evaluates the full costs of a particular MRT activity or project and compares the incremental benefits and costs of different options. More comprehensive transport planning considers a broader range of direct and indirect impacts occurring in community, including some impacts ignored by conventional transport economic evaluation, such as downstream congestion, vehicle ownership costs, parking costs, environmental impacts, mobility of non-drivers, equity objectives and land use impacts. This tends to favor alternative modes and mobility management strategies, because it takes into account a wider range of impacts and users.

Life cycle cost analysis is one of the Benefit-Cost Analysis that incorporates the time value of money which allows comparisons between alternatives that provide benefits and costs at different times. Therefore, this study will help policy makers in planning and decision making, while choosing the right type of mass rapid transit system for the near future application in Addis Ababa.

1.2. Statement of Problem

The Addis Ababa Light Rail Transit might be segregated from the general traffic to remove congestion and other urban transportation challenges but it encounters numerous problems. For instance, the current headway as stated by AA LRT survey data of 2019 is 12 minutes if not interrupted with scarcity of electricity and traffic on at-grade intersections. According to Nallet C. study on 2018, the lack of frequency, train and integration in to the existing transportation network are the obstacles to the AALRT (Nallet, 2018). A report on safety inspection of AALRT corridor discusses that the infrastructures at stations and crossing provided are not appropriately placed with respect to safety of passengers and pedestrian. Intersection points with the traffic are contrasting with the LRT safety standard. There is also an integration problem among the AALRT and other public transportation modes (Imamoglu *et al.*, 2016). There was also a negative effect on the economic benefits of industries and private firms during and after the LRT construction which must be considered before the next expansion stage is started (Negrew, Wubishet and Ginbo, 2016).

As the experiences from other related cities imply, the provision of Bus Rapid Transit systems comes up with diversified challenges. The BRT of Bangkok, Delhi, Hanoi, Lagos, and Lima can be taken an example to show this. Bangkok and Hanoi have fallen below expectations in terms of ridership, and are struggling to survive. Lima's BRT corridor is of high quality but the city has failed to extend it. The BRT system in Lagos is only "lite" although superior to the paratransit services that it replaced. After major controversy, Delhi has already removed its BRT line (Nguyen and Pojani, 2018). As some studies indicate, during BRT operation period, the major cause of delay in the BRT system occurs frequently when encountered by intersections of major roads. This will lead to a reduced ridership, if not managed well (Dube *et al.*, 2017). In addition BRTs that use diesel-fueled vehicles have air pollution and environmental impact needs to be examined carefully (Betancourt *et al.*, 2019). When we come to AA BRT system, there is no compiled study on its impact analysis and life cycle cost analysis to check its long term effect with the city`s context.

The conventional methods of measuring the sustainability benefits of the mass rapid transit system are deeply rooted in the economic theory and tend to evaluate transportation performance based on travel distance, which favors mobility over accessibility, faster modes over slower modes, and speed over comfort (Litman and Doherty, 2011). Accordingly, the reduction of negative impacts of urban transportation through improved public transit is not yet well quantified in Addis Ababa. The growing demand of the city on efficient, affordable, reliable, time saving, safe, clean, secure, attractive and environmental friendly public transportation will not only be fulfilled by prioritizing the expansion of mass rapid transits but also by examining their overall impact with the appropriate and comprehensive method. Thus, the transit systems can give an interminable benefit for the people, the stakeholders, the government and the surrounding environment. Accordingly, the aim of this thesis gives an emphasis on monetizing all the possible and sensitive impacts of Mass Rapid Transit (MRT) options in order to estimate their costs and benefits. This is done by quantifying the life cycle cost of the AA LRT and BRT which helps to include the estimation of almost all of their social, environmental, and economic impacts. So, it will enable us to answer question such as which one is more cost efficient and effective for long term implementation and operation. Since the thesis encompasses multi criteria analysis of the two MRT systems with a comprehensive evaluation method, it will guide policy makers and planners on choosing among the alternatives before challenges reappear. Therefore, the decision of Addis Ababa City Administration to develop an optional mass rapid transit system can use the help of this thesis as an input or as a tool.

1.3. Research Questions

The study gives emphasis on the following research questions in order to achieve its objective.

1. What are the life cycle costs and benefits of the LRT and BRT in Addis Ababa city?
2. What is the effect of the LRT infrastructure location on the surrounding built-ups` activity?

1.4. Objective

1.4.1. General Objective

The general objective of this paper is to examine the recent mass rapid transit modes through multifaceted criteria analysis and to recommend better option for future stability in Addis Ababa city.

1.4.2. Specific Objective

The specific objectives of the study are

1. To compare the life cycle costs and benefits of the Ayat-Torhailoch and Minilik-Kaliti Light Rail Transit and B-2 or Winget-Jemo Corridor of Bus Rapid Transit in Addis Ababa city
2. To examine the impact of the Addis Ababa Light Rail Transit infrastructure`s on the surrounding built-up activities

1.5. The Scope of the Thesis

The study is confined to the capital of Ethiopia, Addis Ababa which involves a rapid increasing of motorization. The overreaching aim of this work is to examine and compare the impacts of the LRT and BRT based on multifaceted criteria and comprehensive analysis and to recommend better option for future public transit development within the city. In order to achieve this, estimation of the life cycle cost and benefit of both mass transit modes is done by monetizing their sensitive and available environmental, social, and economic impacts on the user, the agency and the surrounding environment. Both corridors of the AA LRT are included in this study. The BRT corridor, B-2, located from Winget to Jemo with 23 stations and a total length of 17.7km is included with in the study.

1.6. Significance of the Thesis

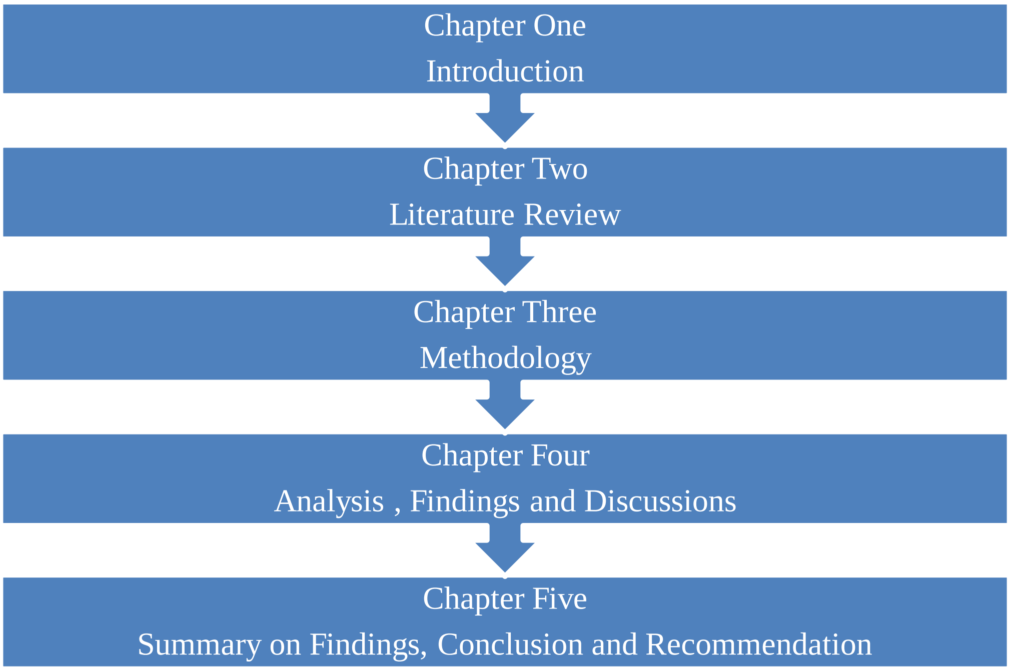
As the current status of Addis Ababa indicates the implementation of cost efficient option like clean, safe and efficient mass rapid transit systems is a basic necessity. Previously, there was no study conducted on the comprehensive analysis of life cycle costs and benefits of the recently developed Mass Rapid Transits in Ethiopia. There are only conventional studies which exclude the adjacent impacts of these modes and result in solutions to one problem that exacerbate other problems. On the contrary, this study quantifies all the sensitive and available social, environmental and economic impacts of these modes through monetizing and subsequently identifying whether the project is cost effective, less life cycle cost, economically viable and affordable. Based on this, it will be possible to choose the better Mass Rapid Transit (MRT) option for current implementation and for future expansion. The budget to be spent on developing MRTs should not lead to any resource loss in the future and debt should be returned at the earliest stages of operation. Questions like how will capital costs be met; how will the year-to-year operating costs be met and other financial issues will be answered by this study. Therefore, it will be easy to improve the growing problem of transportation in Addis Ababa related to the increasing public transport demand, mobility, ridership, accessibility, capacity, congestion, affordability, environment conservation, health and safety problems that need urgent solution. Therefore, this study can be used as an input for Policy and planning decisions often involve economic analysis to determine whether a particular MRT option is cost-effective, and which option provides the greatest overall benefits. In general, the study provides the way forward in the development of the city`s public transportation by recommending the better option and by considering different perspectives.

1.7. Limitations of the Thesis

This study comprises a wide range of impacts incurred by the recent mass rapid transits in Addis Ababa city. In order to convert impacts to cost and benefit values, a number of data are collected from different governmental organization official documents and published related studies from Ethiopia and other countries. So, there were many limitations related to the secondary data`s reliability. Especially, data for life cycle cost analysis are composed of assumptions and trends both from local and foreign countries experience. Due to the un-availability of local data on some cost and benefit input parameters; respective assumptions are taken from the experience of other countries` cities with similar population and economic status. So, these assumptions may be biased due to the difference in geographic, social, political and other status between Addis Ababa and those cities. This was the major limitation while conducting the study. The other general limitations which occurred while collecting secondary data from local governmental organizations can be listed shortly as the following.

I. Unavailability of updated data on the input parameters to calculate cost and benefit which limits the depth and width of the research work.
II. Unreliability and poor quality of transport-related data which is subjective sometimes.
III. Unwillingness of giving secondary data from company`s or an authority`s official document.
IV. Unavailability of organized data or document in some companies which consumes the researcher`s time.

1.8. Structure of the Thesis



1.9. Organization of the Thesis

The study is structured in five chapters. The first chapter is the introductory section which dictates about the current status of public transportation system and its problems in Addis Ababa. It encompasses subtopics such as the general background of the study, statement of problem, objective of the study, research questions, the scope of the thesis, significance of the thesis, limitations of the thesis, and structure and organization of the thesis. In the second chapter of this thesis, literature review on economic, social, safety, health and environmental impacts of both BRT and LRT will be highlighted. The experiences from other successful cities are discussed in this chapter in addition to review on the methodological approach on how to examine both MRTS. Chapter three covers the methodology used to accomplish the objective of this thesis. The subtopics incorporated and clarified in this chapter are data types, sampling method, data collection, data interpretation, data presentation, and data analysis. The next chapter which is chapter four gives the analysis of the findings and discussion on them. Finally, the fifth chapter presents conclusion and recommendation based on the discussions provided.

Chapter Two
2. Literature Review

This chapter offers a detailed literature review on to recent publication. It reviews on the available published journal articles and conference papers on the examination, evaluation and comparison of Mass Rapid Transits specifically Light Rail Transit and Bus Rapid Transit. The recent and comprehensive methods for evaluating mass rapid transits are discussed in details which are used as input for the completion of this thesis.

2.2. Urban Transportation System

Urban transportation is all types of means of transportation used in urban areas. Urban transportation plays a crucial role in urban development by providing access for people to education, markets, employment, recreation, health care and other key services (Pojani and Stead, 2015) .

Globally, highly populated developing cities with adjacent rapid economic growth, income rise and geographical expansion are facing urban transportation challenges. Among the problems, the most noticeable one recently is severe congestion due to high vehicle number on roads. Congested roads lead to delay causing high travel time and thus reduce productivity of the individual because of late arrival at work places which then affects the city`s overall economic growth (Elisonguo, 2013; Raheem S. B., Olawoore W. A., 2015; Lomendra *et al.*, 2018). The other frequent and congestion related problems are air pollution and greenhouse gas emission. As it can be seen from the recent WHO reports, urban air pollution has also become a big problem that adversely influences the health of people and their environment causing approximately 7 million deaths in the world every year (World Health Organization (WHO), 2018a). In 2013 about 93 percent of deaths and nonfatal illnesses attributed to air pollution worldwide occurred in developing countries, where 90% of the population was exposed to dangerous levels of air pollution. Urban transportation systems contribution to an out-door air pollution is significant (Napitupulu, Ismiyati and Handajani, 2018). The discussion about health problems due to urban transportation will lead us to road and traffic safety issue. I.e., road traffic crash causes 1.35 million deaths per 2018 in the world (World Health Organization (WHO), 2018b). Urban transportation system which is occupied by high number of personal cars, old and poor quality vehicles takes the most responsibility on this scenario. The frequent accidents are also the causes of recurrent delay in major roads of developing countries (Edano, 2014). Noise released from those motor vehicles is also the concern of cities which are populated with high number of residents and working and learning environments (Brecard, Boennec and Salladarre, 2018). In addition, the users of personal vehicles will have less walking time or physical exercise and are exposed to the related health problem (Todd Alexander Litman, 2018). Affordability is also another burning issue in developing cities with relatively lower per-capita income. People in those cities who travel for different purposes daily cannot afford to have expensive transport systems. Therefore, they will be forced to seek jobs only within a limited area. This indirectly affects the economy of the people and the city.

2.3. Public Transportation System

Public transportation is a key actor in revitalizing, regenerating and supporting growth in developing areas characterized by high population density, low income and lack of resources forcing them to depend on public transportation/transit systems, which can transport large number of people at low cost. It is a shared passenger transportation service which is available for use by public for the purpose of travelling from an origin to a destination (International Association of Public Transportation, 2018). The importance of public transportation system lies in a broad range of the social, economic and environmental benefit it provides for cities. It also provides long-term sustainability in terms of reducing highway congestion and moving large numbers of people over considerable distances. This enhances systemic mobility, while decreasing the economic and environmental burdens of increasing private motorized travel (Saghapour, Moridpour and Thompson, 2016).

In developing countries, the primary importance of public transportation is to move large number of passengers to meet mobility demand. However, existing public transportation supply in developing countries does not satisfy the demand for a number of reasons (Ranawana and Hewage, 2015).

2.4. Mass Rapid Transit System

Mass Rapid transit represents an integral and important part of the transportation ecosystem, particularly in metropolitan areas. It describes transport technology and systems targeted densely populated urban areas to provide higher levels of passenger Capacity than standard bus services, along with faster and more reliable journey times. The capacity and journey time benefits are achieved by a combination of the use of high capacity vehicles, increased service frequency, and high levels of priority and segregation over other modes, particularly general traffic (S, Liu and Wei, 2018).

The world first rapid transit was the partially underground Metropolitan Railway which was opened as a conventional railway in 1863 and now forms the part of London Underground. Starting from that time, the expansion of Rapid Transits with modernization and technology has increased. Metro Rail, Metro Bus, Mono Rail, Light Rail Transit and Bus Rapid Transit are the among the currently used rapid transit systems (International Association of Public Transportation, 2018). The value of mass rapid transit as a sustainable solution to urban mobility in the case of rising traffic congestion, air and noise pollution and road safety is acceptable in urban areas (Sakamoto, Belka and Mitschies, 2010). Supporting this idea, a finding from a conference paper on air pollution analysis of mass transportation changes in Indonesian cities implicates that the most appropriate way to reduce or decrease the air pollution level is accomplished by increasing the number of mass public transportation such as BRT and city transport units, with the assumption that 60% motorcycle users will move to using modes of mass public transportation. Specifically, 40% of all motorcycle users will begin to use BRT and 20% will move to the smaller city transports. Furthermore, it is assumed that 50% of private car users will move and use BRT. In addition, trucks are prohibited from using the roads (except for local deliveries) (Napitupulu, Ismiyati and Handajani, 2018). Including these and many other reasons are the cause for growing use of MRTS in different cities.

The benefit of good quality public transit used in cities can be summarized as the following according to Todd Litman`s study about the issue of evaluating public transit criticism on 2018 (Litman, 2018b).

1. Mobility Benefits are benefits from improving mobility options for non-drivers such as
    - Improved transit passenger convenience and comfort
    - Improved mobility and economic opportunity for non-drivers
    - Equity objectives (benefits disadvantaged groups)
    - Option value
2. Efficiency Benefits are benefits from reduced automobile travel such as
    - Reduced traffic and parking congestion
    - Road and parking facility cost savings
    - Vehicle cost savings
    - Reduced chauffeuring burdens
    - Traffic safety
    - Public fitness and health
    - Energy conservation and emission reductions
3. Land Use Impacts are benefits from more compact transit oriented development such as
    - Improved accessibility
    - Preserves open space and reduces costs of providing public infrastructure and services
    - Agglomeration efficiencies increase economic productivity
    - Increased local property values and tax revenues

2.5. Light Rail Transit

According to International Association of Public Transport (UITP), light rail transit (LRT) is defined as “a tracked, electrically driven local means of transport, which can be developed step by step from a modern tramway to a means of transport running in tunnels or above ground level”. In general, the terms tramway, light rail and light rapid transit, are used interchangeably, despite the broad variety of technical solutions. Transit Cooperative Research Program (TCRP) defines LRT as a system of electrically propelled passenger vehicles with steel wheels that are propelled along a track constructed with steel rails. It is a mass transport system that uses rail-based technology and typically operates in urban. Vehicles are usually relatively lightweight, run on steel rails and are driven by overhead electrical wires.

There are also different reasons that can explain public interest for LRT applications. The common rationale used to justify LRT is that this modality allows meeting a diverse set of goals that range from economic to social and environmental considerations. The main advantages of LRT with respect to the bus are its higher capacity for both vehicles and line, lower operating costs, smaller loading gauge (essentially in city center), more comfortable ride and higher speed, reliability and efficiency.

The LRT has the potential to open up a new market for public transport travel in cities where demand can justify the volumes of patrons, a natural progression from a bus based system to LRT (modal shift) may occur on defined line haul routes. Moreover, LRT are meant for solving existing public transport system problems, if significant modal shifts towards urban public transport are to be achieved. But it also requires considerable infrastructure investment like power systems with overhead wires to deliver power to the trains, signal systems, guideway-rail, track ballast; etc. that can influence the final cost and thus choice needs to be dependent on both benefit and cost (Grimaldi, Laurino and Beria, 2010).

2.6. Bus Rapid Transit

The Federal Transit Administration (FTA) defines BRT as a “rapid mode of transportation that can provide the quality of rail transit and the flexibility of buses.” The Transit Cooperative Research Program (TCRP) Report 90 expanded the definition to “a flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and ITS elements into an integrated system with a strong image and identity.” As expressed on the 2015 National Transit Database of US, Bus Rapid Transit (BRT) is a fixed-route bus mode that operates frequent service (short headways), has at least 50 percent of its route on exclusive guideways, and includes features that emulate rail transit modes (Federal Transit Administration, 2016).

Bus Rapid Transit was first designed in South America at the beginning of the 70’s. Curitiba in Brazil was the first city to implement such a “surface metro”. Since the first projects, BRT have always been associated with urban projects. Since then, its application has increased and was opened in Quito; Ecuador in 1996, Los Angeles; USA in 1996, and Bogota; Colombia in 2000. Some latest successful examples of Bus Rapid Transit applications are still present in Curitiba, Bogotà, Ottawa and Brisbane and in many other cities (Simon *et al.*, 2010).

BRT flexibly combines stations, buses, exclusive and segregated busways, and intelligent transportation system elements into an integrated transit system with a strong brand that evokes a unique identity. It provides higher quality of service than traditional urban bus operations because of reduced travel and waiting times, increased service reliability and improved user experience. So, its contribution to urban transformation is tremendous (Hidalgo and Carrigan, 2010). There is a report done by World Resources Institute on 2014 that has four case studies from around the world by using the available data to estimate the net benefit to society from a bus rapid transit project. The case studies include TransMilenio, Bogota, Colombia; Metrobús, Mexico City, Mexico; Rea Vaya, Johannesburg, South Africa; Metrobus, Istanbul, Turkey. The four cases suggest several general conclusions and recommendations about BRT costs and benefits as follows (Carrigan *et al.*, 2014) .

- Shifting from informal/unregulated service with smaller vehicles operating in mixed traffic, to newer, larger buses operating at higher speeds results in significant reductions in vehicle operating costs with BRT (Bogota, Mexico City and Istanbul).
- Capital costs and bus operating costs were the most significant portion of project costs in the cities.
- BRT systems should be designed to best accommodate the local travel demand and urban context. Choices about expanding capacity with station by-pass lanes, larger stations, or bi-articulated buses, should be driven by corridor demand and available funding.
- The implementation and operation of BRT systems provide an opportunity to strengthen the capacity of institutions at the local level and to improve urban transport regulation.

Therefore, while planning; developing cities with can learn a lot from the experience of those case studies.

Generally, the BRT mode is quickly becoming an effective way to move people efficiently and in a cost effective manner; in terms of both capital and operating costs. Bus rapid transit systems can provide a number of environmental, economic, and social benefits in cities where they are implemented. It is a high-quality, efficient mass transport mode, providing capacity and speed compared with urban rail (light and heavy rail) (InstitutoNacional de Ecologia (INE), 2008).

2.7. Comparison of Light Rail Transit and Bus Rapid Transit

LRT and BRT can be compared using different criteria such as economically, socially, and environmentally and so on. Different perspectives can be seen while comparing those two. In this study`s context, all impacts are converted to economic costs and comparison is done among the two alternatives. In recent years, Light Rail Transit systems and Bus Rapid Transit systems are experiencing a renewed interest as an attractive urban alternative to classic bus systems. With regard to operating costs, LRT ones tend to be lower than those of buses. However, in many cases patronage levels are not maximized in order to keep higher frequencies and this can reduce the per seat cost advantage of LRT (Prayogi, 2017). On the other hand, LRT generally provides higher capacity than BRT service due to its ability to add cars to the train and increase unit carrying capacity (VTA Transit Sustainability Policy, 2007).

Findings from a study on the comparison of Bus Rapid Transit or Light Rail in Ontario on 2016 included the following points (Savarie, 2016).

- BRT requires less of a capital investment compared to LRT and is less expensive to operate and maintain, up to a ridership level of 5000 passengers per hour per direction. After this point, LRT becomes more cost efficient to operate and maintain due to the larger carrying capacity;

- BRT efficiently supports interregional connectivity due to its flexibility over LRT;
- Through proper integration and planning, both systems can leverage the economic benefits of transit oriented development;
- Safety is largely a function of overall system design; however, increased automation on LRT systems contributes to safer operations;
- Both systems can be environmentally efficient, depending on the power source of the vehicle and mode shift; and
- LRT is the preferred mode of public transit with BRT systems carrying a negative social perception of poor value and service, associated with traditional bus public transit
- There is a major negative social stigma associated with bus based public transit and a very strong preference, both publicly and politically, for LRT due to its higher perceived value.

2.8. Transportation System in Addis Ababa

The current type road transportation modes in Addis Ababa can be grouped as public and private, ranges from motorized to non-motorized. The private motor vehicles are rapidly increasing. This increase is affecting the city`s traffic congestion. The road length increment could not accommodate the existing number of private cars especially at peak hours. This causes a mobility related problem such as delay so that people will have a long travelling time on the road which creates a negative economic impact. The severe congestion is also the reason for high emission from the vehicles which affects the environment and people`s health through air pollution and Greenhouse gas impact. Moreover, the poor quality and aged vehicles add more negative impact on environment and health. The crash rate in the city is also very high in which most of the crash involves these private vehicles. Not only that, these modes are not affordable by most of city`s society who are subjected to low income.

As one of the developing cities, Addis Ababa is facing common transportation problems with a multidimensional consequence. It experiences frequent congestion, raising questions of how traffic is managed. In addition to congestion and delays, the city is fronting problems of high road traffic crashes, air pollution and noise pollution. There are also a high number of traffic crashes around 28,364 annually in the city as the data from Addis Ababa Police Commission on 2018 indicates. Among these private vehicles are accounted for about 50% while public transportation is accounted for 35.5% of the total crash and freight vehicles and unknown. Moreover, as recent studies show emission from aging fleet of vehicles in poor mechanical condition and low levels of fuel efficiency within the city is responsible for the presence of high quantities of air pollutants that cause too series health and environmental problems. It has been estimated that approximately 70% -75% of air pollutants of PM10, SO2, NOX, and CO comes from traffic (Tarekegn and Gulilat, 2018) . According to Benjaminson`s study on 2012, which is cited by Shankute`s report of 2015, the average age of 17 years of vehicles on the city’s streets explains the high number of inefficiently functioning motor vehicle engines that are major contributors to Addis Ababa's air pollution (Shankute, 2015). Consequently, the Addis Ababa Vehicles` carbon emission increases from 105,491.63 on 2009 to 107,601.47 on 2014 in million tons (Mohammed, 2017). This is also related to the low fuel quality used by most vehicles in the city. As a study conducted on sample diesel-fueled vehicles in the city generalizes, Addis Ababa could save between 100 million and 200 million Ethiopian Birr (about $5 million to $10 million US dollars) yearly in fuel costs. Not only that, air pollution produced by these vehicles` emission is creating significant health consequences (Shankute, 2015). Moreover, the aged and low quality vehicles with congestion also produce noise causing a health problem on the people. Even if the increase in road infrastructure which is taken as an action by the city`s authority it could not be balanced with the growth in the number of vehicles (Fenta, 2014; Negrew, Wubishet and Ginbo, 2016). So, it is clear to see that these growing externalities make the city`s transport system economically unsustainable and expensive to the society.

2.8.1. Public Transportation in Addis Ababa

In spite of the above, the better option is to provide an affordable public transportation mode with a sustainable benefit. Taking that into account and in order to improve the increasing demand, the city transport authority has been increasing the capacity, the number and quality of its respective public transportation modes. The currently used public transportation modes are Light Rail transit (LRT), Anbesa City Bus (ACB), Sheger Mass Transport, Public Service Employees Transport, School Buses, Higer buses, Kitkit, Minibuses and Lada Taxi.

As studies indicate, most public transportation modes in Addis Ababa are not affordable especially by the low income people and cannot accommodate the rapidly increasing demand (Fenta, 2014). Even though the role of public transportation is noteworthy, the service provision is not good enough as the demand is much greater than the supply (Tegagne, 2018). This situation is visible at different stations with long waiting lines for minibuses, anbessa buses and inter-city buses especially on peak hours**.** The statistical report of UITP dictates that the abundantly used Minibuses are subjected to congestion and delay. Even if minibuses give door to door transport service than most buses they have higher fares than buses which sometimes instantly increase due to lack of controlling mechanism by the government. Poor service, poor quality and aged fleet are among the characteristics of most of these minibuses (International Association of Public Transportation and African Association of Public Transport, 2010). The number of crash involving min-buses is higher than that of buses and rapidly increasing. As an indicator, the recorded data from Addis Ababa Traffic Police Commission on 2018 displays out of the total annual crash, minibuses contribute about 28% and other buses contribute about 7%. On the other hand, they are overcrowded at places where there is no traffic police to control. This decreases the passengers' security, safety and comfort. On the other hand, to reduce the dependency level of passengers using minibuses, the transport and road sectoral offices under AA City Administration have been taking actions towards improving the public transportation system. Among those actions, increasing the number, the quality and the service of Anbessa City Bus with new and improved vehicles is the major one. Moreover, provision buses for Addis Ababa civil servants only and school buses for students at public schools are done as a solution for the increasing demand. Yet the problem is unsolved and people`s mobility with in the city is still limited. The main problem related to Anbessa bus is delay caused due to its low frequency and long waiting times. The average waiting time for Anbessa is estimated as 21 minutes on 2018 which made the bus unreliable for users and pushed them to prefer minibuses (Addis Ababa City Transport Authority, 2018b). Although it has a better carrying capacity than other public transportation means, it is overly occupied mostly at peak times trying to fulfill the increasing demand (Kenea, Kinnear and Akbar, 2017). This also makes it unattractive by passengers. Not only that, the presence of the old Anbessa buses and Higer buses is contributing to the low quality of air and the associated health problems**.** So, it is possible to conclude that the existing public transportation system needs to be examined properly against social, economic and environmental impacts and improved immediately.

Before AA LRT started, mobility was normal at 1.07 per capita trip rates; walking is the predominant mode (60.5%). Vehicular ownership is low, according Addis Ababa transport authority report on 2017. Vehicular trip rate is also low at 0.47 per capita. Anbassa Bus Service and Mini-bus Taxi Service are the backbone of Addis Ababa's transport system. They provide limited mobility for the population but suffer from many constraints. Access to finance; an ageing bus fleet; inadequate infrastructure; an adverse external operating environment particularly due to severe traffic congestion; extensive competition, etc. have restrained the growth and efficiency of the various systems. They require transformation and their route structure and service pattern improved. Future public transport capacity must be supplemented by medium and large capacity vehicles preferably incorporating some modern technology.

Addis Ababa public transport system in the East-West and North-South corridors carried more than 1.2 million passengers on the Anbessa bus, Midi bus, mini bus and taxi network before construction of LRT. Since most of the trips require transfers, the number of trips per day is estimated to be approaching 2 million. The mini bus/taxi system carries over 0.5 million passengers and medium buses cover over 0.3 million passengers.

2.8.2. Addis Ababa`s Light Rail Transit

The AALRT is a light rail transportation system in Addis Ababa, Ethiopia which is the first light rail and rapid transit in eastern and sub-Saharan Africa. It has been opened on September 2015 with the aim of improving mass transit demand, reducing congestion and promoting environmental friendly transport system. The final capital cost to build the railway was US$475m, with construction taking three years. 85 percent of its funding is from a loan by the Export-Import Bank of China (Ethiopian Railway Corporation, 2009).

The LRT has two lines of Addis Ababa Light Rail Transit (LRT) System totaling 31.6 km with 39 stations (Addis Ababa Light Rail Transit Operator, 2018). Of the two lines, the east-west line extends 17.4 kilometers, stretching from Ayat Village to Torhailoch (East-West line), and passing through Megenagna, Meskel Square, Lagare and Mexico Square. The north-south line, which is 16.9 kilometers in length, extends from Menelik II Square to Kaliti (North-South) and passes through Merkato, Lideta, Legehar, Meskel Square, Gotera. However, two lines have a common track of about 2.7 km. The common track is the elevated section which runs from Stadium to Lideta covering five stations. Among the 39 stations; 18 stations are at grade, 2 stations are at grade and on intersection, 2 are at grade and on roundabouts , 4 stations are Above grade, 9 stations are Elevated, 1 station is below grade, 2 stations are below ground and at roundabouts, and 1 station is underground.

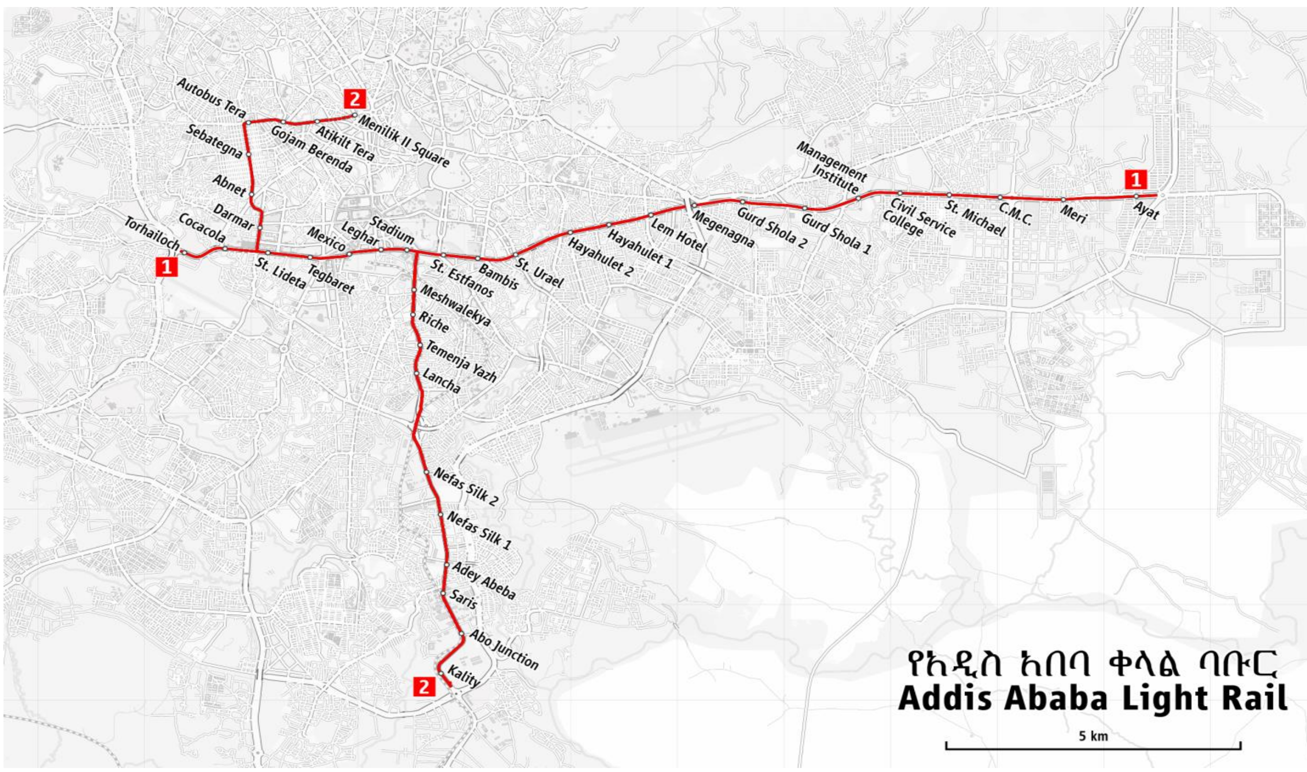


Figure 1: Map of AALRT

Source: (Addis Ababa Light Rail Transit Operator, 2018)

The speed ranges from of 20–70 km/h. Each train has a capacity to carry 317 passengers. It has a capacity of 60,000–80,000 passengers per hour (PPH) in four directions. According to AALRT recently collected data, the system carried on average 115,092 daily passengers in October 2018 with 138,211 passengers as highest passenger load during a single day and the service frequency is 10 minutes during peak hours on both lines and 20 minutes during off-peak hours (Addis Ababa Light Rail Transit Operator, 2018).

Table 1: Annual Ridership of AALRT

PASSENGER VOLUME				
HAULED PASSENGER PER YEAR				
Route	2015	2016	2017	2018
East-West	3053616	27163513	11899465	21825181
North-South	5727157	18128003	11604440	15930180
Total passenger	8780773	45291516	23503905	37755361

Source: (Addis Ababa Light Rail Transit Operator, 2018)

Another WRI inspection report held on 2016 indicates, it transports an average of 120,865 passengers per day (Imamoglu *et al.*, 2016). Moreover, the revenue Tariff or passenger Ticket ranges from 2 – 6 birr as the travel distance increases. This makes the LRT as one of the most affordable modes especially for long distance travelers on the corridor.

Studies that dictate the LRT needs more assessment for future expansion can be seen as the following. There is a lack of frequency; train and integration in to the existing transportation network are the obstacles to the AALRT. The crowd at rush hours and the random waiting time ranging from 10 to 30 minutes with no indication discourages passengers' attraction to the mode. And most of them will be forced to use minibus taxis which take additional advantages at these busy times to increase their price. The other finding from this study shows that the passengers are very satisfied when they travel at times when there is no use which is during the day or at the weekend, for leisure and shopping. This is too far from the main objective of the project to provide a mobility access for work. Additionally, the time spent in other transport modes before and after tram lies between 15 to 40 minutes which makes the entire journey relatively long, approximately one hour. The ticketing stage also takes long time which then sums up to long travel time (Nallet, 2018). A report on safety inspection of AALRT corridor discusses that the infrastructures at stations and crossing provided are not appropriately placed with respect to safety of passengers and pedestrian. The installed infrastructure for physically disabled users is not working. Intersection points with the traffic are contrasting with the LRT safety standard. There is also an integration problem among the AALRT and other public transportation modes (Imamoglu *et al.*, 2016). There was also a negative effect on the economic benefits of industries and private firms during and after the LRT construction which must be considered before the next expansion stage is started (Negrew, Wubishet and Ginbo, 2016).

These issues will raise a sustainability question on its expansion. Therefore, the AALRT needs be examined comprehensively against monetized benefits and costs and put into comparison with other optional and latest mass rapid transits such as BRT. This way it is possible to estimate its life cycle cost which comprises all of its necessary and available social, economic, environmental costs and will help in addressing its problem.

2.8.3. Addis Ababa`s Bus Rapid Transit

The city Government of Addis Ababa has been preparing to implement BRT system in the city starting from the feasibility study of 15 corridors on 2010. Seven of them were selected for detail study. Among these corridors, one is chosen for detail feasibility and design. So, its design was started on 2016 and completed on 2019. This is the BRT line which is selected for this study too. Corridor B2 have 23 stations with a total length of 17.7km and covering Winget, Paster, Atobis Tera, Merkato, Tekele Haymanot, Mexico, Kera, Gofa Gabriel and Jemo areas. The total construction cost for this project is 130 million with 85 million loans from French Development Bank (Addis Ababa Road and Transport Bureau, 2018b).

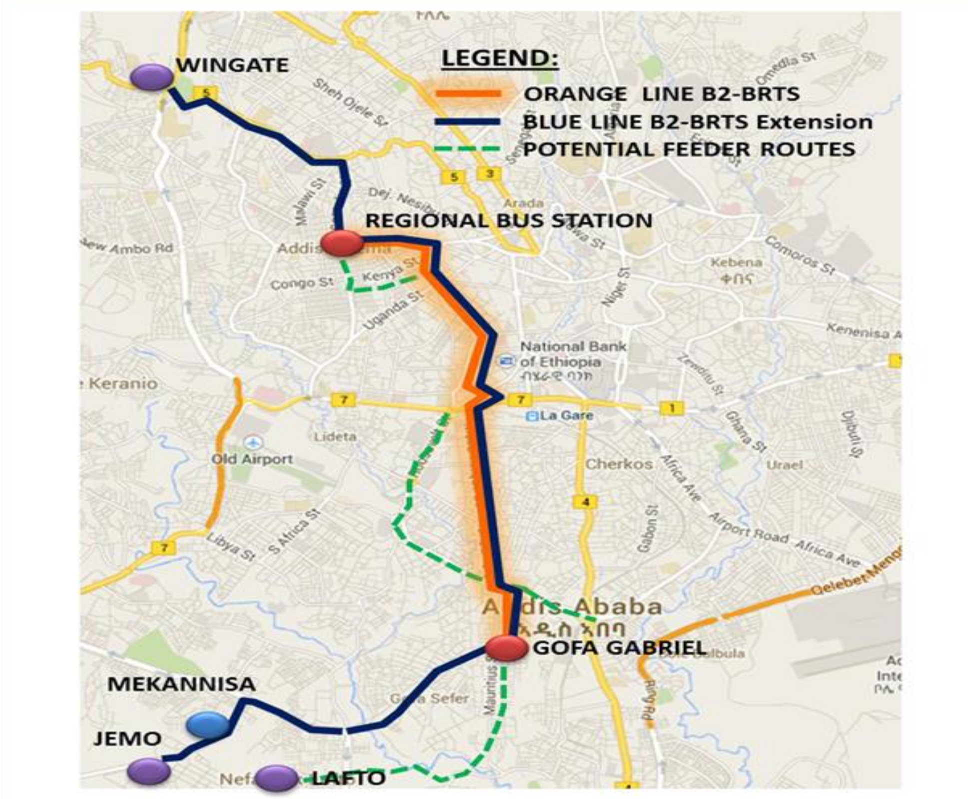


Figure 2: Addis Ababa Bus Rapid Transit Plan

Source: (Addis Ababa City Road Authority (AACRA), 2014)

This project aims to meet urgent needs in terms of urban transport and effective mass transit network development. According to operational plan note of the B2 corridor, the bus line is expected to have a maximum capacity of 6,500 (pphpd) passengers per hour in each direction by using the maximum demand flow of 2019 and to reach more than 400,000 residents. The daily ridership is expected to reach up to 123,000 according to the revised feasibility study of B2 corridor by Addis Ababa City Road Authority. The design headway is 2 minute with an operating speed of ranging from 14 to 40 km/hr. The buses to be used are standard with 18m length articulated and in the future bi-articulated with 24m length. The design capacity of 18m length articulated bus is assumed to be 130 passengers (Addis Ababa Road and Transport Bureau, 2018b).

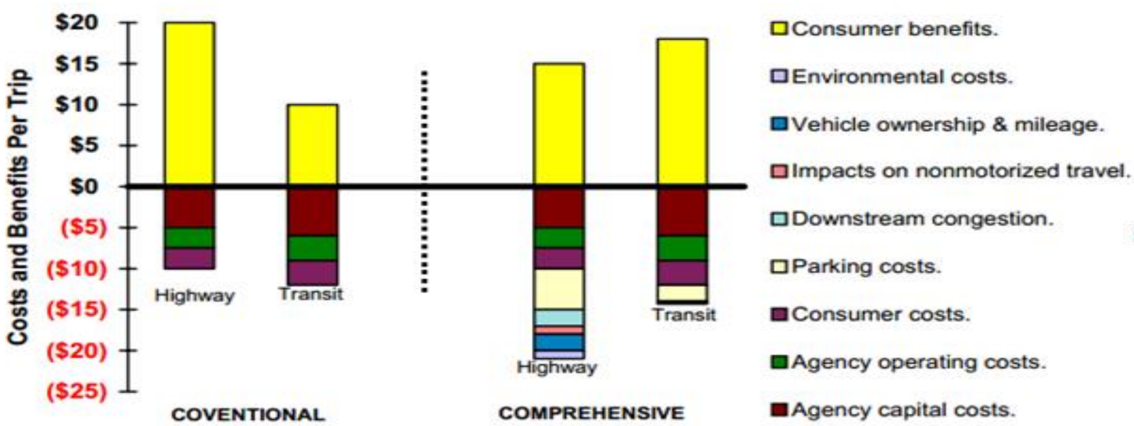
2.9. Approaches to Examine Mass Rapid Transits` Impacts

2.9.1. Comprehensive Analysis Approach

Transportation policy and planning decisions affect virtually every aspect of life which often involves adjustments between conflicting objectives. There should be a framework for evaluating and rationalizing such decisions which helps in examining how benefits and costs vary for different travel modes and conditions. The examination method must support more comprehensive planning analysis by providing benefit and cost information in a convenient and flexible format (Litman, 2012).

There is a recommendation for transport planning policy by the WRI report, i.e., national and municipal urban transport policies dictate the type and quality of urban transport infrastructure cities implement. National and local investment decisions should be predicated on objective and transparent evaluation of alternatives, including an assessment of social costs and benefits (such as a Cost Benefit Analysis) to determine whether proposed projects represent a good use of limited resources. Where possible, project evaluation should consider the distributional impacts which segments of society benefit and which lose (Carrigan *et al.*, 2014).

The more comprehensive analysis uses consumer surplus to calculate consumer benefits. It incorporates parking costs, downstream congestion, impacts on non-motorized modes, additional vehicle costs, and environmental impacts, all of which can be reduced when travel shifts to alternative modes. This analysis indicates that the transit investment provides the greatest net benefits, while the highway option is not cost effective (Litman, 2006).



This figure compares conventional and comprehensive analysis. Bars above the baseline indicate benefits, and those below the line indicate costs.

Figure 3: Conventional and Comprehensive Cost Analysis

Source: (Litman, 2006)

The more comprehensive analysis uses consumer surplus to calculate consumer benefits. It incorporates parking costs, downstream congestion, impacts on non-motorized modes, additional vehicle costs, and environmental impacts, all of which can be reduced when travel shifts to alternative modes. This analysis indicates that the transit investment provides the greatest net benefits, while the highway option is not cost effective.

More comprehensive evaluation is especially vital in growing urban areas where accommodating increased automobile travel is particularly costly; in developing countries where a major portion of residents cannot afford a car; and in any situation where energy conservation, environmental protection or sprawl reduction are considered important objectives (Litman, 2017).

In general, policy and project evaluation should be as comprehensive as possible. Any cost or benefit that may be significant should be considered, including indirect, long-term and non-market impacts. It is particularly important to use a comprehensive evaluation framework when comparing alternatives that affect the range of transportation options available, or the total amount of vehicle travel that will occur in an area (Litman, 2018b). Some impacts are unsuitable for quantification, but should still be considered qualitatively in the analysis.

2.9.2. Economic Evaluation

Economic analysis refers to the evaluation of economic impacts. These impacts are not limited to market resources (goods traded in a conventional market), they can be any scarce and valued resource, which may include money, land, time, health, safety, comfort, and environmental services such as clean air and water. Economic Evaluation (also called Appraisal, Assessment or Analysis) is defined as the method to determine the value of a good, service, activity, policy, program or project. Economic evaluation involves quantifying incremental economic impacts (benefits and costs) to determine net benefits or net value (benefits minus costs), and the distribution of these impacts. In addition, economic evaluation is not limited to market values or measured in monetary unit impacts, it can also incorporate non-market resources or unquantifiable resources such as personal time, health and environmental quality (Litman, 2011).

2.9.2.1. Existing Economic Evaluation Techniques on Mass Rapid Transit Systems

Several previous studies have investigated various types of transportation costs. In addition, different economic evaluation techniques have been used for different types of studies. The purpose also varies which then affects their perspective, methodologies and scope.

A transport cost analysis study on the total costs of private and public transportation in Auckland assesses the external (unpaid) and internal (user paid) cost of transport. It focuses on estimating the total cost of both private and public transport, using a case study for Auckland, New Zealand’s largest city. The external costs (primarily external accident costs, air pollution, and climate change) are significant, 2.23% of regional GDP. Of this private transport generated 28 times more external cost than public transport. The internal cost assessment showed that total revenues collected did not even cover 50% of total transport cost. The study concludes that current pricing results in economically excessive motor vehicle travel (Jakob, Craig and Fisher, 2006).

Another research sponsored by the Swiss government research program on 2010 sited by Victoria Transport Policy Institute`s review on 2018 discusses on the external cost of transport in Switzerland. It estimates various transportation costs, including accidents, noise, building damages, environmental damages (air pollution, climate, natural and landscape damages) and traffic congestion. The summary on the table below shows the estimated costs for 2005. These estimates are based on accident statistics, pollutant or noise emissions and aerial photo analysis. The transport-related proportions were determined and converted into costs. The adopted methods result in an understatement of the effective external transport costs (Victoria Transport Policy Institute, 2018).

Mohapatra, D.R. used Cost Benefit Analysis to show the economic viability of the Addis Ababa LRT. The paper categorizes capital cost, maintenance cost and debt under the project cost. The projects benefits were revenue tariff from LRT, Saving in fuel (gasoline and diesel) due to reduction in number of buses, car and two wheelers, saving in time due to operation of LRT and accidents Savings. These economic parameters are calculated for 32 years from 2016 to 2047. Therefore, the NPV of all the cost streams at 12% calculated as 699.24 million US$. The Economic Internal Rate of Return of LRT project in Addis calculated as 33.63% is by taking the desired rate of return of 12%. Thus the study concluded that the project is economically viable. In addition, the result of the sensitivity analysis from this analysis shows that even in the worst case of increase in cost and decrease in benefits the projects remains economically viable. Even if this work is the first to conduct economic evaluation on AALRT, it did not consider more benefits in reduction in environmental pollutions, reductions in vehicle operating costs, enhancement of health benefit through air quality due to data lack (Mohapatra, 2015).

Abdlemalik Mohammed on 2017 dictates the use of sustainable variables and indicators to assess the performance of AALRT. This study chose sensitive indicators of sustainability using questioners to the professionals from the railway sector, road and transport sector and institutes. The most ranked indicators were benefits such as saving in travel time and reduction of air pollution and Greenhouse gas emissions. These benefits are calculated by comparing the LRT with other modes travelling on the same LRT corridor. The result finally showed that AALRT is able to contribute a sustainable benefit. And it concluded that indicator based multi criteria assessment on large infrastructural projects like Addis Ababa light rail project assessment is reliable because it can prove in a scientific, provable and non-subjective manner, delivering accurate empirical values that are used to measure the rate or level of a sustainability benefit or negative impact, promoting a more informed and reliable implementation. But, the study prioritizes the benefit of stakeholders not travelers in order to select sensitive indicators. This may cause omitting the sustainable development indicators which could be given priority by the society, which benefits the user and surrounding environment. Therefore, the multi criteria assessment should consider all the possible perspectives of users and community (Mohammed, 2017).

Any consumer, business or public policy decision involves some sort of economic analysis. Especially, when making major decisions it is helpful to follow a more explicit and comprehensive process to insure that all significant impacts (costs, benefits and equity effects) are considered.

2.9.2.2. Current Practice on Comprehensive Economic Evaluation of Public Transits

Transit Cooperative Research Program (TCRP) guide book of 2002 on estimating costs and benefits of transit projects and Victoria Transport Policy Institute cost and benefit analysis of 2011 guideline dictates economic evaluation of public transit systems should be supported with comprehensive analysis. The following are some practices of economic evaluation using comprehensive analysis (ECONORTHWEST Eugene and Parsons Brinckerhoff Quade & Douglas, 2002).

Public Transportation Fact Book Statistics of American Public Transit Association on 2002 which is cited by Victoria Transport Policy Institute`s guidebook displays a comparison on different U.S. public transit modes. It can be seen as an example to show the application of comprehensive economic evaluation technique. Expenditures are divided into capital (facilities and vehicles) and operation (labor, maintenance and fuel). Revenues are divided into fares (user payments) and subsidies (other revenues). Transit fares and operating costs vary depending on conditions and perspective. Revenue per-mile is highest for short trips and lower for longer distance trips. Marginal costs tend to be lower than the average costs (a 10% ridership increase increases costs less than 10%) (Victoria Transport Policy Institute, 2017).

As Todd Littman's report of 2011 dictates on economic evaluation, there are several specific techniques are used for transportation economic evaluation. These are cost-effectiveness, benefit cost analysis, life cycle cost analysis, least cost planning, and multiple accounts evaluation. Lifecycle Cost Analysis is Benefit-Cost Analysis that incorporates the time value of money. This allows comparisons between alternatives that provide benefits and costs at different times.

2.9.3. Life Cycle Cost Analysis

Life Cycle Cost Analysis is one of the economic evaluation techniques for transport projects. It is a Benefit-Cost Analysis that incorporates the time value of money in order to allow comparisons between alternative transport modes that provide benefits and costs at different times. For comparison of Mass Rapid Transit projects constructed at different times and conditions, life cycle cost analysis is the best option (Litman, 2006).

This analysis helps in quantifying all the possible transportation impacts into cost components throughout their life time stating from planning until disposal. The transport impacts categorized economic, social and environmental can be converted into monetized terms to ease the comparison. Lifecycle Cost Analysis allows programs or projects to be compared that have benefits and costs occurring at different times. For example, you may want to compare an option that has high capital costs and low operating costs with an alternative that has lower capital costs and higher operating costs. Similarly, it can identify the value of practices that shorten the amount of time required to implement a project, thus delivering benefits sooner (Bangalore Metro Rail Corporation Ltd and Institute of Urban Transport, 2012). Another study dictates that Life Cycle Cost Analysis can be performed at any stage of an asset's life cycle and it can help to provide input to decisions regarding design, manufacture, installation, operation, maintenance, refurbishment & disposal (Sarkar and Shah, 2018).

The practice from India on five urban transportation systems to estimate their full life cycle cost can be taken as an example thereby making "Life Cycle Costs of the Systems" integral to informed decision taking. This report involves Metro Rail, Mono Rail, Light Rail (both at grade and elevated), Bus Rapid Transit System and Ordinary bus Services for cost evaluation with different life spans and capacity by taking assumptions for some inputs. The life cycle cost calculation for 30 years duration for each system involves different specific costs under the categories of operational Infrastructure cost (terminals & depots), opening balance, replacement, maintenance, taxes and duties, non-operating expenses, depreciation expenses, salvage value, and debt. Using these inputs, it calculates Present value of costs and interest amount. These outputs of each transportation systems are compared with each other and helped in deciding on which project to continue with what economic impact (Bangalore Metro Rail Corporation Ltd and Institute of Urban Transport, 2012).

To perform Lifecycle Cost Analysis, benefits and costs are calculated for each time period (usually a year), applying a discount factor to convert all values to a base year. Each future costs and benefits should be expressed in terms of present value in order to calculate Net Present Value. This is done by using discount rates. I.e., the purchasing power of money normally decreases over any given period of time due to inflation and uncertainty. A discount rate adjusts the value of money for time, expressing expected future monetary quantities in terms of their worth today (Kockelman *et al.*, 2013). So, there are the two different kinds of interest rates:

1) Real interest: rate exclusive of inflation
2) Nominal interest: rate inclusive of inflation

The present values are summed to obtain each option's Net Present Value (NPV). This is the full value (benefits minus costs) of the option over the analysis period reflected in one unit.

Litman on 2006 dictates the effect of using discount rate on the final output of economic analysis. Figure 4 shows an analysis without discounting and figure 5 show the same analysis with a 7% discount rate. Without discounting all the costs and benefits are the same annually but with discounting it is possible to observe the change in this values due to time variation.

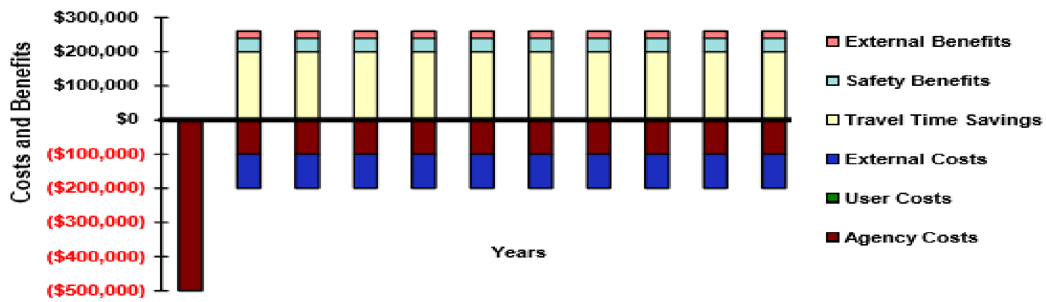


Figure 4: Lifecycle Cost Analysis – No Discounting

Source: (Litman, 2006)

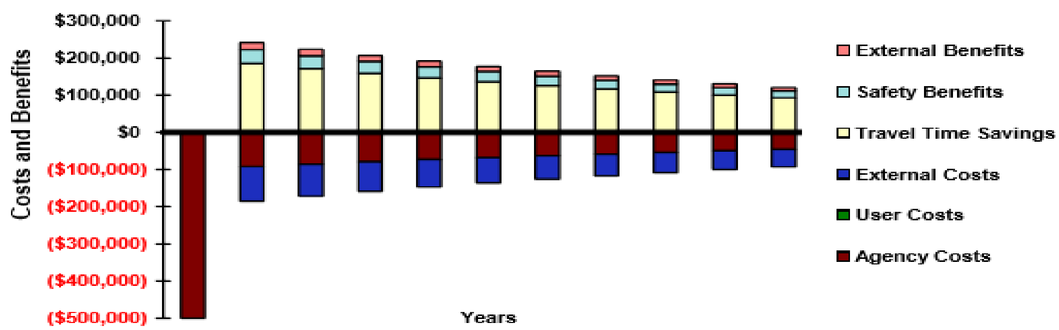


Figure 5: Lifecycle Cost Analysis – With Discounting

Source: (Litman, 2006)

The following general steps summarize a typical economic evaluation using Life Cycle Cost Analysis (ECONORTHWEST Eugene and Parsons Brinckerhoff Quade & Douglas, 2002). This is a hybrid approach that includes life cycle cost analysis of impacts that are suitable for monetization and a rating system for impacts that are unsuited to monetization.

1. Describe each option, including a base-case and one or more alternatives.
2. Define the evaluation framework which identifies all impacts (costs and benefits) and objectives to be considered in the analysis. Classify impacts to avoid double-counting.
3. Quantify and monetize (measure in monetary value) impacts that are suitable for each option.
4. Calculate the total monetized benefits and costs for each year that is being considered (typically 10-20 years for a major investment project), and apply a discount value to

future impacts. Sum the present value of benefits and costs to determine the Net Present Value.

5. Describe, and measure as much as possible, impacts that are unsuited for monetization (such as equity and effects on strategic community development objectives). Rates each alternative according to how much it supports or contradicts the objectives.
6. Conduct sensitivity analysis to determine how changes in key assumptions affect outcomes.
7. Develop various ways to important differences between the options. For example: Produce graphs that illustrate differences in key impacts, Produce a table or matrix that compares each alternative in terms of its costs, benefits and rating in terms of objectives (such as whether it supports or contradicts equity and strategic community development objectives), Identify the distribution of impacts (which individual or group bears costs or gains benefits), and Produce short summaries that describe key differences, and factors that may affect these differences.

These steps can be adjusted and repeated as needed. For example, stakeholders may sometimes request that additional options, impacts or objectives be considered, or that additional analysis be performed to determine the distribution of impacts.

2.9.3.1. Life Cycle Cost and Benefit Components

The detail description of individual cost components that will be used to compare projects is a necessity. According to Todd A. Litman and Eric Doherty report from Victoria Transport Policy Institute Guide line on 2011, the best available 23 costs that comprise all the possible life time impacts of most transportation systems on social life, environment, and economy of all users. These are vehicle ownership, vehicle operation, operating subsidies, travel time, crash (internal and external), Activity (Internal and External), Parking (Internal and External), Congestion, Road Faculties, Land Value, Traffic Services, Transport Diversity, Air Pollution, Greenhouse Gas Pollution, Noise, Resource Externalities, Barrier Impacts, Land use Impacts, Water Pollution and Waste costs (Litman and Doherty, 2011). Some of these costs may be difficult to calculate due to data unavailability and scarce of mechanism in changing into monetized terms. So, all transportation evaluations that use life cycle cost analysis may not include all of the above listed costs.

The life cycle cost components can be categorized into different groups for clarity purpose.

I. <u>Internal and External Costs</u>

Internal costs are costs are borne by a user while external costs are imposed on non-users. Social costs are the total costs to society, including both internal and external impacts.

II. <u>Variable and Fixed Costs</u>

Variable costs are the incremental costs resulting from an incremental change in consumption, and so reflect costs that can be reduced by reduced consumption. Fixed costs are costs which are not affected by consumption. Sunk costs are fixed costs incurred in the past which cannot be recovered.

III. Market and Non-market costs

Market costs involve goods that are traded in a competitive market, such as vehicles, land and fuel. On the other hand, Non-market costs involve goods that are not regularly traded in markets such as clean air, crash risk, and quiet.

At the end of life cycle cost analysis, each projects costs and benefits can be compared using Net Present Value, and Benefit to Cost Ratio. Then it will be possible to check the projects` economic viability. According to the publication of a revised Guideline for the Economic Analysis of Projects, transport Project cost includes Capital cost (infrastructure and equipment), Maintenance cost, Operation cost, Loan interest payment, and Salvage Values (Economic Research and Regional Cooperation Department (ERCD) and Asian Development Bank (ADB), 2017). Project benefit includes Revenue tariff, Fuel saving, Time saving and ridership, Reduction in traffic congestion, Air and noise pollution reduction and Road safety benefits (Injury, fatality, property damage).

The publication also highlighted three summary indicators are used in the cost - benefit analysis.

I. Net present value - Because the costs and benefits of transportation projects will continue over many years, the future costs and benefits are often discounted over the life of a project, in the form of an estimated net present value (NPV). A positive NPV implies that a project offers net benefits.

II. Benefit-cost ratio - A ratio of the net present benefits and cost greater than one indicates that the total benefits to society exceed the costs.

Sensitivity Analysis is also used as one of the main indicators while life cycle cost and benefits analysis. Its importance can be listed as the following (Fuller, 2016).

- It helps to identify which of the input values has the greatest impact on a specific measure of economic evaluation.
- It helps to determine how variability in the input values affects the range of a measure of economic evaluation.
- It helps to test various scenarios to answer “what if” questions.

As mentioned above, some impacts may not be monetized easily; therefore it is important to present the impact using a non-monetized terms if possible. So, the researcher selected one of the impacts of AA LRT on the surrounding residents. This impact is the spatial accessibility of the surrounding residents along LRT corridor towards their destination and other public transportation modes. These residents around the area should be pedestrians while crossing the infrastructure. So, other residents who use automobiles, bicycles and motorcycles are not included under the study in order to be very specific. The residents may travel to work, school, shops, recreation places, social centers, and regional places using walking or using other public transportation modes. While travelling, the residents will encounter LRT corridor. So, the study investigates how their trip is affected by its location. This is done through comparative analysis of before and after LRT impacts on distance and time to travel.

Barrier Effect (also called severance) refers to delays, discomfort and lack of access that vehicle traffic imposes on non-motorized modes (pedestrians and cyclists) (Litman and Doherty, 2016). This report of Victoria transport policy institute by Litman and Dohetry on barrier effects discusses that narrow streets with lower traffic speeds and volumes are easy to cross, wider streets with higher traffic volumes and speeds cause discomfort and delay to non-motorized users. Accordingly, the LRT infrastructure has consumed a wide space along the cross-section of the highways it passes through. This may affect the time of the non- motorized users who cross the road in order to access other transport modes and to reach to any destination.

2.10. Summary of Review

The references discussed above have provided many benefits for the completion of this study. From the literatures, it is possible to grasp that examining mass rapid transits through evaluation and comparison among alternative modes is an important task. But while examining, it is necessary to include all of their available impacts. In order to do that, the best way is a comprehensive method using multifaceted criteria. A comprehensive technique helps in identifying the appropriate impacts in terms of cost for the needed scope and perspective. But, some costs may be difficult to quantify which needs another method of measuring the impact. If that cost has significant impact on the overall comparison result of projects, the need for additional method is necessary. So, it is not recommendable to generalize that all impacts can be quantified using this specific technique

Among the mass rapid transit modes, the literature discussed above is mainly focused on BRT and LRT. The comprehensive evaluation of the two modes can be done through comparison of their respective life cycle costs and benefits. These benefits and costs are preferable if they include almost all impacts on all perspectives by considering the availability of data. The effect of introducing both modes should be evaluated on the users, the agency and the environment which can be expressed as internal and external impacts. The impacts to be converted to monetary terms could be market or non-market in nature. Moreover, they could be variable and fixed according to their incremental nature depending on other increasing factors.

Another input taken from the literature review is that the annual benefits and costs should be discounted to present value in order to consider the time value of money. After discounted, it is possible to put costs and benefits of alternative projects into the same base year and compare the life cycle costs and benefits. In addition, economic indicators such as NPV and BCR can be determined from annual discounted costs and benefits which finally help to compare the projects under any study. Sensitivity analysis is also another important analysis which helps to evaluate projects by altering sensitive inputs. In addition, impacts that could not be monetized must be quantified according to their nature which in non-market way. So that examination can be done on LRT or BRT and the result can be expressed in terms of market or non-market value.

While comparing the two specific modes using comprehensive and multifaceted analysis, almost all studies dictate that the capital, operating and maintaining cost of BRT is lower than that of LRT. But LRT has more benefits with respect to its higher carrying capacity. In other case, LRTs have more environmental benefits than diesel based BRTs due to its zero fuel emission while operated. When travel time saving is considered, which ever fastest and with lower headway can provide more benefit. Accordingly, NPV, BCR, life cycle costs and life cycle benefits are dependent on the above cost and benefit components. The increase and decrease in each cost or benefit components can influence the project`s viability.

2.11. Gaps of Researches on Examining BRT and LRT

Indeed the journals, articles and related papers have helped this study as vital input and supporting material in many ways. But under this section, their gap is discussed which on the other hand is tried to be filled by this study.

Researches done on other cities` mass rapid transit systems tried to examine and evaluate different modes under different perspective. Under most studies, evaluation is done by using conventional methods which does not include all the impacts of mass rapid transits. Not only that, the impacts estimated are only for few stakeholders for example for users only, for agencies only, for external environment only and so on. Especially, external impacts which are impeded on the non-users of the transit modes are mostly ignored by researchers. The other character of most studies using conventional examination method is omitting non-monetary impacts of the projects. Since they are difficult to be monetized, conventional studies have been ignored them. But they should be assessed using a non-market way.

The studies that tried to examine mass rapid transits based in Addis Ababa have been also discussed under this study`s literature review portion. Assessments on ordinary buses, minibuses, Sheger buses and LRT performance have been executed by researchers. But there are few researches on economic evaluation of those public transportation modes. Those who illustrated economic evaluations mostly used conventional methods that lack a full perspective in every direction of the modes` impact. So, they are subjected to the failure of conventional method while evaluating impacts. Those with comprehensive examination tried to include most impacts but lacked the inclusion of long term impacts. Comprehensive evaluation done on recent mass rapid transit in A.A. city have included some impacts of the AA LRT but does not estimate the long term or life cycle effect of the project. So, some of the gaps to be seen and filled by this specific study are generated from this point of view.

Chapter Three
3. Methodology

3.1. Introduction

The third chapter discusses about the research approach, description of the study area, sources of data, data collection mechanisms, variables and method of data analysis. Under this chapter research methods for both objectives are illustrated step by step.

3.2. Research Approach

The multifaceted life-cycle cost and benefit analysis is done through an experimental research type which uses a case study on East-West and North-South corridors of the Addis Ababa Light Rail Transit and on Winget-Jemo corridor of Addis Ababa Bus Rapid Transit located in Addis Ababa City.

The examination of AA LRT infrastructure`s effect on the surrounding built-up activities is done using quantitative research approach in order to get the expected findings. The quantitative research approach is applied by means of questionnaire to residents along the selected LRT line to estimate the impact of its location on the nearby residents` movement towards different destinations such as work, school, and other places.

3.3. Research Design

Descriptive research method is employed to complete the examination of the AA LRT`s infrastructure. It attempts to describe systematically the situation faced by residents living along the line due to LRT infrastructure. The descriptive method would be important to describe prevalent light rail transit effect on spatial accessibility. This is done by comparing the impact before and after LRT construction. The study time covers longitudinal from 2019-2020.

3.4. Description of the Study Area

The study in general covers selected public transport systems located in Addis Ababa different. Addis Ababa lies at an altitude of over 2,300 meters above sea level and is located at 9°1’48”N and 38°44’24”E coordinates. The city`s Population is estimated as 4.2 million on the year of 2017 and projected to increase up to 5 million in 2019 with 3.8 percent of annual growth rate (World Bank, 2018a).

The selected public transport systems for the study are the Addis Ababa Light Rail Transit and Bus Rapid Transit. The AALRT has two lines of Addis Ababa Light Rail Transit (LRT) System totaling 34km with 39 stations which was opened on September 20, 2015 (Addis Ababa Light Rail Transit Operator, 2018). Of the two lines, the east-west line extends 17.4 kilometers, stretching from Ayat Village to Torhailoch, and passing through Megenagna, Meskel Square, Legehar and Mexico Square. The north-south line, which is 16.9 kilometers in length, extends from Menelik II Square to Kaliti and passes through Merkato, Lideta, Legehar, Meskel Square, and Gotera. However, two lines have a common track of about 2.7 km. The common track is the elevated section which runs east to west across the southern edge of the CBD from Meskel Square to Mexico Square, and onwards to Lideta.

The AA BRT corridor selected for this study is Winget-Jemo corridor having 23 stations with a total length of 17.7km covering Winget, Paster, Autobis Tera, Merkato, Tekele Haymanot, Mexico, Kera, Gofa Gabriel and Jemo areas. There are 26 intersections at grade which crosses the busway. This corridor is selected since it is the first one to be constructed amongst the other 14 corridors (Addis Ababa Road and Transport Bureau, 2018b).

While examining the AA LRT infrastructure`s impact, the study is concerned about the East West corridor of Addis Ababa Light Rail Transit`s impact. Specifically, the area under the study starts from Megenagna station to Sealite-Mihiret which covers about 4km longitudinally. There are four LRT stations along this corridor; Megenagna, Gurd Shola 1, Gurd Shola 2 and (Management Institute) Sealite-Mihiret.

3.5. Population and Sample for the Examination of the impact of the Addis Ababa Light Rail Transit infrastructure on the surrounding built-up activities

3.5.1. Sample Design

There are three stations in between the selected line of the LRT. There are also two roundabouts at Megenagna and Sealite-Mihiret. The LRT station at Megenagna is integrated with a road interchange, a below grade LRT line and a pedestrian overpass. These infrastructures consume a very wide area of the carriageway creating a long distance for pedestrians who cross the road and the LRT line. So, this is the major reason to select the corridor. On the other hand, a high number of pedestrians are usually observed crossing the roadway at Megenagna in all directions. Not only that, this place serves as a station/origin/hub for most public transportation modes such as mini-buses, Anbesaa buses, Sheger buses, higer buses and others. The other two stations of the LRT located at Gurd Shola and one station around Sealite-Mihiret are also under the study area in order to collect data from residents who live around the line.

The target population is a group of population from which the sample for statically measurement is taken. The population of this study is residents who lived within 500 meters in both side along the rail transit stations. As the data from Ethiopian Central Statistical Agency shows the total target population that includes who lived under the study area is around 31,230 on 2019. This shows that the residents are more than 10,000 people which will help to calculate the sample size for the study.

3.5.2. Sample Size

The researcher used a statistical formula set by Kothari (1990) based on the population size given above or when the studied area population is above 10,000. So, the

Questionnaire/respondents sample size can be calculated using the following formula by considering the level of acceptable margins of error at 5%.

Questionnaire sample size, $N=z^2pq/(\sigma)^2$,Where, N = the population size

n = the desired sample size

Z = standard normal variable at the required level of confidence at 95%=1.96

P = the proportion in target population estimated to have characteristic being measured

q = 1-p - the probably of failure

σ = the level of statistical significance set or margin of error = 5%

Since the expected accuracy level is 95%, σ = (100%-95%) =1-0.95 =0.05 and Z=1.96 and there is no estimate available of the proportion in the target population, it is assumed to have characteristic of interest or it is possible to predict the proportion of target population 'p' to be 0.5 and 'q' 0.5 will be taken.

- p=0.5, q=0.5, Z = 1.96 and σ = 0.05

So, by taking an assumption of that the size of population is greater or equal to 10,000, the sample size of the study becomes:

- $N = \frac{(1.96^2 * 0.5 * 0.5)}{(0.05)^2}$ = 384 respondents are needed from the surrounding residents.

Therefore, 384 questionnaires are distributed to the residents who lived at a distance of 500m from each corridor to the left and the right. The respondents should give response only about their home based trip i.e., home to work, home to school, home to shop, and home to social and religious centers or vise-versa. This will help to investigate pre and post impact of the facility on their movement.

Observation around all the three stations and throughout the corridor is also done to check the condition of pedestrian movement while crossing LRT infrastructure.

3.5.3. Sampling Technique

Purposive sampling was also used to distribute questionnaires among households in order to get information from workers, students and those who go for other activities by crossing the LRT infrastructure. Therefore, the sample subjects were also selected based on the judgement of the researcher in order to include all kinds of respondents.

3.6. Method of Data Collection

The data collection involves two sources: one from official documents of different offices in road and transport sector and two from manuals, books and guide lines that can be used for selecting variables.

The secondary data from different offices and their respective official documents is used in this study. The data sources are Addis Ababa Light Rail Office, Ethiopian Railway Corporation, Addis Ababa City Transport Authority, Addis Ababa Road and Transport Bureau, Addis Ababa City Police Office, Addis Ababa Finance and Economic Development Bureau, Addis Ababa Environmental Conservation Authority, Governmental Statistical Agencies, and Ethiopian Road Authority.

The other sources used for selecting cost components and analysis are recent economic evaluation manuals, relevant books, recent journals and articles, research papers, and official websites.

Secondary data collected from the above sources are the following.

- Construction cost, maintenance cost, operating cost and replacement cost for both LRT and BRT. These data helps in estimating the cost of both transport means.
- Cost of passenger ticket, passenger number per day, rate for the price are used to calculate revenue tariff of both transport means.
- Time saved on average passenger is used to calculate the savings in time by individual passenger travelling in LRT and BRT. Moreover, data such as average monthly earning per person in Addis Ababa, hourly income, and value of time are gathered from governmental statistical agencies in order to find the savings in passenger time.
- Reduction in number of vehicles in percent, motorization rate and vehicle numbers in Addis Ababa is collected from both LRT and BRT offices which are then used for the estimation of fuel savings. In addition the current price of diesel and gasoline per liter has been used.
- Number of death, serious injury and property damage in Addis Ababa for recent years is gathered from Addis Ababa Police Commission. Average working life of a person and per capita earning of a person are also other data that helped in the estimation of accident savings.
- Number of trips diverted to LRT and BRT from other transportation modes is used to estimate the reduction in amount of air pollutants. It is collected from the feasibility report of both projects. The experience of other countries on the impact of mass rapid transits to reduce the amount of air pollutants is also included as a bench mark.

On the other hand, the researcher prepared the collecting tool carefully in order to get valuable data from sample subjects to check about LRT infrastructure's effect on people`s day to day activity. So, questionnaires were used to collect data for this specific study.

3.6.1. Questionnaires

The overall form of a questionnaire can either be structured or unstructured questionnaire. Structured questionnaires are those questionnaires in which there are definite and pre-determined questions. The questions are presented with exactly the same phrasing and in the same order to all respondents. Choice is taken to this sort of standardization to ensure that all respondents reply to the same set of questions. The form of the question may be either closed (i.e., of the type 'yes' or 'no') or open (i.e., inviting free response) but should be stated in advance and not constructed during questioning. Structured questionnaires may also have fixed alternative questions in which responses of the informants are limited to the stated alternatives. Thus a highly structured questionnaire is one in which all questions and answers are specified and comments in the respondent's own words are held to the minimum. When these characteristics are not present in a questionnaire, it can be termed as unstructured questionnaire (Kothari, 1990).

So, in this study the questionnaire were classified in terms of the nature of questions that are used. These are closed-ended question and Open-ended question. Closed-ended question consists of questions that offer respondents a set of answers to choose. Open-ended question consists of questions that are not followed by any kind of specified choice but require respondents to write their answers. Among these, closed ended questionnaires were distributed to all 384 sample respondents.

The sources of data for this study were both primary and secondary. The primary data are collected through questionnaires. Whereas, secondary data were collected from the ECSA report, AA LRT official documents and other related publications.

3.7. Data Description

First description of data is discussed on the life cycle cost analysis of both AA BRT and AA LRT. The inputs data for LCCA are explained briefly after discussing on the outputs expected from it.

3.7.1. Outputs

In this study, life cycle costs and benefits of the two projects are the major final outputs calculated from different individual costs. The environmental, social and economic impacts or costs are added up to produce the life cycles cost. Using the estimated life cycle cost and benefit per km value, the study compares AA LRT and BRT. In addition, Net present values and Benefit to Cost Ratio are calculated to compare the projects.

3.7.2. Inputs

The input values which affect the final result of the analysis are categorized in this study. The change in each value affects the life cycle costs and benefits value expressed in terms of money. The direct inputs or data collected from different secondary sources are

1. Economic impact inputs
    - Capital, maintenance, and operation cost
    - Number of passenger per trip, per day, per station and per kilometer
    - Travel time
        - Headway and frequency
    - Fare affordability
        - User fee per trip length, revenue tariff
    - Number of crash reduced due to project
    - Number of persons killed, seriously injured and slightly injured per year
        - Per capita income
        - Average working life of a person assumed
    - Number of property damage per year
2. Environmental impact inputs
    - Reduced Number of vehicles due to project
    - Vehicle travel per year, per kilometer
    - Fuel used per year or per kilometer
    - Amount of air pollutant and greenhouse gas emission
3. Social impact inputs
    - Health benefits
        - Saving from Road Traffic Crash reduction
        - Saving from Air pollution reduction

The study also categorizes these costs under the following categories.

I. Internal and External Costs

II. Variable and Fixed Costs

III. Market and Non-market costs

Based on the above categorical approach, the author included the following costs and benefits in this study in order to conduct a comprehensive and multifaceted analysis.

Table 2: Transport cost categories and their components for comprehensive evaluation

Cost	Internal/External	Variable/Fixed	Market/Non-market
Vehicle Ownership	Internal	Fixed	Market
Vehicle Operation	Internal	Variable	Market
Operating Subsidies	External	Fixed	Market
Travel Time	Internal	Variable	Non- market
Internal Crash	Internal	Variable	Non- market
External Crash	External	Variable	Mixed
Road Facilities	External	Variable	Market
Air Pollution	External	Variable	Non- market
Greenhouse Gas Emissions	External	Variable	Mixed
Resource Consumption	External	Variable	Non- market
Barrier Effect	External	Variable	Non- market

3.8. Data Analysis and Presentation

Based on the collected quantitative data and using comprehensive economic evaluation method, the comparison of the two MRTS impact on environment, social life and economy is performed in this study. During the data analysis, cost and benefit calculations are made carefully using different standards, data and formula.

Among the specific techniques used for transportation economic evaluation, Lifecycle Cost Analysis is used in this study. It is a Benefit-Cost Analysis that incorporates the time value of money. This allows comparisons between LRT and BRT that provide benefits and costs at different times. The analysis period chosen by the author is 30 years based on an assumption made by both AA LRT and AA RTB offices for economic analysis. In addition, standardized transit manuals such as TRB recommend 30 years of duration for life cycle cost analysis by taking into account the infrastructure`s life. In addition, LCCA requires applying the same time frame over all alternatives for analysis, to ensure consistency of comparison.

This economic analysis involves comparison of project costs and benefits in economic terms under the project conditions. This shows the return which the society could expect from the proposed investment during the project life, i.e. the benefit period. The main steps to be followed are the following.

I. Estimating the life time costs of both projects separately
II. Estimating the life time benefits of both projects separately
III. Performing economic analysis of each project using Benefit to Cost Ratio (BCR) and Net Present Value (NPV)
IV. Performing Sensitivity Analysis of both projects for selected and sensitive input values

By inserting capital costs, maintenance costs, operating costs, debt-equity, revenue tariff, fuel saving, time saving accident saving and employment generation benefits and costs are estimated. Then, the NPV and BCR are calculated using a discount rate of 10.23%, taken from Ethiopian Road Authority road projects appraisal report on 2019 and recommended by Ministry of Finance and Economic Development (MoFED) for evaluation of infrastructure projects, in order to determine the present value of future cash flows. This allows in identifying which mass transit system is better in economic viability or feasibility perspective.

Moreover, Sensitivity analysis is done by increasing the total cost or decreasing the total benefit by 10 % and by combining the effects of both on the net benefit. Costs and benefits with greater weight of impact on the project`s NPV or BCR result are also selected to make sensitivity analysis. These selected costs are increased by 5% or benefits will be reduced by 5% to show the change in NPV and BCR of each project. This will help us to test the economic strength of the two projects. At the end, the monetized costs and benefits are presented in tables. The calculation results are generated in order to evaluate the two projects. Microsoft office excel is used to construct those tables. The analyses of the collected information from the different sources are organized into their representative categories so as to come up with logical results.

The method of data analysis to examine the effect of AA LRT`s infrastructure on the surrounding`s built-up activity. After gathering all the data using different instruments mentioned in the previous sessions, it was analyzed and interpreted quantitatively. The data collected through document analysis were analyzed and interpreted qualitatively. While the data obtained from the questionnaire was interpreted and analyzed using MS-EXCEL 2010 quantitatively. Through questionnaire, the demographic character of the sample subjects are gathered and inserted into MS-excel. The percentage of transportation modes that are used by the respondents are analyzed under the categories of walking and walking plus other public transportation modes. Finally, the respondents view whether the LRT structure has increased their walking distance and time while crossing it will be analyzed accordingly by classifying the distance and time travelled. In addition, analysis to check whether the infrastructure has consumed excess land of the roadway or not, the pedestrian crossings are in good or poor condition, the distance between pedestrian crossings along the line is excess or not, and the infrastructure has a negative impact on the interaction of neighborhoods or not. Results are expressed and summarized as frequency and percentage and are presented by a table and charts.

Chapter Four
4. Analysis, Result and Discussion

4.1. Introduction

This chapter presents analysis and discussion on the major findings of data collected through methods stated under methodology. In this part, detail analysis, results and discussion for both objectives is done. MS-Excel is used to analyze the data gathered from document analysis, primary sources and secondary sources. The analysis method used under here is gathered from different literatures which are reviewed under chapter two.

The first section discusses on the results from the estimation of life cycle cost and benefit analysis of AA LRT and AA BRT. Cost and benefit related data from secondary sources are inserted into MS-Excel and analyzed categorically. Different formulas and standards are used for analysis which is collected through document analysis. Finally, discussion on major findings has been held. Although some of the raw data used for this study were dated according to Ethiopian Calendar, they are changed to Gregorian calendar while analysis and the results are also.

The second section contains results on the other objective, examining the impact of the Addis Ababa Light Rail Transit infrastructure`s on the surrounding built-up activities. It involves

4.2. Components of Project Life Cycle Costs

Under this sub section, only the components of the project life cycle costs of Addis Ababa Light Rail Transit (EW and NS corridors) and Addis Ababa Bus Rapid Transit (B-2 corridor) are estimated. Simultaneously, categorizing of each cost components as internal/external, fixed variable and market/non-market is also clearly discussed. Therefore, the main components to be categorized, clarified and estimated are

- Capital cost
- Operating and Maintenance Cost
- Replacement cost

The sub-components under each main component are going to be listed out, categorized and estimated individually since they differ from each other in many aspects. While estimating each life cycle cost components, various assumptions on different input parameters is taken by the author based on the annual official reports of the projects, national reports and related foreign country experiences. So, the assumptions used for both projects under the study scope can be seen with in the following discussion.

4.2.1 Assumptions

I. Addis Ababa Light Rail Transit: The AA LRT has taken three year for constructing its infrastructure as the AA LRT operator indicates. The following information on the inputs are collected from the feasibility study of AA LRT and the annual budget and finance reports of AA LRT starting from 2016.

- Construction period - 3 years
- Construction Completion year - 2015
- Beginning year of operation - 2016
- Analysis period – 30 years
- Total length of line – 34km

In addition, the discount rate used is 10.23% as indicated on methodology section of the study. Note that a real discount rate is used in this analysis which is an interest rate that has been adjusted to remove the effect of expected or actual inflation. Therefore, no inflation rate is required.

II. Addis Ababa Bus Rapid Transit: The former feasibility report of AA BRT on 2010 and the revised feasibility study of AA BRT on 2014 include a number of valuable information about the implementation plan and operation plan of the project. So, the following data is taken from this report.

- Duration of construction – 3 years
- Construction completion year - 2019
- Beginning Year of Operation – 2020
- Analysis period – 30 years
- Total length of the line – 17.7km

The two projects should have the same base year and the same period of analysis as different LCCA guidelines and journals dictated (Stanford University Land and Buildings, 2005; Fuller, 2016; Mearig *et al.*, 2018). For the sake of comparing the life cycle cost and benefit of the two projects, the same starting year of operation has been chosen by the author which is 2020 (the paper year) and construction completion year is taken as 2019. All the expenditures of construction are calculated on this year because of un-availability of data on expenditure plan for 3 years of construction.

For comparison of the two projects, the same unit is used by dividing all the total benefit and cost components with their respective total line length in km. Therefore, the components are presented in terms of cost/km or benefit/km at the end of the analysis. So, that it is possible to compare the projects.

4.2.2. Capital Costs

I. Capital Costs of AA LRT

The capital cost includes the cost expended during pre-construction stage and construction of AA LRT. The construction cost comprises the cost for constructing at grade, below grade, above grade and underground lines, stations and depots, laying of tracks, signaling and telecommunication, power traction line, rolling stock, and man power. The Construction task had been held for 3 years during the period between 2012 and 2015 for the Phase I of LRT construction. The other portions of capital cost i.e., vehicle and facility expenses are spent before the first year of its operation or 2015.

All of the financial costs have been converted into economic costs by using a Standard Conversion Factor (SCF) of 0.85 to take care of distortions in prices due to market imperfections. This value is recommended by the Ethiopian Ministry of Transport and African Development Bank/World Bank which is generally used for economic evaluation of transport projects in Africa.

The construction cost of the AA LRT project in economic term is 403,750,000 USD on 2015. This cost is taken from the annual financial report of AA LRT on 2015. The other parts of capital cost are purchasing value of the train vehicle and the rail infrastructure. The annual depreciation rates for each asset are taken from the AALRT financial document.

Table 3: Fixed Assets and Annual Depreciation Rates of AA LRT

Components of Investment cost	Expected Useful Life	Depreciation Rates per Year (%)	Original Cost	Depreciation Per Year
Railway Infrastructures	30	3	9,191,501,405.36	275,745,042.16
Rolling Stock	30	3	2,482,036,066.86	74,461,082.01
Total (ETB)			**11,673,537,472.22**	**350,206,124.17**
Total (2015 USD)			**583,676,873.61**	**17,510,306.21**

(Source: Annual Financial Report of AA LRT on 2015)

The summation of these assets` cost can be taken as the investment cost of AA LRT which is 11,673,537,472.22ETB or 583,676,873.61 USD (2015). An assumption is taken that this cost is expended on 2015.

Therefore, the capital cost for AA LRT implementation is the summation of investment cost and construction cost which becomes 987,426,874USD on 2015. The total Length of the two lines of AA LRT is 34km. Therefore, the capital cost per km becomes **29,041,966.87 USD**.

II. Capital Costs of AA BRT

Capital costs of the Winget-Jemo line include construction costs, rolling stock costs and traffic management costs. The proposed vehicle is a single deck articulated bus supported by diesel, 18.0m long. The seating capacity is 49 persons and standing capacity is 111 persons which results in a total capacity of 161 persons per bus. The cost of each bus is estimated to be ETB 5,197,500 based on quotes received from manufactures and adjusting it to landed cost in Addis Ababa. The life of the bus is expected to be 10 years. For the opening year, the total number of fleet is taken as 43 as proposed by the agency. Therefore, the total cost of rolling stock is

- 5,197,500*43 = 223,492,500 ETB or 447,289.16*43 = 19,233,434 USD

The total cost approaches to **770.79 million ETB** derived from the following table as estimated on ERC feasibility study on 2010.

Table 4: Capital costs of AA BRT

Capital Cost Components	Estimated Cost	Cost per km
Infrastructure	488,600,000.00	27,604,519.77
Rolling Stock	223,492,000.00	12,626,666.67
Risks and uncertainties	58,700,000.00	3,316,384.18
Total 2010 ETB	770,792,000.00	43,547,570.62
Total 2010 USD	66,333,218.59	3,747,639.47
Total (2019 USD)	159,378,353.96	9,004,426.78

(Source: Calculated by the author using the Feasibility study of AA BRT on 2010)

Therefore, the capital cost for AA BRT corridor B-2 implementation is 770.79 million ETB on 2010 which becomes 159,378,353.96 USD on 2019 using a discount rate of 10.23% every year. The winget-Jemo route has 17.7km thereby has 9,004,426.78 USD per km capital cost. Finally, at the end of this chapter, this value will be brought to 2019 price using discount rate of 10.23% for life cycle cost analysis.

The other optional BRT vehicle is electrically operated known as trolley which is 18m articulated bus. Its rolling stock and infrastructure is higher than that of diesel based BRT. The cost of one trolley bus was 900,000 USD and investment cost for infrastructure development is about 5 million USD per km on 2010 (Simon *et al.*, 2010). The requirement for the implementation of AA BRT B2 project is 43 rolling stocks on the first year of its operation. So, the total cost of the buses becomes 38,700,000 USD. In addition, the life of trolley buses is 20 years which indicates it does not need replacement within the first 20 years of its operation (Keskin, 2019). The following is the total capital cost of AA BRT project with trolley vehicle converted to 2019 price.

Table 5: Capital Cost AA BRT on 2019 operated with Electricity

Capital Cost Components	Estimated Cost in 2019 USD	Cost per km
Rolling Stock	102,496,500.85	5,790,762.76
Infrastructure	234,391,222.86	13,242,441.97
Risks and Uncertainties	13,379,196.96	755,886.83
Total	**350,266,920.67**	**19,789,091.56**

(Source: Calculated by the author using the Feasibility study of AA BRT on 2010)

Therefore, the capital cost of AA BRT if operated with electricity becomes 350,266,920.67 USD or 19,789.091.56 USD per km. This value is greater than that of BRT operated with diesel since it includes more expenditure for electric infrastructures and the trolley bus is more expensive.

4.2.3. Operating and Maintenance Cost

I. AA LRT Operating and Maintenance Costs

Operating cost includes all costs for labor, materials, tools and equipment (labor, maintenance and fuel) during its operation time in each sector of the AALRT office. These costs are collected from the annual financial report of AALRT office specifically from 2015 up to 2018. In the absence of actual costs by cost center, the budgeted costs for each cost center is used collected from the budget plan of AALRT. In this thesis, the operation and maintenance costs of 2017 or 2018 has been used since it is the latest data obtained from AA LRT office. These costs are then brought to 2019 price using discount rate.

The costs are categorized as operation, maintenance and depreciation expenses. There are both fixed and variable cost components under each category. The operation cost of AA LRT includes cost of ticket, electricity cost, safety and security, administration expenses, staff salary and related expenses, contract management expense, workshop and tools and so on. Among the cost components; electricity price and staff salary is expected to increase at a rate of 5% annually. In addition, the agency has a plan to reduce the expense of Management Contractors by 80% after 2018 (after four years of operation).

The maintenance cost includes expenditure for repairing and maintaining rolling stock, infrastructures, vehicles, computers, buildings and other supporting equipment. The last component included under O & M cost is depreciation expense for different facilities. Their depreciation rate and life time has been presented previously on capital cost of AA LRT. Therefore, the summary of operation and maintenance cost for the base year can be calculated as follows by the author.

Table 6: Summary of an annual Operation and Maintenance Cost including Depreciation on 2018

Operation and Maintenance Cost Components	Annual Cost (2018)
Electricity	6,829,881.98
Cost for Ticket Production	2,206,581.87
Safety and Security	21,118,100.84
Workshop and Tools	16,160,400.74
Other Operating Expenses	241,010,710.00
Admin Expenses	75,386.36
Miscellaneous Expenses	75,386.36
Staff Salary and Related Expenses	82,829,973.95
Contract Management Cost	977,563,012.05
Total Operating Cost	**1,347,869,434.15**
Total Maintenance Costs	**906,779.72**
Total O and M Costs	**1,348,776,213.87**

(Source: Calculated by the Author)

Assuming that electricity cost and staff salary increase with an annual rate of 5%, the life cycle operation and maintenance cost for AA LRT excluding depreciation can be seen from appendix 1.C.

II. AA BRT Operating and Maintenance Costs

In case of AA BRT, the cost data are collected from the revised feasibility study of the project on 2014. Since the service is not started yet, it was unable to generate actual operating costs as well as maintenance costs.

A. Variable costs

The components under variable cost are fuel, tire, lubricants, spare parts, and some of the staff costs. These costs vary or increase with the km travel of vehicle.

The assumptions taken by the agency for the BRT operations are as follows:-

- Fuel efficiency: Fuel efficiency of one articulated bus is assumed 2.5 km/lit (km per liter). The expenditure for fuel per day is estimated by using diesel price on 2014 was 19.31ETB/per liter. But annually it has been hiked by 5%.
- Tire life: The original life is assumed as 35000km and after retreading 70000km.
- Lubricant: premium multi-grade oil at 10,000 Km life time
- Spare Parts: for all the spare parts and consumables, a life of 10,000 km is assumed

All the above costs are changed to annual values in order to show the life cycle expenditure of operation and maintenance per year.

B. Staff details and employee payment

Labor costs represent perhaps the greatest difference into operating costs between systems in developed nations and systems in developing nations. Whereas staff salaries can represent between 35 and 75 percent of operating costs in Europe and North America, the labor component of systems in developing countries may be well less than 20 percent (Menchkoff, 2007).

The AA BRT daily operating and maintenance cost as estimated by the agency and re-estimated by the author can be seen in the following table. In addition, the total estimation of annual operation and maintenance cost for the corridor BRT is estimated based on the above assumptions and calculations for 2014.

Table 7: Annual Operation and Maintenance Cost Excluding Depreciation for 2014 in ETB

Cost Components	**Operation and Maintenance cost**	
	Birr / Bus / day	**Birr/year**
Bus Running Cost		
Fuel Cost	1,236	19,399,020
Lubricant Cost	96	1,506,720
Tire Cost	549	8,616,555
Spare parts	115	1,804,925
Overhead cost		
Employee Remuneration	760	11,928,200
Overtime & Allowances	210	3,295,950
Depot		
Maintenance Cost	1,424	22,349,680
Other Cost		
Misc. Cost	220	3,452,900
Total	**4,610**	**72,353,950**

Therefore, the annual operation and maintenance cost for AA BRT is **72,353,950** ETB on 2014. In order to estimate life cycle O and M costs, an assumption 5% annual increase for the price of fuel and employee salary is taken by the author by referring other similar documents.

Appendix 1.D. contains the estimation of life cycle expenditure for operation and maintenance work of AA BRT excluding depreciation. The annual costs are expressed in 2014 ETB but for the sake of price uniformity, they are converted to 2014 USD prices. Note that the average conversion value of 1 USD was 19.47 ETB on 2014. Therefore, the 2014 total operation and maintenance cost becomes 3,716,176.17 USD or 209,953.46USD per km. The same is performed for all the annual costs. But later on the life cycle cost analysis the values will be brought to 2019 prices using discount rate.

As case studies on BRT experience from different cities such as Bogota, Sao-Paulo, and Lagos show the trolley bus`s operating and maintenance cost is 30% higher than for diesel buses (Wirasinghe *et al.*, 2013). Therefore, the estimation of operating and maintenance costs for AA BRT if operated by electricity is done by increasing O&M cost of the diesel BRT with 30%. Hence, this is going to be discussed after the calculation of the annual O&M costs of diesel based BRT starting from 2020 at the end of this chapter.

4.2.4. Replacement Costs

I. Replacement cost for AA LRT`s Selected Fixed Assets

Replacement cost includes the expenditure for replacing old fixed assets such as rolling stock and infrastructures. The following table shows the fixed assets of the project and their life time.

Table 8: Expected useful life time and depreciation of the AA LRT selected fixed assets

Fixed Assets	Expected Useful Life	Depreciation Rates per Year	Original Cost	Depreciation Per Year
Rail Infrastructures	30	3%	9,191,501,405.36	306,383,380.18
Rolling Stock	30	3%	2,482,036,066.86	82,734,535.56
Total (ETB)			**11,673,537,472.22**	**389,117,915.74**
Total (2015 USD)			**583,676,874**	**19,455,896**

(Source: Annual Financial Report of AA LRT office, Budget and Expenditure Sector)

Both assets have a life time of 30 years which is equal to the period of analysis for the project; therefore the assets should not be replaced for 30 years. So, zero replacement cost is taken for AA LRT project within 30 years of time.

I. Replacement cost for AA BRT`s selected Fixed Assets

Unlike AA LRT`s rolling stock, the AA BRT bus (rolling stock) has less life time which implies that it should be replaced at the end of its life time as it can be seen in the following table.

Table 9: Life time and Depreciation of selected AA BRT`s Fixed Assets

Fixed Assets	**Expected Useful Life**	**Depreciation Rates/Year**	**Original Cost**	**Depreciation/Year**
Infrastructure	30	3%	3,170,672,045.51	105,689,068.18
Rolling Stock	10	10%	223,492,000.00	22,349,200.00
Total 2010 ETB			**3,394,164,045.51**	**128,038,268.18**
Total 2010 USD			**292096733.7**	**11018783.84**

(Source: Estimated by the Author using the Revised Feasibility Study of AA BRT on 2014)

From the above table, it is possible to see that the BRT line infrastructure have the same life time as the analysis period of the project, so it will not be replace within the given 30 years. But the rolling stock or bus of AA BRT should be replaced every 10 years which is three times throughout the analysis period. The first expenditure is to purchase the bus, 223,492,000ETB or 11,478,788 USD on 2014 which is included in capital cost estimation. The second expenditure will be paid at the 20th year or 2034 and depreciate for the next 10 years. So, two replacement costs will be done within the analysis period. Since purchasing power of money varies for different years the original price is escalated by using a discount rate of 10.23%.

Table 10: Replacement Cost for AA BRT Rolling stock

	Replacement Cost		
Year	**ETB (2014)**	**USD(2014)**	**Feature Value**
2024	223,492,000	11,478,788	30,401,436.47
2034	223,492,000	11,478,788	80,517,851.66

The costs written on the feature value column are calculated using discount rate of 10.23%. This is done to put the 2014 price of the rolling stock in terms of 2024 and 2034, because those are the years in which the bus is going to be replaced. So, 30,401,436.47USD and 80,517,851.66USD are the price of the rolling stock on 2024 and 2034 respectively. Later on this chapter, for the calculation of the life cycle costs, these values will be escalated to fit with the other costs by following the given base year.

The trolley vehicle has 20 years of life. Therefore, it should be replaced at the end of its 20 years. The original purchasing value of the buses on 2019 is 102,496,500.85 USD. At its cost at the end of its 20 years becomes 271,460,792.91 USD by converting it to its future values using 10.23% of discount rate. So, there will be an expenditure of 271,460,792.91 USD, on 2040, in order to replace the rolling stock of the BRT vehicle.

4.3. Components of Project Life Cycle Benefits

Under this portion, the annual benefits from both projects are estimated by categorizing them accordingly. Project benefits of both AA LRT and AA BRT included under this study are categorized as follows.

- Passenger Revenue
- Savings in time for passengers
- Savings from fuel reduction
- Savings from road traffic crash reduction
- Savings from Reduction in air pollution and green-house gas emission

There are indeed more benefits gained from these projects that should be included but due to shortage of data, the above are the only benefit components to be discussed. These benefits are forecasted to be gained for 30 years of the project life time. So, different growth rates are used under each benefit category to show the effect of the projects for long term on the user, the agency and the environment in general. Discount rate is finally used to convert all the future savings into present value which helps to compare the alternative projects. The same assumptions are taken as those which are used cost calculation. Other specific assumptions are also used under each category taken from national official documents, agency-wise official documents and related local and foreign publications.

4.3.1. Revenue Tariff

I. Revenue Tariff for AALRT

Revenue is income that an organization receives from its normal business activities, usually from the sale of goods and services to customers. In the case of AA LRT operation, revenue can be derived from fare box. Fare box revenue is the payment received from passengers for the journey performed through tickets. So, fare box revenue is calculated in this study as a benefit for the agency operating the LRT. This revenue is estimated annually by using the average user fare and annual passenger trips collected by the agency.

The price of passenger ticket is 4 birr for any distance travelled by passengers. This price is expected to be raised in every five-year slab by 5% of the existing price. As the collected data by AA LRT officials indicates, the number of passengers per day is 120,865 on the year 2016. It is expected that the growth of passenger number at 5% for each five- year slab starting from 2016. Accordingly, the passenger numbers and passenger tariff for 30-years of study period is presented as the following.

Table 11: Revenue Tariff from Ticket in Birr and Passenger Number for 30 years

Year	2016-20	2021-25	2026-30	2031-35	2036-40	2041-45
Passenger per day	120,865.00	126,908.25	133,253.66	139,916.35	146,912.16	154,257.77
Ticket Tariff in birr	4.40	4.62	4.85	5.09	5.35	5.62
Tariff in USD	0.22	0.23	0.24	0.25	0.27	0.28

Note that 1US$ = 20ETB on 2015

The revenue tariff has been calculated from 2016 by taking into account that the operation of LRT begin on 2016. Accordingly, the annual revenue tariff for 30 years (2015 to 2045) is calculated.

On the first year of its operation, the LRT gained about 9,705,459.5 USD. But this value becomes 307,134.79 USD when estimated per km on 2016. This revenue value and all the annual savings are going to be changed to 2020 prices while life cycle benefit analysis.

II. Revenue Tariff collected from AA BRT

According the final demand forecasting report of BRT corridor B-2 the daily ridership on 2022 was 123,917. It is expected that the growth of passenger number at 5% for each five- year slab starting from the opening year. The BRT fares recommended by the agency are used in this analysis. So, the average passenger ticket price is assumed as 2.88 birr for average journey distance since the minimum and maximum price in birr is 1.4 and 4.35 according to the operational plan prepared by AACRA on 2014. For Revenue calculations 5% revision of fares every year has been considered.

Therefore, the annual ridership on that year becomes 45,229,705. But this number must be brought back to 2020 which is the fare collection year. So, it has been mentioned that the number of passengers is expected to increase by 5% every five year slab which shows the given number of passenger should be brought back by 5% for the previous five year slab. I.e., the number of passenger on 2020 is 45,229,705 since number of passengers within five year slab is unchanged but will increase after five years with 5%. It is possible to multiply the number of passengers by the respective tariff per year in order to get the revenue collected from passengers every year starting from 2020. For example, Revenue on 2020 is 45,229,705 *2.88birr which becomes 130,261,550.6 ETB.

Therefore, the revenue on 2019 from AA BRT passengers is 130,261,550.40ETB or 7,359,409.63 ETB/km. The same estimation is done for all annual revenues to put the result per unit km. Since the fare is lower than that of AA LRT, the revenue to be collected by the agency is lower.

4.3.2. Saving in Time of Passengers

I. Saving in Time for AA LRT users

The Value of Travel Time Savings (VTTS) implies to the benefits of faster travel that saves time and the Value of Travel Time (VTT) refers to the cost of time spent on transport or VTT is the amount of money a traveler is willing to pay for time savings (Kockelman *et al.*, 2013). The travel time includes in-vehicle time, waiting time and access time. In this case, the savings of travel time of passengers traveling in LRT are calculated by multiplying the number of passengers travelled daily and the time saved on the average passenger lead in Addis.

Value of Travel Time (VOTT*)*

The estimation is done for the population of greater than 5 years of age, based on the average monthly earnings per person in Ethiopia by taking its unit for work trips as the average earning per hour. The unit VOT of commuting trips has been taken as 30% of VOT of work or business trips (Trottenberg and Belenky, 2011). The unit VOT of a person in Ethiopia can be estimated based on the following inputs.

Inputs for VOT estimation

- The average monthly earning per person in Addis Ababa according to Addis Ababa Finance and Economic Development Bureau on 2019 and World Fact Book reports is 301 USD or 8,970 ETB per month on 2019.
  Note that 1USD = 29.8 ETB on 2019.
- Consider 8 work hours a day and 22 work days a month to convert monthly income to hourly income.
  Hourly income = $\frac{301}{22*8}$ = 1.71 USD
  This value is the VOT or the wage rate for business trips.
- Therefore, VOT for Non-business trip which is 30% of VOT of business trip is
  VOT for Non-business trip = 0.3*1.71 ETB = 0.51 USD
- In order to find the average VOT per hour, it has also been assumed that business trips are 25% and non-business trips are 75% of total trips.
  Therefore,
  Average VOT per Hour = 0.25(1.71) + 0.75(0.51) = 0.56USD

Travel Time Savings

The final result of VOT is going to be used to calculate time savings of LRT passengers or what the passengers will benefit by saving their travel time. As the AALRT feasibility report shows the savings in time by individual passenger travelling in LRT per day is 12.6 minutes (Dixie Metropolitan Planning Organization, 2010; Mohapatra, 2015). In order to calculate the time savings in hour per person per year, 300 days of working is assumed. Therefore,

- Savings in time by individual passenger travelling in LRT per year in hours =(12.6min*300days)/60 = 63 hrs. /year per person

From above, Value of time of a person per hour is 20 Ethiopian Birr (ETB) or 0.56 USD. On the other hand, total numbers of passengers in Addis who are assumed to save time by travelling in LRT in 2019 was 120,865 as it can be seen on passenger revenue estimation.

Finally, the travel time saving has been estimated as the following.

- Total hours saved in a year in million in 2019 (= time saved by a passenger in a year × number of passenger using LRT = 63 * 120,865) =7,614,495.

Therefore, the benefits due to time savings in year in 2015 will be calculated as follows.

- Benefit from time saving = 0.56USD*7,614,495= 4,264,117.2 USD

NB: Value of Time increases @5% per annum. Using this annual increment in VOT, the benefit from time saving due to AA LRT for the passengers can be calculated for 30 years.

For instance, the passengers of AA BRT can save about 4,264,117.20USD from less travel time on 2016 which can be put as 125,415.21 USD per km.

II. Saving in Time for AA BRT Passengers

As mentioned above on time saving due to LRT, Total travel time includes in vehicle time, access time and waiting time. So, the total travel time expected to be saved by AA BRT along B-2 corridor is approximately 15 minutes per day as estimated by AACRA (Addis Ababa City Road Authority (AACRA), 2014). This time saving is the result of the increase in frequency of buses, increase in average speed of vehicles and decrease in access time by BRT service.

The value of time (VOT) is calculated in the same procedure as before which is used in LRT time saving except that the wage rate for 2019 is 301 USD or 8,970 ETB. So, average VOT per hour becomes 0.56USD. In order to calculate the time savings in hour per person per year, 300 days of working is assumed. Therefore,

- Savings in time by individual passenger travelling in LRT per year in hours = (15min*300days)/60 = 75 hrs. /year

From above, Value of time of a person per hour is 11.45 Ethiopian Birr (ETB) or 0.4 USD. The total number of passengers in Addis Ababa who are assumed to save time by travelling in LRT in 2020 (opening year) is 123,917.

Finally, the travel time saving has been estimated as the following.

- Total hours saved in a year in million in 2020 (= time saved by a passenger in a year × number of passenger using LRT = 75 * 123,917) =9,293,775 hrs/year

Therefore, the benefits due to time savings in year in 2015 will be calculated as follows.

- Benefit due to travel time saving
  = 0.56USD * 9,293,775
  = 5,204,514 USD

So, the total time savings for 30 years due to AA BRT for passengers from 2019 to 2049 in monetary terms is calculated at the end of this analysis by taking into account that VOT increases 5% per annum. For instance, the passengers of AA BRT can save about 5,204,514 USD on the first year of its operation due to less travel time. The saving per km becomes 294,040.34 USD.

4.3.3. Saving in Fuel

I. Saving in Fuel due to AA LRT

AA LRT can be taken as an example for a reduced use of fuel since it is operated using electricity. It also reduces the number of vehicles used in the city as some passengers will divert to LRT. Both of these show that the LRT has benefits by reducing the usage of fuel. The vehicle reduction amount in percent due to LRT can be taken from other countries` experience i.e., 30% influence on vehicles` number. Among these, Cars comprise 45% and buses comprise 25%.

The first step is estimation of the total number of vehicles that are affected by AA LRT on the base year and the life cycle period. For this purpose, the number of registered vehicles in Addis Ababa on the year 2015 has been taken from Addis Ababa Road and Transport Authority. But their number will be reduced by their respective reduction percentage given above. Additionally, the annual motorization rate at that period of time which is 5.8% for cars and buses helps to forecast the number of vehicles to be reduced within 30 years. Reduction in vehicle number is calculated on the year 2016 or the opening year. Afterwards, only the motorization rate is used to show yearly change in vehicle number.

The second step is to forecast the price of the respective fuel type used by the above vehicles for 30 years. In order to do that, a consideration on the savings of fuel by cars and buses is taken as the following. Savings by car is taken as 1 liter of gasoline and savings by bus is taken as 3 liters of diesel. The price of 1 liter of gasoline and diesel on 2015 was 0.82USD and 0.74 USD respectively. This price will increase annually at a rate of 3%. For 2016, Gasoline price = (0.82*0.03) + 0.82 = 0.84 and so 0n until the end of 30 years. The final step is the estimation of fuel savings for 30 years by using the above two tables, i.e. Annual Fuel Savings (Gasoline or Diesel Saving in USD) is equal to savings of fuel in liter by vehicle type per day*Fuel Price per liter*Number of vehicles reduced. Note that gasoline saving is 1 liter per a car or a two wheeler and 3 liter per a bus.

For 2015, saving in USD of gasoline from car reduction due to LRT can be calculated as

= 1 liter*0.82USD*65,768*365 = 19.68 million USD

The calculation is done accordingly for 30 years under the three vehicle categories. This can be seen in the following table.

Table 12: The savings of fuel due to the reduction of number of vehicles after AALRT`s operation

Year	Number of cars reduced/year	Saving from Car reduction in USD	Number of buses reduced/year	Saving from bus reduction(USD)	Total Savings (USD)
2015	65,768	19,684,362.40	21,795.00	17,660,488.50	37,344,850.90
2016	69,583	21,450,837.08	23,059.11	19,245,340.74	40,696,177.82
2017	73,618	23,375,835.20	24,396.54	20,972,417.62	44,348,252.82
2018	77,888	25,473,582.65	25,811.54	22,854,482.37	48,328,065.03
2019	82,406	27,759,581.96	27,308.61	24,905,443.62	52,665,025.58
2020	87,185	30,250,726.84	28,892.51	27,140,458.13	57,391,184.98
2021	92,242	32,965,427.07	30,568.27	29,576,042.84	62,541,469.92
2022	97,592	35,923,744.50	32,341.23	32,230,196.93	68,153,941.43
2023	103,252	39,147,541.33	34,217.02	35,122,534.80	74,270,076.13

2024	109,241	42,660,641.69	36,201.61	38,274,431.07	80,935,072.76
2025	115,577	46,489,007.67	38,301.30	41,709,178.52	88,198,186.19
2026	122,280	50,660,931.22	40,522.78	45,452,160.20	96,113,091.42
2027	129,373	55,207,243.19	42,873.10	49,531,037.06	104,738,280.24
2028	136,876	60,161,541.19	45,359.74	53,975,952.32	114,137,493.51
2029	144,815	65,560,437.90	47,990.60	58,819,754.28	124,380,192.18
2030	153,214	71,443,831.60	50,774.06	64,098,239.03	135,542,070.63
2031	162,101	77,855,201.04	53,718.96	69,850,415.00	147,705,616.05
2032	171,503	84,841,926.78	56,834.65	76,118,791.24	160,960,718.03
2033	181,450	92,455,641.29	60,131.06	82,949,691.57	175,405,332.87
2034	191,974	100,752,610.54	63,618.67	90,393,596.89	191,146,207.44
2035	203,108	109,794,149.81	67,308.55	98,505,518.28	208,299,668.09
2036	214,889	119,647,076.82	71,212.44	107,345,403.49	226,992,480.31
2037	227,352	130,384,205.49	75,342.77	116,978,580.00	247,362,785.49
2038	240,539	142,084,884.09	79,712.65	127,476,237.77	269,561,121.86
2039	254,490	154,835,581.59	84,335.98	138,915,955.34	293,751,536.93
2040	269,250	168,730,526.68	89,227.47	151,382,273.17	320,112,799.86
2041	284,867	183,872,404.15	94,402.66	164,967,318.37	348,839,722.52
2042	301,389	200,373,113.70	99,878.01	179,771,485.52	380,144,599.22
2043	318,870	218,354,596.92	105,670.94	195,904,178.63	414,258,775.55
2044	337,364	237,949,738.45	111,799.85	213,484,619.62	451,434,358.07
2045	356,931	259,303,347.98	118,284.25	232,642,729.39	491,946,077.36

II. Saving in fuel due to AA BRT

The BRT bus chosen for operation uses diesel which indicates there is a higher fuel cost for operation when compared to AA LRT. But there is some fuel saving benefits by BRT due to the reduction of Vehicle numbers on the road. Those who prefer to use BRT rather than private vehicles, other ordinary buses or mini-buses will create a situation where vehicle miles travel is reduced. This effect is directly related with fuel usage. What makes the BRT different from other public transport modes (ordinary buses, midi-buses and mini-buses) is that it uses a dedicated lane. So, its benefit to passengers increases accordingly.

The fuel consumption of AA BRT and Anbessa City Bus is similar but not equal as reports indicate, so no significant reduction of fuel consumption is assumed when compared to Anbessa bus. But mini bus and other passenger cars consume more fuel per km per vehicle than BRT. Therefore, saving from reduction in fuel consumption is calculated by comparing the BRT consumption with minibuses and cars. Both type of vehicles use gasoline.

From other countries experience, the introduction of BRT tends to decrease the number of vehicles with 20% annually. This indirectly helps to reduce the amount of fuel consumed by other vehicles.

The recent data on total number of minibus taxis and private cars shows that, there were 11,576 minibuses and 138,529 private cars including small taxis on 2017. The motorization rate per year is 5.8%. So, these numbers are forecasted to reach to 2020 fiscal year.

The price of 1 liter gasoline on 2020 is taken as 21.5 ETB or 0.72 USD and it is expected to increase at annual rate of 3%. For fuel saving calculation, a saving of 1 liter of gasoline per car and 2 liter of gasoline per minibus on a day is assumed. Therefore, final saving from fuel reduction is calculated by multiplying the amount of fuel saved, the fuel price and fuel saved per day for each vehicle type.

Table 13: Life Cycle Saving from Reduction of Fuel due to AA BRT operation

Annual Savings in USD			
Year	Cars	Mini buses	Total
2019			
2020	8,622,894.23	1,441,122.42	10,064,016.64
2021	9,396,712.75	1,570,448.74	10,967,161.50
2022	10,239,973.76	1,711,380.81	11,951,354.57
2023	11,158,909.00	1,864,960.13	13,023,869.13
2024	12,160,309.50	2,032,321.65	14,192,631.14
2025	13,251,575.67	2,214,702.19	15,466,277.86
2026	14,440,772.07	2,413,449.57	16,854,221.64
2027	15,736,686.96	2,630,032.53	18,366,719.49
2028	17,148,897.24	2,866,051.65	20,014,948.89
2029	18,687,839.28	3,123,251.12	21,811,090.41
2030	20,364,885.98	3,403,531.68	23,768,417.66
2031	22,192,430.85	3,708,964.61	25,901,395.46
2032	24,183,979.59	4,041,807.10	28,225,786.69
2033	26,354,249.92	4,404,518.87	30,758,768.79
2034	28,719,280.31	4,799,780.39	33,519,060.70
2035	31,296,548.52	5,230,512.68	36,527,061.21
2036	34,105,100.79	5,699,898.89	39,804,999.68
2037	37,165,692.53	6,211,407.82	43,377,100.35
2038	40,500,941.78	6,768,819.55	47,269,761.34
2039	44,135,496.30	7,376,253.42	51,511,749.72
2040	48,096,215.73	8,038,198.40	56,134,414.14
2041	52,412,370.13	8,759,546.33	61,171,916.46
2042	57,115,856.23	9,545,628.02	66,661,484.25
2043	62,241,433.17	10,402,252.67	72,643,685.84
2044	67,826,979.38	11,335,750.83	79,162,730.21
2045	73,913,772.51	12,353,021.11	86,266,793.62
2046	80,546,794.45	13,461,581.22	94,008,375.68
2047	87,775,063.79	14,669,623.52	102,444,687.31
2048	95,651,998.01	15,986,075.54	111,638,073.55
2049	104,235,808.32	17,420,665.96	121,656,474.27

From the above table, the savings from less fuel usage due to the AA BRT is 10,064,016.64USD on 2020 or 568,588.51USD per km.

4.3.4. Saving in Crash Cost

I. Saving in Crash Cost due to AA LRT

According to AA Police Commission annual report on 2015, the number of total crash occurred was 22,939. It comprises

- 439 persons killed
- 1924 persons injured seriously
- 1165 persons injured slightly
- 19,411 number of property damage

Among these, the savings from reduction in number of fatality and serious injury (KSI) can be calculated using the following formula (DFID, 2003; Mohapatra, 2015).

- $S = S_{monthly} * 12 * \frac{((1+r)^{n+1})-1}{(1+r)-1}$ ….Equation 1: Annual Savings in future earnings due to fatal crash reduction

Where, S= saving in future earnings,

r=rate of growth of earnings per annum

n= working life of a person

$S_{monthly}$ = average per person earnings (income) per month.

Thera are a number of assumptions in order to use the above formula and calculate savings.

- The average monthly income per person is 340USD on 2015 or 6858 ETB.
- The growth rate of earning is taken as 5% per year.
- The average working life of a person is taken as 20 years.

Therefore, the future earning saved due to saving of fatal crash per person can be calculated as the following.

- $S = S_{monthly} * 12 * \frac{((1+r)^{n+1})-1}{(1+r)-1}$ =340USD*12months* $\frac{((1+0.05)^{20+1})-1}{(1+0.05)-1}$
  - Earnings from reduction of fatal crash = 145,576 USD per person

The cost of serious injury has been assumed to be 25% of the cost of fatal crash (iRAP, 2008). So, it can be calculated as follows.

- Cost of serious injury = 0.25 * 145,576 USD = 36,394 USD per person

This number can also be used to indicate the savings gained from reduction of serious injury.

Finally another assumption that shows the relationship between the introduction of LRT and the respective reduction in fatal crash and serious injury number is included in this document. As studies from different experience on provision of public transportation modes like LRT such as Sub-Saharan African Transport Project in Africa (SSATP), shows that there is a reduction in the number of these crashes by 30%. In this case, the total number of fatality on 2015 was 439 and serious injury was 1924. Therefore,

- Annual Reduction in fatality number = 0.3*439 =132 persons saved
- Annual Reduction in serious injury number = 0.3*1924 = 577 persons saved

Finally, the saving in productivity due to reduction of KSI has been estimated by multiplying the annual reduction in number of KSI with annual savings gained by reducing KSI number per person.

- Saving by reducing fatal crash = 132 persons*145,756USD
  = 19,216,032 USD
- Saving by reducing serious injury number = 577 persons * 36,394 USD
  = 20,999,338 USD

The unit cost of slight injury is 2000 ETB as studies in developing countries show. So, the reduction in slight injury can be calculated as follows.

- 1165*0.3 = 350 persons saved from slight injury
- Saving by reducing slight injury number = 350 persons * 2000 ETB
  = 700,000 ETB or 35,000 USD

Therefore, the summation of the above savings will result in the total benefits of reducing KSI and slight injury due to LRT is 40,250,370 USD.

According to Addis Ababa Police Commission`s annual report the cost due to property damage on 2015 was 296,315,747 ETB. So, the reduction of this cost with 30% results in saving of 88,894,724.1 ETB or 4,444,736.21 USD.

The annual benefit value has been taken the same for each year till the end of the 30 years since future earnings is done for 20 working years of a person saved. Therefore, 44,695,106.21USD have been saved by the reduction of road traffic crash due to the introduction of AA LRT which is the same as 1,314,561.95USD per km.

I. Saving in Crash Cost due to AA BRT

Public transportations tend to reduce the occurrence of traffic crashes as different experiences indicate. Specially, mass rapid transits with segregated lanes and with priority at signalized intersections have a decreased record of crash numbers. So, the AA BRT with those features is also expected to do so. Studies from different cities show that after BRT implementation, total number of traffic crash reduces with approximately 30% per year. Therefore, the savings in reduction of crash can be calculated based on this assumption.

The recent available data from AA Police commission shows that there are 459 fatalities, 1903 severe injuries, 1074 slight injuries and 24,928 property damages recorded on 2018. The total number of crash on that year was 28,364.

The savings from reduction in number of fatality and serious injury (KSI) can be calculated using the following formula.

$$S = S_{monthly} * 12 * \frac{((1+r)^{n+1}) - 1}{(1+r) - 1}$$

Where, S= saving in future earnings,

r=rate of growth of earnings per annum

n= work life

$S_{monthly}$ = average per person earnings (income) per month .

Thera are a number of assumptions in order to use the above formula and calculate savings.

- Per capita income (average monthly earning per person) is 8,970 ETB or 301 USD per month 2019.
- The growth rate of earning is taken as 5% per year.
- The average working life of a person is taken as 20 years.

Therefore, the future earning saved due to saving of fatal crash per person can be calculated as the following.

- $S = S_{monthly} * 12 * \frac{((1+r)^{n+1}) - 1}{(1+r) - 1}$ = 301USD*12months* $\frac{((1+0.05)^{20+1}) - 1}{(1+0.05) - 1}$
  - Earnings from reduction of fatal crash = 129,017.9 USD per person

The cost of serious injury has been assumed to be 25% of the coast of fatal crash. So, it can be calculated as follows.

- Cost of serious injury = 0.25 * 129,017.9 USD = 32,254.48 USD per person

This number can also be used to indicate the savings gained from reduction of serious injury.

Finally another assumption that shows the relationship between the introduction of LRT and the respective reduction in fatal crash and serious injury number is included in this document. As studies from different experience of LRT shows, there is a reduction in the number of these crashes by 30%. In this case, the total number of fatality on 2015 was 439 and serious injury was 1924. Therefore,

- Annual Reduction in fatality number = 0.3*459 =138 persons saved
- Annual Reduction in serious injury number = 0.3*1903 = 571 persons saved

Finally, the saving in productivity due to reduction of KSI has been estimated by multiplying the annual reduction in number of KSI with annual savings gained by reducing KSI number per person.

- Saving by reducing fatal crash = 138 persons*129,017.9USD
  = 17,804,470.2 USD
- Saving by reducing serious injury number = 571 persons * 32,254.48 USD
  = 18,417,308.08 USD

As mentioned above, the unit cost of slight injury is 2000 ETB in developing countries show. So, the reduction in slight injury can be calculated as follows.

- 1074*0.3 = 322 persons saved from slight injury
- Saving by reducing slight injury number = 322 persons * 2000 ETB
  = 644,000 ETB or 21,610.74 USD

Therefore, the summation of the above savings will result in the total benefits of reducing KSI and slight injury due to AA BRT is 36,243,389.02 USD.

According to Addis Ababa Police Commission`s annual report the cost due to property damage on 2018 was 109,882,371 ETB. So, the reduction of this cost with 30% results in saving of 32,964,711.3 ETB or 1,106,198.37 USD.

The benefit value has been taken the same for each year till the end of the 30 years since future earnings is done for 20 working years. As stated above, the introduction of BRT helps to reduce the number of road traffic crashes. Accordingly, the AA BRT can save about 37,349,587.39USD by minimizing the number of crashes which can be expressed as 2,110,146.18USD per km.

4.3.5. Reduction in Air Pollution

I. Reduction of Air Pollution due to AA LRT

It is indeed well agreed on the benefit of LRT towards air quality since it has less impact of air pollution including green-house gas emission while operated. So, in this portion, the thesis quantifies its benefit to keep the air quality for 30 years. Since LRT has started operation, there is a shift of car and bus users towards LRT. This reduction in road kilometers of cars and buses will also reduce the emission amount of gases from them. The emitted gases are Carbon di-oxide (CO_2 or GHG), Carbon mono-oxide (CO), Particulate matter (PM) and Hydrocarbon (HC). So there is a reduction in the volume of the gases as well as their percentage from the surrounding air due to the introduction of LRT in Addis Ababa.

The feasibility study of AA LRT has assumed that about 500,000 passengers will use the LRT at the first year but the actual collected data from the ticket office shows the two LRT corridors accommodated around 120.865 passengers per day on 2015. The total number of trips per day in the city was around 1.27 million but some trips are added because of transfer made by passengers from one mode to another mode to make it reach up to 2 million. Thus the reduction of trip due to LRT will be about 8% of the total trip in Addis Ababa, since the total passenger was 2 million.

Before AA LRT had been constructed, the amount of these air pollutant gases released every year can be seen in the following table. In addition, the future amount of emission per year by considering that there is no LRT to be introduced has also been presented for every 5 year interval.

Table 14: Amount of Emission from vehicles in A.A. with no LRT construction

Pollutant Gases	Emission volume (Mega Tones/Year)					
	1999	**2004**	**2009**	**2014**	**2019**	**2024**
CO	1,244.00	1,268.88	1,294.26	1,320.14	1,346.55	1,373.48
THC	110.7	112.91	115.17	117.48	119.83	122.22
PM10	40.57	41.38	42.2	43.05	43.91	44.79
CO2	100,000.00	102,000.00	104,040.00	106,120.80	108,243.22	110,408.08
TOTAL	101,395.27	103,423.17	105,491.63	107,601.47	109,753.51	111,948.57

(Source: Federal Transport Master Plan Study, Appendix 1.9, Environmental Studies, November 2008, Carbon Dioxide Emissions in Addis Ababa, Transportation)

Assuming that the emission trend continues with no interruption in the future, different prediction has been done on this study. The emission trend from the above figure shows that there is an average of 2% increase in each pollutant gas amount every five year which implies 0.4% increase per year, if and only if distributed equally for each year. But this percentage is an approximated prediction value which may be altered due to unexpected incidents in the future. So, it is used for estimation purpose on this study only.

In order to quantify the reduction amount due to BRT, 8% of each pollutant gases volume is deducted per year. So, this amount is taken to calculate the saving amount from emission reduction.

The reduction amount of these gases will be converted to benefits using the cost of each gas emitted in the air per MT. After quantifying the amount of Pollutant gases to be reduced, the benefit from reduction is calculated using unit cost of reducing each gas. Accordingly, United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol is a legally binding global agreement to combat climate change through a reduction of greenhouse gas (GHG) emissions. So, any project that works towards reducing one tone of each gas is awarded with Certified Emission Reductions (CERs). Therefore, the saving from C02 can be calculated as

Certified emission reductions (CERs) = €8.23 or 12.35 USD per one MT of CO2, (Source: Investing.com/commodities/Emission, 2019)

That means there will be a cost of 12.35USD per MT CO_2 emission. Therefore, reducing one MT of CO2 saves 12.35USD. The same unit cost is used for all pollutant gases. So, the following table shows the estimation of saving from reduction of the four pollutant gases.

Table 15: Life Cycle Benefit from Reduction of emission due to AA LRT

Year	Reduced amount of gases (M Tones/year)				Savings from reduction (USD)				
	CO	CO2	HC	PM10	CO	CO2	HC	PM10	Total
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	108.15	8,694.10	9.62	3.53	1,335.71	107,372.08	118.87	43.56	108,870.21
2021	108.59	8,728.87	9.66	3.54	1,341.06	107,801.57	119.34	43.73	109,305.69
2022	109.02	8,763.79	9.70	3.56	1,346.42	108,232.77	119.82	43.91	109,742.92
2023	109.46	8,798.84	9.74	3.57	1,351.81	108,665.70	120.30	44.08	110,181.89
2024	109.90	8,834.04	9.78	3.58	1,357.21	109,100.37	120.78	44.26	110,622.62
2025	110.34	8,869.37	9.82	3.60	1,362.64	109,536.77	121.26	44.43	111,065.11
2026	110.78	8,904.85	9.86	3.61	1,368.09	109,974.92	121.75	44.61	111,509.37
2027	111.22	8,940.47	9.90	3.63	1,373.56	110,414.82	122.23	44.79	111,955.40
2028	111.66	8,976.23	9.94	3.64	1,379.06	110,856.47	122.72	44.97	112,403.23
2029	112.11	9,012.14	9.98	3.66	1,384.58	111,299.90	123.21	45.15	112,852.84
2030	112.56	9,048.19	10.02	3.67	1,390.11	111,745.10	123.71	45.33	113,304.25
2031	113.01	9,084.38	10.06	3.69	1,395.67	112,192.08	124.20	45.51	113,757.47
2032	113.46	9,120.72	10.10	3.70	1,401.26	112,640.85	124.70	45.69	114,212.50
2033	113.92	9,157.20	10.14	3.71	1,406.86	113,091.41	125.20	45.88	114,669.35
2034	114.37	9,193.83	10.18	3.73	1,412.49	113,543.78	125.70	46.06	115,128.03
2035	114.83	9,230.60	10.22	3.74	1,418.14	113,997.95	126.20	46.24	115,588.54
2036	115.29	9,267.53	10.26	3.76	1,423.81	114,453.94	126.71	46.43	116,050.89
2037	115.75	9,304.60	10.30	3.77	1,429.51	114,911.76	127.21	46.62	116,515.09
2038	116.21	9,341.81	10.34	3.79	1,435.22	115,371.41	127.72	46.80	116,981.16
2039	116.68	9,379.18	10.38	3.80	1,440.97	115,832.89	128.23	46.99	117,449.08
2040	117.14	9,416.70	10.42	3.82	1,446.73	116,296.22	128.75	47.18	117,918.88
2041	117.61	9,454.37	10.47	3.84	1,452.52	116,761.41	129.26	47.37	118,390.55
2042	118.08	9,492.18	10.51	3.85	1,458.33	117,228.46	129.78	47.55	118,864.11
2043	118.56	9,530.15	10.55	3.87	1,464.16	117,697.37	130.30	47.75	119,339.57
2044	119.03	9,568.27	10.59	3.88	1,470.02	118,168.16	130.82	47.94	119,816.93
2045	119.51	9,606.55	10.63	3.90	1,475.90	118,640.83	131.34	48.13	120,296.20
2046	119.98	9,644.97	10.68	3.91	1,481.80	119,115.39	131.87	48.32	120,777.38
2047	120.46	9,683.55	10.72	3.93	1,487.73	119,591.86	132.39	48.51	121,260.49
2048	120.95	9,722.29	10.76	3.94	1,493.68	120,070.22	132.92	48.71	121,745.53
2049	121.43	9,761.17	10.81	3.96	1,499.65	120,550.50	133.45	48.90	122,232.51

(Source: Calculated by the Author)

This table clearly shows the increase in saving starting from the operation of AA LRT (2020), as assumed on this study. For example, on the year 2020, the LRT will save about 108,870.21USD due to the reduction of air pollution. Consecutively, the saving per km becomes 3,202.07USD. Later on this chapter, each annual saving will be converted to present value to calculate net present savings.

II. Reduction of Air Pollution due AA BRT

The introduction of BRT is expected to attract other vehicle users towards it. So, other mode users will be attracted by its time saving benefit and reliability. This will reduce the number of trips done by other vehicle modes in some amount. A CRGE strategic final report dictates that AA BRT is expected to accommodate 3% of total trips from Addis Ababa (Federal Democratic Republic of Ethiopia, 2011). On the other hand, 3% of passengers from other modes such as public and private vehicles will be shifted to BRT. So, the reduction of passenger-km travel will take place which decrease the amount of emission from other vehicles.

As mentioned above, the pollutant gases to be discussed with in this study are CO, CO2, PM10 and THC. The emission of these gases from motor vehicles present in Addis Ababa is expected to be reduced by 3% annually. This value is less than that of LRT since the AA BRT uses buses with diesel while LRT uses electricity. Since the thesis assumes that the operation of BRT will be started on 2020, the reduction impact is quantified starting from this year. Additionally, the trend of emission from motor vehicles in the city is taken from the Federal Transport Master Plan Study on Environmental Studies. So, the following table shows trend of the emitted gases before the operation of BRT.

Table 16: Trend of Emission per in AA City before AA BRT

Pollutant Gases	Emission (MT/Year)										
	1999	2004	2009	2014	2019	2024	2029	2034	2039	2044	2049
CO	1,244.00	1,268.88	1,294.26	1,320.14	1,346.55	1,373.48	1,400.95	1,428.97	1,457.55	1,486.70	1,516.43
HC	110.7	112.91	115.17	117.48	119.83	122.22	124.6644	127.15769	129.70084	132.2949	134.94076
PM10	40.57	41.38	42.2	43.05	43.91	44.79	45.6858	46.599516	47.531506	48.48214	49.451779
CO_2	100,000	102,000	104,040	106,120.8	108,243.22	110,408.08	112,616	114,869	117,166	119,509.3	121,899.44
TOTAL	101,395.27	103,423.17	105,491.63	107,601.47	109,753.51	111,948.57	114,187.54	116,471.29	118,800.72	121,176.73	123,600.27

(Source: Federal Transport Master Plan Study on 2008 and compiled by the Author)

After BRT is implemented the amount of emission for each pollutant gas will be reduced by 3% annually starting from 2020 as seen on the following table. The same benefit estimation method is used as it is done with AA LRT`s saving from emission reduction. Therefore, the saving from C02 can be calculated as the following.

Certified emission reductions (CERs) = €8.23 or 12.35 USD per one MT of CO2

In other word, there will be a cost of 12.35USD per MT CO_2 emission. Therefore, reducing one MT of CO2 saves 12.35USD. The same unit cost is used for all pollutant gases. So, the following table shows the estimation of saving from reduction of the four pollutant gases due to AA BRT.

Table 17: Life Cycle Saving from Reduction of Emission due to AA BRT

Year	Reduced amount of gases (M Tones/year)				Savings from reduction (USD)				
	CO	CO_2	HC	PM_{10}	CO	CO_2	HC	PM_{10}	Total
2019	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	40.56	3,260.29	3.61	1.32	500.892362	40264.53	44.574603	16.33372962	40,826.33
2021	40.72	3,273.33	3.62	1.33	502.895932	40425.59	44.752901	16.39906454	40,989.64
2022	40.88	3,286.42	3.64	1.33	504.907515	40587.29	44.931913	16.4646608	41,153.59
2023	41.05	3,299.57	3.65	1.34	506.927145	40749.64	45.111641	16.53051944	41,318.21
2024	41.21	3,312.76	3.67	1.34	508.954854	40912.64	45.292087	16.59664152	41,483.48
2025	41.38	3,326.02	3.68	1.35	510.990673	41076.29	45.473256	16.66302808	41,649.42
2026	41.54	3,339.32	3.70	1.35	513.034636	41240.59	45.655149	16.7296802	41,816.01
2027	41.71	3,352.68	3.71	1.36	515.086775	41405.56	45.837769	16.79659892	41,983.28
2028	41.87	3,366.09	3.73	1.37	517.147122	41571.18	46.02112	16.86378531	42,151.21
2029	42.04	3,379.55	3.74	1.37	519.21571	41737.46	46.205205	16.93124045	42,319.81
2030	42.21	3,393.07	3.76	1.38	521.292573	41904.41	46.390026	16.99896542	42,489.09
2031	42.38	3,406.64	3.77	1.38	523.377743	42072.03	46.575586	17.06696128	42,659.05
2032	42.55	3,420.27	3.79	1.39	525.471254	42240.32	46.761888	17.13522912	42,829.69
2033	42.72	3,433.95	3.80	1.39	527.573139	42409.28	46.948936	17.20377004	43,001.01
2034	42.89	3,447.69	3.82	1.40	529.683432	42578.92	47.136731	17.27258512	43,173.01
2035	43.06	3,461.48	3.83	1.40	531.802166	42749.23	47.325278	17.34167546	43,345.70
2036	43.23	3,475.32	3.85	1.41	533.929374	42920.23	47.514579	17.41104216	43,519.08
2037	43.41	3,489.22	3.86	1.42	536.065092	43091.91	47.704638	17.48068633	43,693.16
2038	43.58	3,503.18	3.88	1.42	538.209352	43264.28	47.895456	17.55060908	43,867.93
2039	43.75	3,517.19	3.89	1.43	540.362189	43437.33	48.087038	17.62081151	44,043.40
2040	43.93	3,531.26	3.91	1.43	542.523638	43611.08	48.279386	17.69129476	44,219.58
2041	44.10	3,545.39	3.92	1.44	544.693733	43785.53	48.472504	17.76205994	44,396.46
2042	44.28	3,559.57	3.94	1.44	546.872508	43960.67	48.666394	17.83310818	44,574.04
2043	44.46	3,573.81	3.96	1.45	549.059998	44136.51	48.861059	17.90444061	44,752.34
2044	44.64	3,588.10	3.97	1.46	551.256238	44313.06	49.056504	17.97605837	44,931.35
2045	44.81	3,602.45	3.99	1.46	553.461263	44490.31	49.25273	18.0479626	45,111.07
2046	44.99	3,616.86	4.00	1.47	555.675108	44668.27	49.449741	18.12015446	45,291.52
2047	45.17	3,631.33	4.02	1.47	557.897808	44846.95	49.64754	18.19263507	45,472.68
2048	45.35	3,645.86	4.04	1.48	560.129399	45026.33	49.84613	18.26540561	45,654.57
2049	45.54	3,660.44	4.05	1.48	562.369917	45206.44	50.045514	18.33846724	45,837.19

(Source: Calculated by the Author)

So, the AA BRT project will save about 40,826.33USD by reducing the impact of the above mentioned air pollutants. The saving per km will be 2,306.57USD on 2020. This saving is less than that of AA LRT since the LRT is electrically operated.

4.4. Calculation of Life Cycle Costs and Life Cycle Benefits

The two projects have different stating year of operation and construction. AA LRT has two corridors, EW and NS, whose starting year of operation was on 2015 and AA BRT has one corridor, B-2 corridor, whose operation is not yet started. So, the study assumed that both projects start operation on 2020 after the construction has been finished on 2019 for the sake of life cycle cost analysis. Therefore all the costs and benefits that have occurred before and after this year are converted to 2019 prices using discount rate of 10.23%. Forecasting costs and benefits for 30 years is done using this discount rate value.

4.4.1. The case of Addis Ababa Light Rail Transit E-W and N-S Corridors

So, the first task is to convert the starting year of operation of AA LRT to 2020 and the base year to 2019. In order to do that, prices put in terms of 2015 and 2016 must be brought to 2019 and 2020 using discount rate i.e., 10.23%. The formula to past prices to future prices is the following.

- $FV = PV(1+R)^N$

Where FV = Present value (2019), PV = Future Value (2015), R = Discount Rate (10.23%), and N = Difference in Year.

All annual costs should start from 2019 and all benefits should start from 2020. Using the above formula, past prices are brought to 2019 and 2020 and the estimation can be seen in the following table.

Table 18: Annual Change in Life Cycle Costs and Benefits of AA LRT

No	Year	Life Cycle Costs			Life Cycle Benefits					
		Capital	Operation and Maintenance	Total Cycle Cost	Passenger Revenue	Fuel Savings	Time Savings	Crash Savings	Reduction of Air Pollution	Total Life Cycle Benefits
0	2019	1,457,820,900.62	0.00	**1,457,820,900.62**	0.00	0.00	0.00	0.00	0.00	**0.00**
1	2020	0.00	54,995,005.42	**54,995,005.42**	14,328,981.81	60,083,171.92	4,264,117.20	65,987,124.44	108,870.21	**144,772,265.58**
2	2021	0.00	55,177,794.98	**55,177,794.98**	14,328,981.81	65,475,035.76	4,701,189.21	65,987,124.44	109,305.69	**150,601,636.92**
3	2022	0.00	55,369,724.02	**55,369,724.02**	14,328,981.81	71,350,765.47	4,936,248.67	65,987,124.44	109,742.92	**156,712,863.32**
4	2023	0.00	55,571,249.51	**55,571,249.51**	14,328,981.81	77,753,783.17	5,183,061.11	65,987,124.44	110,181.89	**163,363,132.41**
5	2024	0.00	23,895,525.51	**23,895,525.51**	14,328,981.81	84,731,407.67	5,442,214.16	65,987,124.44	110,622.62	**170,600,350.70**
6	2025	0.00	24,117,707.37	**24,117,707.37**	15,797,702.44	92,335,204.19	5,714,324.87	65,987,124.44	111,065.11	**179,945,421.06**
7	2026	0.00	24,350,998.32	**24,350,998.32**	15,797,702.44	100,621,365.42	6,300,043.17	65,987,124.44	111,509.37	**188,817,744.84**
8	2027	0.00	24,595,953.81	**24,595,953.81**	15,797,702.44	109,651,126.75	6,615,045.33	65,987,124.44	111,955.40	**198,162,954.37**
9	2028	0.00	24,853,157.08	**24,853,157.08**	15,797,702.44	119,491,218.86	6,945,797.60	65,987,124.44	112,403.23	**208,334,246.57**
10	2029	0.00	25,123,220.51	**25,123,220.51**	15,797,702.44	130,214,360.84	7,293,087.47	65,987,124.44	112,852.84	**219,405,128.05**
11	2030	0.00	25,406,787.12	**25,406,787.12**	17,416,966.94	141,899,797.58	7,657,741.85	65,987,124.44	113,304.25	**233,074,935.07**
12	2031	0.00	25,704,532.05	**25,704,532.05**	17,416,966.94	154,633,885.42	8,442,660.39	65,987,124.44	113,757.47	**246,594,394.66**
13	2032	0.00	26,017,164.24	**26,017,164.24**	17,416,966.94	168,510,730.30	8,864,793.41	65,987,124.44	114,212.50	**260,893,827.59**
14	2033	0.00	26,345,428.03	**26,345,428.03**	17,416,966.94	183,632,883.23	9,308,033.08	65,987,124.44	114,669.35	**276,459,677.05**
15	2034	0.00	26,690,105.01	**26,690,105.01**	17,416,966.94	200,112,098.18	9,773,434.73	65,987,124.44	115,128.03	**293,404,752.32**
16	2035	0.00	27,052,015.84	**27,052,015.84**	19,202,206.06	218,070,157.87	10,262,106.47	65,987,124.44	115,588.54	**313,637,183.37**
17	2036	0.00	27,432,022.21	**27,432,022.21**	19,202,206.06	237,639,773.83	11,313,972.38	65,987,124.44	116,050.89	**334,259,127.61**
18	2037	0.00	27,831,028.90	**27,831,028.90**	19,202,206.06	258,965,567.14	11,879,671.00	65,987,124.44	116,515.09	**356,151,083.73**
19	2038	0.00	28,249,985.92	**28,249,985.92**	19,202,206.06	282,205,137.13	12,473,654.55	65,987,124.44	116,981.16	**379,985,103.34**
20	2039	0.00	28,689,890.80	**28,689,890.80**	19,202,206.06	307,530,226.14	13,097,337.28	65,987,124.44	117,449.08	**405,934,343.00**
21	2040	0.00	29,151,790.92	**29,151,790.92**	21,170,432.18	335,127,988.63	13,752,204.14	65,987,124.44	117,918.88	**436,155,668.27**
22	2041	0.00	29,636,786.04	**29,636,786.04**	21,170,432.18	365,202,374.33	15,161,805.07	65,987,124.44	118,390.55	**467,640,126.57**
23	2042	0.00	30,146,030.92	**30,146,030.92**	21,170,432.18	397,975,635.40	15,919,895.32	65,987,124.44	118,864.11	**501,171,951.46**
24	2043	0.00	30,680,738.05	**30,680,738.05**	21,170,432.18	433,689,968.93	16,715,890.09	65,987,124.44	119,339.57	**537,682,755.20**
25	2044	0.00	31,242,180.53	**31,242,180.53**	21,170,432.18	472,609,306.74	17,551,684.59	65,987,124.44	119,816.93	**577,438,364.88**
26	2045	0.00	31,831,695.13	**31,831,695.13**	23,340,401.48	515,021,265.92	18,429,268.82	65,987,124.44	120,296.20	**622,898,356.86**
27	2046	0.00	32,450,685.47	**32,450,685.47**	23,340,401.48	561,239,274.33	20,318,268.87	65,987,124.44	120,777.38	**671,005,846.50**
28	2047	0.00	33,100,625.32	**33,100,625.32**	23,340,401.48	611,604,886.81	21,334,182.32	65,987,124.44	121,260.49	**722,387,855.53**
29	2048	0.00	33,783,062.17	**33,783,062.17**	23,340,401.48	666,490,309.35	22,400,891.43	65,987,124.44	121,745.53	**778,340,472.23**
30	2049	0.00	34,499,620.85	**34,499,620.85**	23,340,401.48	726,301,149.71	23,520,936.00	65,987,124.44	122,232.51	**839,271,844.15**

(Source: Calculated by the Author)

The next task is to estimate the present value of annual costs and benefits using discount rate. So, present value of each future cost and benefit is estimated by using the following formula

- PV = $\frac{FV}{(1+R)^N}$, Where PV = Present value, FV = Future Value, R = Discount Rate (10.23%), N = Year Difference

In addition, Net Present Flow is estimated by subtracting present value of costs from present value of benefits. I.e.,

- Net present flow on year i = Present value of benefits on year i – Present value of costs on year i

The following table summarizes annual present values of benefits and costs with respect to the total km of AA LRT line which is 34km and unit km.

Table 19: Present value of Annual Costs and Benefits for AA LRT

No	Year	Present Value (DR @10.23%)				Net Present Flow
		Life Cycle Costs (LCC)	LCC/KM	Life Cycle Benefits (LCB)	LCB/KM	
0	2019	1,457,820,900.62	42,877,085.31	-	-	-42,877,085.31
1	2020	49,891,141.63	1,467,386.52	131,336,537.77	3,862,839.35	2,395,452.83
2	2021	45,411,382.77	1,335,628.91	123,945,304.14	3,645,450.12	2,309,821.22
3	2022	41,340,234.58	1,215,889.25	117,005,216.22	3,441,329.89	2,225,440.64
4	2023	37,640,114.19	1,107,062.18	110,650,867.36	3,254,437.28	2,147,375.09
5	2024	14,683,092.98	431,855.68	104,828,864.73	3,083,201.90	2,651,346.23
6	2025	13,444,268.49	395,419.66	100,309,474.55	2,950,278.66	2,554,859.00
7	2026	12,314,537.87	362,192.29	95,486,979.21	2,808,440.57	2,446,248.27
8	2027	11,284,055.39	331,883.98	90,912,585.52	2,673,899.57	2,342,015.59
9	2028	10,343,875.82	304,231.64	86,708,645.02	2,550,254.27	2,246,022.62
10	2029	9,485,871.48	278,996.22	82,841,642.25	2,436,518.89	2,157,522.67
11	2030	8,702,657.00	255,960.50	79,835,801.62	2,348,111.81	2,092,151.31
12	2031	7,987,521.00	234,927.09	76,627,650.80	2,253,754.44	2,018,827.35
13	2032	7,334,364.04	215,716.59	73,547,227.87	2,163,153.76	1,947,437.17
14	2033	6,737,642.37	198,165.95	70,702,454.76	2,079,483.96	1,881,318.01
15	2034	6,192,316.86	182,126.97	68,072,238.57	2,002,124.66	1,819,997.70
16	2035	5,693,806.64	167,464.90	66,013,175.78	1,941,563.99	1,774,099.09
17	2036	5,237,946.98	154,057.26	63,824,371.86	1,877,187.41	1,723,130.14
18	2037	4,820,951.13	141,792.68	61,693,262.40	1,814,507.72	1,672,715.04
19	2038	4,439,375.64	130,569.87	59,713,184.17	1,756,270.12	1,625,700.25
20	2039	4,090,088.89	120,296.73	57,870,821.44	1,702,082.98	1,581,786.25
21	2040	3,770,242.50	110,889.49	56,408,631.71	1,659,077.40	1,548,187.92
22	2041	3,477,245.40	102,271.92	54,867,605.36	1,613,753.10	1,511,481.18
23	2042	3,208,740.31	94,374.71	53,344,688.91	1,568,961.44	1,474,586.72
24	2043	2,962,582.31	87,134.77	51,919,527.31	1,527,044.92	1,439,910.15
25	2044	2,736,819.48	80,494.69	50,583,683.28	1,487,755.39	1,407,260.70
26	2045	2,529,675.26	74,402.21	49,501,936.93	1,455,939.32	1,381,537.11
27	2046	2,339,532.46	68,809.78	48,376,172.48	1,422,828.60	1,354,018.82
28	2047	2,164,918.69	63,674.08	47,247,173.07	1,389,622.74	1,325,948.66
29	2048	2,004,493.25	58,955.68	46,182,261.76	1,358,301.82	1,299,346.13
30	2049	1,857,035.05	54,618.68	45,176,068.29	1,328,707.89	1,274,089.21
Total		**1,791,947,431.07**	**52,704,336.21**	**2,225,534,055.16**	**65,456,883.98**	**12,752,547.77**

(Source: Calculated by the Author)

On the above table, net present flow is calculated for the difference of LCC/KM and LCC/KM only. This is done since per unit km value of costs and benefits are needed while comparing AA LRT with AA BRT.

The summation of present value of costs/km and benefits/km can also be seen in the above table which implies the total life cycle cost and benefit of AA LRT project for 30 years. So,

- Present Value of Life Cycle Cost of AA LRT per km = **52,704,336.21 USD (2019 price)**
- Present Value of Life Cycle Benefit of AA LRT per km = **65,456,883.98 USD (2019 price)**

Finally the Net Present Value of the project is calculated by adding all the present flow values of 30 years.

- Net Present Value (NPV @ 10.23%) = Summation of annual present value of flow or
  = PV of Life Cycle Benefit per km – PV of Life Cycle Cost per km
  = **65,456,883.98 USD - 52,704,336.21 USD**
  = **12,752,547.77 USD (2019 price) per km**

From this result, we can conclude that the NPV of AA LRT is greater than zero, which implies the project is acceptable or efficient.

Life Cycle Benefit to Cost Ratio is also another indicator while life cycle cost analysis. Therefore, BCR is also estimated in this study to show the difference between the project`s benefit and cost. I.e.,

- If BCR < 1, Accept the project since the benefit is higher than the cost.
- If BCR >1, Reject the project since the benefit is less than the cost.

In our scenario, BCR is calculated as the following.

- $\text{BCR} = \frac{\text{Present value of life cycle benefit per km}}{\text{Present value of life cycle cost per km}} = \frac{65{,}456{,}883.98\ \text{USD}}{52{,}704{,}336.21\text{USD}}$ **= 1.24**

So, the project is acceptable since BCR is 1.24 which greater than 1 and the present value of total benefit is greater than that of total cost. Using NPV and BCR criteria, it is now possible to conclude the AA LRT project is efficient and acceptable.

4.4.2. The case of Addis Ababa Bus Rapid Transit

Under this section, both vehicle options for AA BRT are going to be assessed, buses operated with diesel and electricity. These two have different capital, replacement, operating and maintenance costs. Among the benefit categories, passenger revenue, travel time saving and crash saving the same for both options. But benefit from fuel saving and air pollution reduction is different for the two cases. The trolley vehicle is operated electrically so its contribution to fuel saving and air pollution reduction is higher than that of diesel bases vehicle. So, savings in dollar for trolley buses is taken the same as that of LRT which is operated electrically.

I. AA BRT with Diesel Buses

The same procedure is used to estimate NPV and BCR for AA BRT. Firstly, conversion of operation year to 2020 and construction end year to 2019 is done to all annual cost and benefit categories using the following formula.

- $FV = PV(1+R)^N$

Where FV = Present value (2019), PV = Future Value (2015), R = Discount Rate (10.23%), and N = difference in Year.

Table 20: Annual Change in Life Cycle Costs and Benefits of AA BRT Project

No	Year	Life Cycle Costs				Life Cycle Benefits					
		Capital	Operation and Maintenance	Replacement	Total Cycle Cost	Passenger Revenue	Fuel Savings	Time Savings	Crash Savings	Reduction of Air Pollution	Total Life Cycle Benefits
0	2019	159,378,353.96	0.00	0.00	**159,378,353.96**	0.00	0.00	0.00	0.00	0.00	**0.00**
1	2020	0.00	6,666,457.86	0.00	**6,666,457.86**	4,818,366.01	10,064,016.64	5,204,514.00	1,381,558.73	40,826.33	**21,509,281.71**
2	2021	0.00	6,810,777.28	0.00	**6,810,777.28**	5,059,284.31	10,967,161.50	5,464,739.70	1,381,558.73	40,989.64	**22,913,733.87**
3	2022	0.00	6,962,312.66	0.00	**6,962,312.66**	5,312,248.52	11,951,354.57	5,737,976.69	1,381,558.73	41,153.59	**24,424,292.10**
4	2023	0.00	7,121,424.81	0.00	**7,121,424.81**	5,577,860.95	13,023,869.13	6,024,875.52	1,381,558.73	41,318.21	**26,049,482.54**
5	2024	0.00	7,288,492.57	0.00	**7,288,492.57**	5,856,754.00	14,192,631.14	6,326,119.30	1,381,558.73	41,483.48	**27,798,546.65**
6	2025	0.00	7,463,913.72	0.00	**7,463,913.72**	6,457,071.28	15,466,277.86	6,974,546.52	1,381,558.73	41,649.42	**30,321,103.81**
7	2026	0.00	7,648,105.93	0.00	**7,648,105.93**	6,779,924.84	16,854,221.64	7,323,273.85	1,381,558.73	41,816.01	**32,380,795.08**
8	2027	0.00	7,841,507.74	0.00	**7,841,507.74**	7,118,921.09	18,366,719.49	7,689,437.54	1,381,558.73	41,983.28	**34,598,620.12**
9	2028	0.00	8,044,579.65	0.00	**8,044,579.65**	7,474,867.14	20,014,948.89	8,073,909.42	1,381,558.73	42,151.21	**36,987,435.39**
10	2029	0.00	8,257,805.15	0.00	**8,257,805.15**	7,848,610.50	21,811,090.41	8,477,604.89	1,381,558.73	42,319.81	**39,561,184.34**
11	2030	0.00	8,481,691.93	54,537,214.07	**63,018,906.00**	8,653,093.07	23,768,417.66	9,346,559.39	1,381,558.73	42,489.09	**43,192,117.95**
12	2031	0.00	8,716,773.05	0.00	**8,716,773.05**	9,085,747.73	25,901,395.46	9,813,887.36	1,381,558.73	42,659.05	**46,225,248.33**
13	2032	0.00	8,963,608.22	0.00	**8,963,608.22**	9,540,035.11	28,225,786.69	10,304,581.73	1,381,558.73	42,829.69	**49,494,791.95**
14	2033	0.00	9,222,785.15	0.00	**9,222,785.15**	10,017,036.87	30,758,768.79	10,819,810.81	1,381,558.73	43,001.01	**53,020,176.21**
15	2034	0.00	9,494,920.93	0.00	**9,494,920.93**	10,517,888.71	33,519,060.70	11,360,801.36	1,381,558.73	43,173.01	**56,822,482.51**
16	2035	0.00	9,780,663.50	0.00	**9,780,663.50**	11,595,972.31	36,527,061.21	12,525,283.49	1,381,558.73	43,345.70	**62,073,221.44**
17	2036	0.00	10,080,693.19	0.00	**10,080,693.19**	12,175,770.92	39,804,999.68	13,151,547.67	1,381,558.73	43,519.08	**66,557,396.09**
18	2037	0.00	10,395,724.37	0.00	**10,395,724.37**	12,784,559.47	43,377,100.35	13,809,125.05	1,381,558.73	43,693.16	**71,396,036.76**
19	2038	0.00	10,726,507.11	0.00	**10,726,507.11**	13,423,787.44	47,269,761.34	14,499,581.31	1,381,558.73	43,867.93	**76,618,556.75**
20	2039	0.00	11,073,828.99	0.00	**11,073,828.99**	14,094,976.81	51,511,749.72	15,224,560.37	1,381,558.73	44,043.40	**82,256,889.04**
21	2040	0.00	11,438,516.96	144,441,178.51	**155,879,695.46**	15,539,711.94	56,134,414.14	16,785,077.81	1,381,558.73	44,219.58	**89,884,982.19**
22	2041	0.00	11,821,439.32	0.00	**11,821,439.32**	16,316,697.53	61,171,916.46	17,624,331.70	1,381,558.73	44,396.46	**96,538,900.88**
23	2042	0.00	12,223,507.81	0.00	**12,223,507.81**	17,132,532.41	66,661,484.25	18,505,548.28	1,381,558.73	44,574.04	**103,725,697.71**
24	2043	0.00	12,645,679.72	0.00	**12,645,679.72**	17,989,159.03	72,643,685.84	19,430,825.70	1,381,558.73	44,752.34	**111,489,981.64**
25	2044	0.00	13,088,960.23	0.00	**13,088,960.23**	18,888,616.98	79,162,730.21	20,402,366.98	1,381,558.73	44,931.35	**119,880,204.25**
26	2045	0.00	13,554,404.76	0.00	**13,554,404.76**	20,824,700.22	86,266,793.62	22,493,609.60	1,381,558.73	45,111.07	**131,011,773.25**
27	2046	0.00	14,043,121.51	0.00	**14,043,121.51**	21,865,935.24	94,008,375.68	23,618,290.08	1,381,558.73	45,291.52	**140,919,451.24**
28	2047	0.00	14,556,274.11	0.00	**14,556,274.11**	22,959,232.00	102,444,687.31	24,799,204.58	1,381,558.73	45,472.68	**151,630,155.31**
29	2048	0.00	15,095,084.34	0.00	**15,095,084.34**	24,107,193.60	111,638,073.55	26,039,164.81	1,381,558.73	45,654.57	**163,211,645.26**
30	2049	0.00	15,660,835.07	0.00	**15,660,835.07**	25,312,553.72	121,656,474.27	27,341,123.05	1,381,558.73	45,837.19	**175,737,546.96**

(Source: Calculated by the Author)

From the above table it is possible to see that capital cost is expended on 2019 while operating costs are started to expend on 2020 and continue till the projects life time. For benefit category, all benefits are assumed to be gained starting from 2020 which is the first year of operation. Both categorical and total benefits tend to increase annually.

The estimation of present values of annual costs and benefits is done also in the same way as that of AA LRT project using the present value formula. Thus, the following table summarizes annual present values of benefits and costs both for the total km of the BRT line which is 17.7km and for the unit km.

Table 21: Present value of Annual Costs and Benefits including net present flow for AA BRT

No	Year	Present Value (DR @10.23%)				Net Present Flow
		Life Cycle Costs (LCC)	LCC/KM	Life Cycle Benefits (LCB)	LCB/KM	
0	2019	159,378,353.96	9,004,426.78	-	-	-159,378,353.96
1	2020	6,047,770.90	341,681.97	19,513,092.36	1,102,434.60	13,465,321.46
2	2021	5,605,276.80	316,682.30	18,858,026.86	1,065,425.25	13,252,750.06
3	2022	5,198,213.35	293,684.37	18,235,705.21	1,030,265.83	13,037,491.86
4	2023	4,823,559.76	272,517.50	17,644,114.64	996,842.64	12,820,554.88
5	2024	4,478,562.90	253,026.15	17,081,383.91	965,049.94	12,602,821.01
6	2025	4,160,713.06	235,068.53	16,902,313.90	954,932.99	12,741,600.84
7	2026	3,867,721.93	218,515.36	16,375,284.58	925,157.32	12,507,562.66
8	2027	3,597,502.60	203,248.73	15,873,047.62	896,782.35	12,275,545.02
9	2028	3,348,151.41	189,161.10	15,394,158.47	869,726.47	12,046,007.06
10	2029	3,117,931.41	176,154.32	14,937,269.29	843,913.52	11,819,337.88
11	2030	21,586,040.03	1,219,550.28	14,794,715.53	835,859.63	-6,791,324.50
12	2031	2,708,682.18	153,032.89	14,364,203.99	811,536.95	11,655,521.81
13	2032	2,526,884.37	142,761.83	13,952,820.48	788,294.94	11,425,936.11
14	2033	2,358,656.99	133,257.46	13,559,505.86	766,073.78	11,200,848.86
15	2034	2,202,897.25	124,457.47	13,183,268.35	744,817.42	10,980,371.10
16	2035	2,058,597.30	116,304.93	13,064,938.39	738,132.11	11,006,341.09
17	2036	1,924,835.73	108,747.78	12,708,655.19	718,003.12	10,783,819.47
18	2037	1,800,769.90	101,738.41	12,367,376.18	698,721.82	10,566,606.28
19	2038	1,685,628.96	95,233.27	12,040,308.82	680,243.44	10,354,679.86
20	2039	1,578,707.47	89,192.51	11,726,708.57	662,525.91	10,148,001.10
21	2040	20,160,142.29	1,138,991.09	11,624,952.34	656,776.97	-8,535,189.95
22	2041	1,386,994.04	78,361.25	11,326,783.17	639,931.25	9,939,789.13
23	2042	1,301,068.86	73,506.72	11,040,552.17	623,760.01	9,739,483.31
24	2043	1,221,087.54	68,988.00	10,765,655.20	608,229.11	9,544,567.65
25	2044	1,146,594.79	64,779.37	10,501,523.02	593,306.39	9,354,928.24
26	2045	1,077,173.00	60,857.23	10,411,548.63	588,223.09	9,334,375.64
27	2046	1,012,438.97	57,199.94	10,159,589.09	573,988.08	9,147,150.12
28	2047	952,040.93	53,787.62	9,917,243.40	560,296.24	8,965,202.47
29	2048	895,655.77	50,602.02	9,684,043.41	547,121.10	8,788,387.64
30	2049	842,986.64	47,626.36	9,459,546.96	534,437.68	8,616,560.32
Total		**274,051,641.08**	**15,483,143.56**	**407,468,335.60**	**23,020,809.92**	**7,537,666.36**

(Source: Calculated by the Author)

The table also includes the summation of present value of costs and benefits which implies the total life cycle cost and benefit of AA BRT project for 30 years. So,

- Present Value of Life Cycle Cost per km of AA BRT = **15,483,143.56USD (2019 price)**
- Present Value of Life Cycle Benefit per km of AA BRT = **23,020,809.92USD (2019 price)**

Thus, the Net Present Value of the project is calculated by adding all the present flow values of 30 years.

- Net Present Value (NPV @ 10.5%) = Summation of annual present value of flow
  = PV of Life Cycle per km Benefit – PV of Life Cycle Cost per km
  =**23,020,809.92USD - 15,483,143.56USD**
  = **7,537,666.36USD (2019 price)**

As the result shows NPV of AA BRT project is greater than zero, so the project is acceptable or efficient.

Benefit to Cost Ration (BCR) of AA BRT project is also estimated in order to compare the project`s life cycle benefit and cost. I.e.

- If BCR < 1, Accept the project since the benefit is higher than the cost.
- If BCR >1, Reject the project since the benefit is less than the cost.

In our scenario, BCR is calculated as the following.

- BCR = $\frac{\text{Present value of life cycle benefit per km}}{\text{Present value of life cycle cost per km}} = \frac{23{,}020{,}809.92\text{USD}}{15{,}483{,}143.56\text{USD}}$ **= 1.49 or 1.5**

So, the project is acceptable since BCR is 1.5 which greater than 1 and the present value of total benefit is greater than that of total cost. Using NPV and BCR criteria, it is now possible to conclude the AA BRT project is cost effective and acceptable.

I. AA BRT with Trolley Buses

The annual costs and benefits of AA BRT operated with trolley buses can be found by using a discount rate of 10.23% for future values. All capital expenditure is on 2019 and operation and maintenance expenditure starts from 2020. There will be replacement expenditure on 2040 in order to replace the rolling stock. The operation and maintenance cost is calculated by adding 30% on diesel based BRT annual O&M costs for 17.17 km. The benefits from travel time saving, passenger fare and crash reduction is taken the same as that of diesel BRT. Air pollution reduction saving and fuel saving is taken the same as that of AA LRT except the change in total route length in km. So, these savings in USD of AA LRT are divided by 34km to find out per km saving and multiplied with 17.17km. So, the following table summarizes the annual change in benefits and costs of AA BRT with trolley bus.

Table 22: Annual Change in Life Cycle Costs and Benefits of AA BRT Project using Trolley bus

No	Year	Life Cycle Costs				Life Cycle Benefits					
		Capital	Operation and Maintenance	Replacement	Total Cycle Cost	Passenger Revenue	Fuel Savings	Time Savings	Crash Savings	Reduction of Air Pollution	Total Life Cycle Benefits
0	2019	350,266,920.67	0.00	0.00	**350,266,920.67**	0.00	0.00	0.00	0.00	0.00	**0.00**
1	2020	0.00	8,666,395.22	0.00	**8,666,395.22**	4,818,366.01	31,278,592.44	5,204,514.00	1,381,558.73	56,676.55	**42,739,707.73**
2	2021	0.00	8,854,010.46	0.00	**8,854,010.46**	5,059,284.31	34,085,533.32	5,464,739.70	1,381,558.73	56,903.26	**46,048,019.32**
3	2022	0.00	9,051,006.46	0.00	**9,051,006.46**	5,312,248.52	37,144,369.08	5,737,976.69	1,381,558.73	57,130.87	**49,633,283.89**
4	2023	0.00	9,257,852.26	0.00	**9,257,852.26**	5,577,860.95	40,477,704.77	6,024,875.52	1,381,558.73	57,359.40	**53,519,359.36**
5	2024	0.00	9,475,040.35	0.00	**9,475,040.35**	5,856,754.00	44,110,173.99	6,326,119.30	1,381,558.73	57,588.83	**57,732,194.85**
6	2025	0.00	9,703,087.84	0.00	**9,703,087.84**	6,457,071.28	48,068,621.01	6,974,546.52	1,381,558.73	57,819.19	**62,939,616.73**
7	2026	0.00	9,942,537.71	0.00	**9,942,537.71**	6,779,924.84	52,382,299.05	7,323,273.85	1,381,558.73	58,050.46	**67,925,106.94**
8	2027	0.00	10,193,960.07	0.00	**10,193,960.07**	7,118,921.09	57,083,086.57	7,689,437.54	1,381,558.73	58,282.67	**73,331,286.60**
9	2028	0.00	10,457,953.55	0.00	**10,457,953.55**	7,474,867.14	62,205,722.76	8,073,909.42	1,381,558.73	58,515.80	**79,194,573.85**
10	2029	0.00	10,735,146.70	0.00	**10,735,146.70**	7,848,610.50	67,788,064.32	8,477,604.89	1,381,558.73	58,749.86	**85,554,588.30**
11	2030	0.00	11,026,199.51	0.00	**11,026,199.51**	8,653,093.07	73,871,365.21	9,346,559.39	1,381,558.73	58,984.86	**93,311,561.27**
12	2031	0.00	11,331,804.96	0.00	**11,331,804.96**	9,085,747.73	80,500,581.53	9,813,887.36	1,381,558.73	59,220.80	**100,840,996.15**
13	2032	0.00	11,652,690.69	0.00	**11,652,690.69**	9,540,035.11	87,724,703.71	10,304,581.73	1,381,558.73	59,457.68	**109,010,336.97**
14	2033	0.00	11,989,620.70	0.00	**11,989,620.70**	10,017,036.87	95,597,118.63	10,819,810.81	1,381,558.73	59,695.51	**117,875,220.55**
15	2034	0.00	12,343,397.21	0.00	**12,343,397.21**	10,517,888.71	104,176,004.05	11,360,801.36	1,381,558.73	59,934.30	**127,496,187.15**
16	2035	0.00	12,714,862.55	0.00	**12,714,862.55**	11,595,972.31	113,524,758.65	12,525,283.49	1,381,558.73	60,174.03	**139,087,747.22**
17	2036	0.00	13,104,901.15	0.00	**13,104,901.15**	12,175,770.92	123,712,470.50	13,151,547.67	1,381,558.73	60,414.73	**150,481,762.55**
18	2037	0.00	13,514,441.68	0.00	**13,514,441.68**	12,784,559.47	134,814,427.60	13,809,125.05	1,381,558.73	60,656.39	**162,850,327.24**
19	2038	0.00	13,944,459.24	0.00	**13,944,459.24**	13,423,787.44	146,912,674.33	14,499,581.31	1,381,558.73	60,899.01	**176,278,500.82**
20	2039	0.00	14,395,977.68	0.00	**14,395,977.68**	14,094,976.81	160,096,617.72	15,224,560.37	1,381,558.73	61,142.61	**190,858,856.25**
21	2040	0.00	14,870,072.04	271,460,792.91	**286,330,864.95**	15,539,711.94	174,463,688.20	16,785,077.81	1,381,558.73	61,387.18	**208,231,423.86**
22	2041	0.00	15,367,871.12	0.00	**15,367,871.12**	16,316,697.53	190,120,059.58	17,624,331.70	1,381,558.73	61,632.73	**225,504,280.27**
23	2042	0.00	15,890,560.15	0.00	**15,890,560.15**	17,132,532.41	207,181,433.73	18,505,548.28	1,381,558.73	61,879.26	**244,262,952.41**
24	2043	0.00	16,439,383.64	0.00	**16,439,383.64**	17,989,159.03	225,773,895.59	19,430,825.70	1,381,558.73	62,126.78	**264,637,565.82**
25	2044	0.00	17,015,648.29	0.00	**17,015,648.29**	18,888,616.98	246,034,844.98	20,402,366.98	1,381,558.73	62,375.28	**286,769,762.96**
26	2045	0.00	17,620,726.18	0.00	**17,620,726.18**	20,824,700.22	268,114,011.97	22,493,609.60	1,381,558.73	62,624.78	**312,876,505.30**
27	2046	0.00	18,256,057.97	0.00	**18,256,057.97**	21,865,935.24	292,174,563.40	23,618,290.08	1,381,558.73	62,875.28	**339,103,222.73**
28	2047	0.00	18,923,156.34	0.00	**18,923,156.34**	22,959,232.00	318,394,308.72	24,799,204.58	1,381,558.73	63,126.78	**367,597,430.81**
29	2048	0.00	19,623,609.64	0.00	**19,623,609.64**	24,107,193.60	346,967,013.98	26,039,164.81	1,381,558.73	63,379.29	**398,558,310.42**
30	2049	0.00	20,359,085.59	0.00	**20,359,085.59**	25,312,553.72	378,103,833.82	27,341,123.05	1,381,558.73	63,632.81	**432,202,702.13**

(Source: Calculated by the Author)

Therefore, from the above table it is possible to see the operation and maintenance cost increases starting from 2020 and there is a replacement cost of buses on 2040. The total costs and benefits of the project every year are also estimated. So, the next step is to calculate the present value (2019) of annual benefits and costs both for the total km and for unit km. The unit km costs and benefits are used to compare this alternative with the other two. In addition, NPV and BCR per km are also calculated using the same procedure as for the above alternatives.

Table 23: PV of Annual Costs and Benefits with net present flow for AA BRT of Trolley Buses

No	Year	Present Value (DR @10.23%)				Net Present Flow
		Life Cycle Costs (LCC)	LCC/KM	Life Cycle Benefits (LCB)	LCB/KM	
0	2019	350,266,920.67	19,789,091.56	-	-	-350,266,920.67
1	2020	7,862,102.17	444,186.56	38,773,208.50	2,190,576.75	30,911,106.33
2	2021	7,286,859.84	411,687.00	37,897,567.89	2,141,105.53	30,610,708.06
3	2022	6,757,677.35	381,789.68	37,057,284.20	2,093,631.88	30,299,606.84
4	2023	6,270,627.69	354,272.75	36,250,305.97	2,048,039.89	29,979,678.27
5	2024	5,822,131.78	328,934.00	35,474,724.52	2,004,221.72	29,652,592.75
6	2025	5,408,926.98	305,589.09	35,085,304.45	1,982,220.59	29,676,377.47
7	2026	5,028,038.50	284,069.97	34,350,390.53	1,940,700.03	29,322,352.03
8	2027	4,676,753.38	264,223.35	33,642,700.20	1,900,717.53	28,965,946.82
9	2028	4,352,596.83	245,909.43	32,960,755.63	1,862,189.58	28,608,158.80
10	2029	4,053,310.83	229,000.61	32,303,176.60	1,825,038.23	28,249,865.76
11	2030	3,776,834.59	213,380.49	31,962,266.95	1,805,777.79	28,185,432.36
12	2031	3,521,286.83	198,942.76	31,335,702.70	1,770,378.68	27,814,415.87
13	2032	3,284,949.69	185,590.38	30,730,539.57	1,736,188.68	27,445,589.89
14	2033	3,066,254.09	173,234.69	30,145,689.01	1,703,146.27	27,079,434.92
15	2034	2,863,766.43	161,794.71	29,580,130.52	1,671,193.81	26,716,364.09
16	2035	2,676,176.49	151,196.41	29,274,666.37	1,653,935.95	26,598,489.88
17	2036	2,502,286.45	141,372.12	28,733,408.24	1,623,356.40	26,231,121.80
18	2037	2,341,000.87	132,259.94	28,209,286.53	1,593,745.00	25,868,285.66
19	2038	2,191,317.65	123,803.26	27,701,482.22	1,565,055.49	25,510,164.58
20	2039	2,052,319.71	115,950.27	27,209,224.79	1,537,244.34	25,156,905.08
21	2040	37,031,577.21	2,092,179.50	26,930,865.63	1,521,517.83	-10,100,711.58
22	2041	1,803,092.25	101,869.62	26,458,122.72	1,494,809.19	24,655,030.47
23	2042	1,691,389.52	95,558.73	25,999,322.53	1,468,888.28	24,307,933.01
24	2043	1,587,413.80	89,684.40	25,553,836.71	1,443,719.59	23,966,422.90
25	2044	1,490,573.22	84,213.18	25,121,072.22	1,419,269.62	23,630,498.99
26	2045	1,400,324.90	79,114.40	24,864,398.60	1,404,768.28	23,464,073.71
27	2046	1,316,170.66	74,359.92	24,447,649.86	1,381,223.16	23,131,479.20
28	2047	1,237,653.20	69,923.91	24,042,402.29	1,358,327.81	22,804,749.09
29	2048	1,164,352.50	65,782.63	23,648,165.39	1,336,054.54	22,483,812.89
30	2049	1,095,882.64	61,914.27	23,264,474.94	1,314,377.12	22,168,592.31
Total		**485,880,568.73**	**27,450,879.59**	**899,008,126.31**	**50,791,419.57**	**23,340,539.98**

(Source: Calculated by the Author)

Using the above table, the following results can be generated for AA BRT with trolley buses.

- Present Value of Life Cycle Cost/km of AA BRT = **27,450,879.59 USD (2019 price)**
- Present Value of Life Cycle Benefit/km of AA BRT = **50,791,419.57 USD (2019 price)**

Thus, the Net Present Value of the project is calculated by adding all the present flow values of 30 years.

➢ Net Present Value (NPV @ 10.23%) = Summation of annual present value of flow
= PV of Life Cycle per km Benefit – PV of Life Cycle Cost per km
=**50,791,419.57 USD - 27,450,879.59 USD**
= **23,340,539.98 USD (2019 price)**

As the result shows NPV of AA BRT project with trolley buses is greater than zero, so the project is acceptable or efficient.

Benefit to Cost Ration (BCR) of AA BRT project is also estimated in order to compare the project`s life cycle benefit and cost. I.e.

- If BCR > 1, Accept the project since the benefit is higher than the cost.
- If BCR < 1, Reject the project since the benefit is less than the cost.

In our scenario, BCR is calculated as the following.

- BCR = $\frac{\text{Present value of life cycle benefit per km}}{\text{Present value of life cycle cost per km}} = \frac{\textbf{50,791,419.57 USD}}{\textbf{27,450,879.59}\text{USD}}$ **= 1.9 or 2**

So, the project is acceptable since BCR is 2 which greater than 1 and the present value of total benefit is greater than that of total cost. Using NPV and BCR criteria, it is now possible to conclude the AA BRT project with trolley is cost effective and acceptable.

4.4.3. Comparison of AA LRT and AA BRT projects using Multifaceted LCCA

Both projects are viable according to the above estimation done on this study. But to indicate which one is more beneficial than the other, comparison is executed using life cycle costs, life cycle benefits, NPV and BCR.

The present value of LCC per km of AA LRT is 52,704,336.21 USD which includes capital, operating and maintenance costs. While the present value of LCC per km of AA BRT is 15,483,143.56USD which is much less that of AA LRT, even if it includes replacement costs during the analysis period. This result absolutely agrees with the conclusion of related researches done on the life cycle cost comparison of LRTs and BRTs. On the other hand the LCC per km of AA BRT with trolley bus is 27,450,879.59 USD which is less that of AA LRT but greater than that of AA BRT. So, both the options of AA BRT are less costly than AA LRT.

The other parameter which is suitable to compare the two projects is life cycle benefit per km. PV of LCB per km of AA LRT is 65,456,883.98USD which is greater than that of AA BRT which is 23,020,809.92USD. The LCB of AA BRT with trolley buses is 50,791,419.57USD which is greater than BRT with diesel and less than LRT. The benefit components included under LCB estimation for both projects are passenger revenue saving for the agency, travel time saving for users, fuel savings, savings from traffic crash reduction, and savings from air pollution reduction. The most significant benefit components that raised the total benefit of AA LRT project are fuel savings and savings air pollution reduction. This is because of that the LRT is operated electrically which leads to zero fuel usage for operation and no emission at all. On the other hand, the BRT which uses diesel for operation creates a situation of more fuel cost and more emission. So, its contribution for air pollution reduction and less fuel usage is less than that of AA LRT. On the contrary, the BRT with trolley buses has a benefit value which is very close to that of AA LRT due to its increasing savings from air pollution reduction and less fuel usage. It has both the benefits of BRT with diesel and LRT. The only thing that decreases the LCB of BRT with trolley buses is the collected revenue from passenger fare. The saving from passenger revenue is 421,440.64USD/km for AA LRT while it is 272,224.07USD/km for AA BRT with trolley. This is due to that the average tariff for AA LRT is 0.2USD (4.4ETB) which is greater than 0.1USD (2.8ETB) for AA BRT.

NPV of the two projects is calculated by deducting net LCC (Costs) from net LCB (Benefits). The result shows the NPV of AA LRT and AA BRT is 12,752,547.77USD and 7,537,666.36USD respectively. In this case, the LRT is better for choice. This is due to the higher present value of benefits by AA LRT as discussed on the previous paragraph. But the NPV of AA BRT with trolley buses is 23,340,539.98 USD which is greater than both of the above. BCR of the two projects under three alternatives has another way of comparing the two projects. The BCR of AA LRT is 1.24 while that of AA BRT is 1.5 which indicates the AA BRT project is more cost effective. But the AA BRT with trolley buses has the highest BCR value which is 2.0. This does also indicate if BRT is chosen to be used in the future and supported with electricity and its benefit will be doubled thereby making it more efficient and viable.

As a summary the following table comprises the comparison among the two projects with three alternatives using NPV and BCR results from the above.

Table 24: Summary of the Comparison between AA BRT and AA LRT

Economic Indicators	**AA BRT**		**AA LRT**
	BRT with Diesel buses	**BRT with Trolley buses**	**LRT**
NPV (2019 USD)	7,537,666.4	23,340,540.0	12,752,547.8
BCR	1.5	2	1.24

(Source: Calculated by the Author)

4.5. Sensitivity Analysis

Sensitivity analysis is executed during life cycle cost analysis since it helps to assess the effect on the NPV and BCR value by changing the input values of cost and benefit components. There is an assumption that the following four inputs are more sensible than the others to affect the final result of the analysis due to different uncertainties during data collection. Uncertainties on variables like traffic forecasts, cost changes, price changes, and so on may affect the input values and indirectly the outputs. The chosen inputs are

- Operating and Maintenance Cost
- Revenue saving from Passenger Tariff
- Time Saving
- Total Benefit and Cost

4.5.1. Sensitivity Analysis for AA LRT Project

The final output of the life cycle cost benefit analysis from above dictates that the project is feasible and viable according to NPV and BCR values. But the change in the value of inputs may affect the results. Therefore, in this section, the project is evaluated against sensitive input values.

I. Change in Operating and Maintenance Costs, Revenue from Tariff and Benefit from time saving by 5%

The scenario to be tested is the change in O and M cost revenue from tariff and benefit from time saving by 5% from the original value. So, the table below shows the result of altering these costs on NPV and BCR.

Table 25: Sensitivity analysis result for AA LRT project

Year	Present Value of Cash Flow per Km			
	O & M Cost increase by 5%	Revenue from Tariff decrease by 5%	Benefit from Time Saving decreased by 5%	Combination
2019	-42,877,085.31	-42,877,085.31	-42,877,085.31	-42,877,085.31
2020	2,322,083.50	2,376,336.41	2,389,764.03	2,297,278.28
2021	2,243,039.77	2,292,478.91	2,304,131.39	2,220,007.64
2022	2,164,646.17	2,209,707.80	2,220,020.77	2,143,493.47
2023	2,092,021.98	2,133,102.36	2,142,212.38	2,072,586.53
2024	2,629,753.44	2,638,398.09	2,646,428.46	2,611,887.54
2025	2,535,088.02	2,541,908.51	2,550,174.57	2,517,453.10
2026	2,428,138.66	2,434,499.67	2,441,562.99	2,411,704.77
2027	2,325,421.39	2,331,357.33	2,337,552.61	2,310,300.14
2028	2,230,811.04	2,236,353.51	2,241,771.39	2,216,890.69
2029	2,143,572.86	2,148,750.91	2,153,473.14	2,130,751.57
2030	2,079,353.29	2,083,377.96	2,088,293.92	2,066,722.54
2031	2,007,080.99	2,010,868.21	2,014,969.25	1,995,263.76
2032	1,936,651.34	1,940,216.69	1,943,762.13	1,925,755.82
2033	1,871,409.71	1,874,767.63	1,877,817.34	1,861,358.66
2034	1,810,891.35	1,814,055.23	1,816,663.12	1,801,614.31
2035	1,765,725.85	1,768,155.55	1,770,922.73	1,756,605.94
2036	1,715,427.28	1,717,738.20	1,719,953.20	1,706,858.39
2037	1,665,625.40	1,667,823.50	1,669,688.83	1,657,707.65
2038	1,619,171.76	1,621,262.67	1,622,817.62	1,611,851.55
2039	1,575,771.41	1,577,760.51	1,579,040.39	1,568,999.81
2040	1,542,643.44	1,544,161.44	1,545,572.34	1,536,001.39
2041	1,506,367.58	1,507,828.38	1,508,865.12	1,500,098.74
2042	1,469,867.99	1,471,272.93	1,472,094.79	1,464,062.27
2043	1,435,553.41	1,436,903.89	1,437,536.45	1,430,173.46
2044	1,403,235.97	1,404,533.45	1,404,999.63	1,398,247.64
2045	1,377,817.00	1,378,809.36	1,379,383.31	1,372,935.45
2046	1,350,578.34	1,351,544.23	1,351,864.64	1,345,949.55
2047	1,322,764.95	1,323,703.72	1,323,896.68	1,318,468.04
2048	1,296,398.35	1,297,309.54	1,297,391.51	1,292,407.13
2049	1,271,358.28	1,272,241.62	1,272,227.33	1,267,648.81
NPV	**12,261,185.22**	**12,530,142.89**	**12,647,766.76**	**11,933,999.34**
BCR	**1.23**	**1.24**	**1.24**	**1.22**

(Source: Calculated by the Author)

The result shows that NPV is greater than zero and BCR is greater than one which means the project is still viable under the above each individual three scenarios and their combination. There will be a decrease in BCR and NPV if the operation and maintenance cost of the LRT is raised by 5%. This indicates that compensation by increasing its benefits should be done to confirm its viability. So further expansion of the project should include a way of increasing travel time saving, saving from passenger revenue through lower headway, higher frequency, more flexibility, and more passenger number.

II. Change in Total Cost and Benefit value by 10%

The following table shows the change on NPV and BCR due to cost decrease by 10%, benefit increase by 10% and the combined effect of the two.

Table 26: Sensitivity analysis of AA LRT project for annual cost and benefit variation with 10% from the original value

Year	Present Value of Cash Flow		
	Total Cost Increase by 10%	Total Benefit Increase by 10%	Combined Effect
2019	-47,164,793.84	-42,877,085.31	-47,164,793.84
2020	2,248,714.18	2,009,168.89	1,862,430.24
2021	2,176,258.33	1,945,276.20	1,811,713.31
2022	2,103,851.71	1,881,307.65	1,759,718.72
2023	2,036,668.87	1,821,931.37	1,711,225.15
2024	2,608,160.66	2,343,026.04	2,299,840.47
2025	2,515,317.04	2,259,831.14	2,220,289.17
2026	2,410,029.05	2,165,404.22	2,129,184.99
2027	2,308,827.19	2,074,625.63	2,041,437.24
2028	2,215,599.46	1,990,997.20	1,960,574.03
2029	2,129,623.05	1,913,870.78	1,885,971.16
2030	2,066,555.26	1,857,340.13	1,831,744.08
2031	1,995,334.64	1,793,451.90	1,769,959.19
2032	1,925,865.51	1,731,121.80	1,709,550.14
2033	1,861,501.42	1,673,369.62	1,653,553.02
2034	1,801,785.00	1,619,785.23	1,601,572.53
2035	1,757,352.60	1,579,942.69	1,563,196.20
2036	1,707,724.42	1,535,411.40	1,520,005.68
2037	1,658,535.77	1,491,264.27	1,477,085.00
2038	1,612,643.26	1,450,073.24	1,437,016.25
2039	1,569,756.58	1,411,577.95	1,399,548.28
2040	1,537,098.97	1,382,280.18	1,371,191.23
2041	1,501,253.98	1,350,105.87	1,339,878.67
2042	1,465,149.25	1,317,690.58	1,308,253.11
2043	1,431,196.67	1,287,205.66	1,278,492.18
2044	1,399,211.23	1,258,485.16	1,250,435.69
2045	1,374,096.89	1,235,943.18	1,228,502.95
2046	1,347,137.85	1,211,735.96	1,204,854.99
2047	1,319,581.25	1,186,986.38	1,180,618.98
2048	1,293,450.56	1,163,515.95	1,157,620.38
2049	1,268,627.35	1,141,218.42	1,135,756.56
NPV	**7,482,114.15**	**6,206,859.37**	**936,425.75**
BCR	**1.13**	**1.12**	**1.02**

(Source: Calculated by the Author)

The table summarizes the effect of increasing cost and decreasing benefit by 10% on NPV and BCR. So, both results imply the project is viable even if combined effect is added on the input values. But it has been noticed that there is a significant change in NPV and BCR exists especially if the percentage is increased more than 10%.

4.5.2. Sensitivity Analysis for AA BRT

The same procedure is used as above to evaluate the effect of input values on the final output of the analysis for AA BRT.

I. Change in Operating and Maintenance Costs, Revenue from Tariff and Benefit from time saving by 5%

Here, O and M cost are increased revenue from tariff is decreased and benefit from time saving is decreased by a common percentage of 5% from their respective original value. Accordingly, the table below shows the result of altering these costs on NPV and BCR.

Table 27: Sensitivity analysis result for AA BRT project with diesel buses

Year	Present Value of Cash Flow			
	O & M Cost increase by 5%	Revenue from Tariff decrease by 5%	Benefit from Time Saving decreased by 5%	Combined Effect
2019	-9,004,426.78	-9,004,426.78	-9,004,426.78	-9,004,426.78
2020	743,668.53	748,404.62	747,415.04	717,982.94
2021	732,908.83	736,980.80	736,038.18	708,441.93
2022	721,897.24	725,377.39	724,479.49	698,591.20
2023	710,699.26	713,652.66	712,797.36	688,499.01
2024	699,372.48	701,857.68	701,042.96	678,225.54
2025	708,111.03	709,696.50	708,881.63	686,960.26
2026	695,716.19	696,956.44	696,180.23	675,568.94
2027	683,371.18	684,307.64	683,568.26	664,179.84
2028	671,107.32	671,777.13	671,072.83	652,826.54
2029	658,951.49	659,387.93	658,717.05	641,538.06
2030	-391,897.59	-392,063.44	-392,734.44	-409,314.18
2031	650,852.41	650,528.52	649,889.36	634,262.18
2032	638,395.02	637,935.99	637,327.15	622,591.93
2033	626,153.45	625,579.65	624,999.70	611,100.16
2034	614,137.08	613,466.63	612,914.20	599,798.01
2035	616,011.93	614,932.61	614,380.08	601,670.26
2036	603,817.95	602,687.89	602,161.57	590,156.74
2037	591,896.49	590,727.56	590,226.21	578,883.45
2038	580,248.50	579,051.13	578,573.57	567,852.88
2039	568,873.77	567,657.10	567,202.20	557,066.28
2040	-486,393.10	-487,891.45	-488,346.43	-498,202.74
2041	557,651.95	556,162.05	555,728.65	546,402.63
2042	546,577.96	545,101.92	544,689.09	535,862.38
2043	535,791.71	534,334.15	533,940.91	525,584.55
2044	525,288.05	523,852.88	523,478.29	515,565.18
2045	524,322.99	522,690.87	522,316.21	514,598.36
2046	513,928.15	512,334.97	511,978.08	504,664.91
2047	503,819.23	502,266.72	501,926.77	494,995.50
2048	493,988.97	492,478.45	492,154.63	485,583.90
2049	484,430.00	482,962.40	482,653.95	476,423.71
NPV	**7,319,271.66**	**7,318,768.64**	**7,301,225.99**	**6,863,933.58**
BCR	**1.47**	**1.47**	**1.47**	**1.44**

(Source: Calculated by the Author)

The result shows that NPV is greater than zero and BCR is greater than one which means the AA BRT project is still viable under the above three scenarios and their combination. But the decrease in these two values should be given consideration by generating more benefits to the environment and to the users. This can be done by introducing electrical buses, attracting more passengers, increasing flexibility and so on.

II. Change in Total Cost and Benefit value by 10%

Here, the purpose is to check whether alteration of annual cost and benefit value shows a significant change in NPV and BCR of the project. So, the following table shows the change on NPV and BCR due to cost decrease by 10%, benefit increase by 10% and the combined effect of the two.

Table 28: Sensitivity analysis of AA BRT project for annual cost and benefit variation with 10% from the original value

Year	Present Value of Cash Flow		
	Total Cost Increase by 10%	Total Benefit Increase by 10%	Combined Effect
2019	-9,904,869.45	-9,004,426.78	-9,904,869.45
2020	726,584.43	650,509.17	616,340.97
2021	717,074.71	642,200.42	610,532.19
2022	707,213.02	633,554.88	604,186.44
2023	697,073.38	624,640.87	597,389.12
2024	686,721.17	615,518.79	590,216.18
2025	696,357.60	624,371.16	600,864.30
2026	684,790.42	614,126.23	592,274.69
2027	673,208.74	603,855.38	583,530.51
2028	661,649.26	593,592.72	574,676.61
2029	650,143.77	583,367.85	565,752.42
2030	-505,645.68	-467,276.61	-589,231.64
2031	643,200.77	577,350.36	562,047.07
2032	631,256.93	566,703.62	552,427.44
2033	619,490.57	556,208.94	542,883.20
2034	607,914.20	545,878.21	533,432.46
2035	610,196.69	548,013.97	536,383.48
2036	598,380.56	537,455.03	526,580.25
2037	586,809.56	527,111.22	516,937.38
2038	575,486.83	516,985.82	507,462.49
2039	564,414.14	507,080.80	498,161.55
2040	-596,113.23	-547,891.82	-661,790.93
2041	553,733.88	497,576.88	489,740.76
2042	542,902.62	487,877.29	480,526.62
2043	532,342.31	478,418.20	471,519.40
2044	522,049.08	469,196.38	462,718.44
2045	521,280.13	468,543.55	462,457.82
2046	511,068.15	459,389.33	453,669.34
2047	501,129.85	450,478.99	445,100.23
2048	491,458.87	441,806.97	436,746.76
2049	482,048.68	433,367.55	428,604.91
NPV	**5,989,352.00**	**5,235,585.36**	**3,687,271.01**
BCR	**1.35**	**1.34**	**1.22**

(Source: Calculated by the Author)

The table above summarizes the effect of increasing cost and/or decreasing benefit by 10% on NPV and BCR. The finding implies that the project is viable even if combined effect is added on the input values. But the combined effect of reduced benefits and increased costs with 10% or above may decrease the NPV and BCR of the project.

4.6. Findings on the Impact of the AA LRT Infrastructure on the Surrounding Built-up Activities

This section discusses on the major findings from distributed questionnaire for respondents who live around the LRT corridor located around Megenagna to Sealite-Mihiret. Analysis and discussion has been held under this section on the socio-economic status of the respondents, the activity of the respondents and their perspective about the LRT infrastructure's impact.

4.6.1. Socio-Economic Status of the Respondents

The questionnaire was distributed among residents who live up to 500m distance from the LRT`s corridor in both direction. These residents should those who cross the LRT line by walking in order to reach to their destination or to use another public transportation mode than the LRT. Their origin is home but their destination is categorized among work, school and other. So, respondents may either use walking only or walking plus any public transportation mode to reach to the three destinations mentioned.

So, among the 384 respondents there were 202 female residents by covering 52.6% and male residents were 182 male residents taking 47.4%. Most of the female and male respondents are from 19-30 years of old with 99(49.01%) and 83(45.57%) coverage respectively.

Table 29: Gender and Age Interval of Respondents

Age	Female		Male		Total	Percent (%)
	Frequency	Percent (%)	Frequency	Percent (%)		
Below 18	40	19.80	45.00	24.73	85.00	22.14
19-30	99	49.01	76.00	41.76	175.00	45.57
31-50	40	19.80	43.00	23.63	83.00	21.61
Above 50	23	11.39	18.00	9.89	41.00	10.68
Total	**202**	**100.00**	**182**	**100**	**384**	**100.00**
Percent	**52.6**		**47.40**		**100.00**	

(Source: Own survey on 2020)

According to the above table, most respondents are females and between the age of 19 and 30. Female respondents with below 18 of ages were 40(19.8%), between 31 and 50 were 40(19.8%) and above 50 were 23(11.39%). The male respondents` age below 18 were 45(24.73%), between 31 and 50 were 43(23.63%) and below 50 were 18(9.89%). Moreover the age interval that lies below 18 has included most students whose trip destination is school.

The other indicators of socio-economic character of the respondents are their education level, employment status and monthly income status. The following table summarizes these three elements.

Table 30: Educational Level, Employment Status and Monthly Income of the Respondents

Educational Background	Frequency	Percent (%)	Employment Status	Frequency	Percent (%)	Monthly Income	Frequency	Percent (%)
Illiterate	34	8.85	Government	70	18.23	None	119	30.99
Primary School	91	23.70	Private Company	178	46.35	1000-2000	80	20.83
Secondary School	172	44.79	Self Employed	17	4.43	2001-3000	72	18.75
Above Secondary	87	22.66	Student	92	23.96	3001-4000	30	7.81
Total	384	100.00	Unemployed	27	7.03	4001-5000	27	7.03
			Total	384	100.00	Above 5000	56	14.58
						Total	384	100.00

(Source: Own survey on 2020)

Most respondents who cross the LRT infrastructure by walking have an educational background of secondary school. There are 172 respondents covering about 44.79% of the total. Respondents who attend only primary schools are 97(23.7%), only above secondary schools are 87(22.66%) and who do not attend ordinary school are 34(8.5%) with decreasing order.

On the other hand, the employment status of the respondents shows that those who work are private companies are highest in number than the others with 178(46.35%) composition. Respondents who are employed at government companies are 70(18.23%) and self-employed are 17(4.4.3%). Those that are unemployed comprise about 7.03% (27) of the total respondents. The left respondents are students who cross the LT infrastructure for school purpose with 23.96% (92) composition. So, the study has conducted survey on 265 numbers of employed respondents to inspect their home to work trip, on 92 students to inspect their home to school trip and 27 unemployed respondents to grasp their perspective on other trips originated from home. The respondents on home to work trip takes the highest number in this case.

Monthly income for students and unemployed respondents is zero as collected from the questionnaire and they are accounted for 30.99% of the total respondents. So, the interval of monthly income for private, government and self-employed respondents is summarized. Among the total respondents, 20.8% (80) have an income that lies between 1000 and 2000ETB. There are 72(18.75%), 56(14.58%), 30(7.81%) and 27(7.03%) respondents with a monthly income of 2001-3000ETB, above 5000ETB, 3001-4000ETB and 4001-5000ETB respectively. Therefore most respondents on home to work trip have a monthly income with in the interval of 1000-2000birr and 2001-3000birr followed by above 5000birr. Employees with an income per month of between 3001-4000birr and 4001-5000 have less response frequency.

4.6.2. Journey Destination and Transportation Mode of the Respondents Crossing the LRT Infrastructure

The trip origin of the respondents is home. So their destination is classified as work, school and other under this study. On the other hand, their trip to the three destination may include only walking or public transportation after walking by crossing the LRT infrastructure. So, the following table shows the combined results from destination and used transportation modes.

Table 31: Journey Destination and Transportation Mode of the Respondents Crossing the LRT Infrastructure

Mode choice	Respondents` Destination of Home originated Trips						Total	Percent (%)
	Work		School		Other Places			
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)		
Walking	59	22.52	18	19.57	20	66.67	97	25.26
Walking + PT	203	77.48	74	80.43	10	33.33	287	74.74
Total	262	100	92	100	30	100	384	100.00
Percent	68.23		23.96		7.81		100	

(Source: Own survey on 2020)

From the above table, it is possible to grasp that most respondents use other public transportation modes after crossing the LRT corridor by walking to reach to their work place, school or other places. Others whose destination is close to their home and who uses walking have less frequency. From out of 384 respondents 287(74.74%) are other public transportation users and 97(25.26%) are pedestrians who use only walking to reach to their destination. Moreover, respondents who travel from home to work are 262(68.23%), from home to school are 92(23.96%) and from home to other places are 30(7.81%).

Among the respondents who are classified under home to work, about 203(77.48%) uses public transportation after crossing the LRT infrastructure by walking while those who only uses walking to reach to their work places by crossing are 59 respondents with 22.52% composition. So, most respondents use public transportation after crossing the line by walking. Similar generalization can be used for those respondents who cross the LRT infrastructure to reach to their school. 74 out of 92 students use walking plus public transportation comprising 80.43% while those who use walking only are 18 out of 92 students which means about 19.57%. The other respondents are who only travel to other places but not to work and school use walking only for their trip. Those who use walking comprises about 66.67% (20) and public transportation after walking comprises about 33.33% (10) of the total respondents under the category of other places.

4.6.3. Perception of Walking Distance and Time by Respondents

In this section, the distance and time to cross the LRT infrastructure by walking is estimated and is compared to the one before its construction. The first discussion is on the result of Home to

Work trips. Respondents whose destination is work and use walking only to reach to their work place are 59. Among those, 3.39% put their distance 1-100m, 1.69% under 100-200m, 22.03% under 200-200m and 72.88% walk above 300m. So, most respondents who use walking only travel more than 300m to reach to their work place. On the following, the above perception on walking distance travelled by respondents after LRT will be compare with the one before LRT.

Table 32: Walking Distance for Work after LRT`s Construction

Mode choice	Walking Distance for Work			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	76.27	6.78	16.95	**100**
Walking + PT	68.47	1.97	29.56	**100**
Total	**70.23**	**3.05**	**26.72**	**100**

(Source: Own survey on 2020)

Among the work related respondents who use walking only, 76.27% travels longer distance after LRT is constructed while 16.95% travels similar distance and 6.78% shorter distance. For those who also use public transportation modes after walking, the above distance they mentioned is longer for about 68.47%, similar for about 29.56% and shorter for only 1.97%. In both cases, the distance they walk has increased after LRT is constructed. As an aggregate, 70.23% of respondents from this category walk longer distance, 26.72% walk similar distance and 3.05 walk shorter distances.

Among the 59 respondents who use walking only to reach to their work place, 62.71% consumes 15-30min to walk, 25.42% consumes 30-45min, 8.47% consumes 0-15min and 3.39% consumes more than 45 minutes. So, most of them walk for about 15 to 30 minutes to their work place by crossing the LRT infrastructure. This result in walking time by alone itself does not indicate the increase and decrease in walking time for the surrounding residents after AA LRT infrastructure is introduced. So, the following categorical result is generated based on the respondents` reaction.

Table 33: Walking Time for Work After LRT`s Construction

Mode choice	Walking Time for Work			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	76.27	1.69	22.03	**100**
Walking + PT	62.07	4.43	33.50	**100**
Total	**65.27**	**3.82**	**30.92**	**100**

(Source: Own survey on 2020)

The duration to walk from home to work is longer for 76.27%, similar for 30.92% and shorter for 3.82% of the respondents who travel for work. This shows that most of the above time interval mentioned by the respondents is longer after LRT is constructed. For most of them this duration is long and consumes their working time. On the other hand, for most residents who travel for work using walking and public transportation modes, the crossing the LRT corridor has increased their walking time. I.e. for 62.07% of them the time to walk is longer, for 33.5% similar and 4.43% shorter. Totally, 65.27% takes the walking time as longer, 30.92% as similar and 3.82% shorter which indicates the LRT infrastructure is creating delay for most residents who travel to work by crossing it using walking only and public transportation modes after walking.

The following result and discussion is on the walking distance and time of respondents who travel to work from their home. There were 92 respondents who travel to school crossing the selected line of LRT. Among them, 18 students use walking only to reach to their school. So, the distance they walk is greater than 300m for 55.56% of them, between 200 and 300m for 27.78% of them, between 100 and 200m for 11.11% of them and between 1 and 100m for 5.56% of them. Hence, most students walk more than 300m to go to school crossing the LRT line. Similar findings are written on the table for those who use public transportation modes after crossing the line by walking. I.e. 51.35% of 74 respondents walk more than 300m. This distance interval is the greatest value among the alternative distance intervals. So, most respondents whether students or workers are travelling the longest distance due to LRT infrastructure.

In order to take the above collected distance as longer or shorter or similar when compare to the one before the LRT has been constructed, the following table can be referred.

Table 34: Walking Distance to School after LRT`s Construction

Mode choice	Walking Distance to School			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	77.78	0.00	22.22	**100**
Walking + PT	70.27	1.35	28.38	**100**
Total	**71.74**	**1.09**	**27.17**	**100**

(Source: Own survey on 2020)

As it can be seen from the above table, again most of the students take the distance they walk as a longer distance as compared to the one before the construction of the LRT corridor. Among those who walk only, the distance is longer for 77.78% and similar for 22.22% of them. But no students take their walking distance as a shorter distance. Those who use walking and public transportation who walk longer distance are 70.27%, similar distances are 28.38% and shorter distances are 1.35%. As the aggregate result shows, Out of the total student respondents, 71.74% travel longer, 27.17% similar and 1.09% shorter distance than the one before the LRT is constructed.

The result from walking time reaction shows that among the 18 students who use walking only, about 66.67% walk for 15-30min, 22.22% for 30-45min and 11.11% for 0-15 minutes while no student spends more than 45 minute to walk to school. Among the 74 students who use public transportation mode to get to school, 71.62% travels for 15-30min. Both results show, most students walk for about 15-30 minutes. The total result for the students' trip to school indicates, 70.65% of them spend between 15 and 30 minutes of walking and no students walks for more than 45 minutes at all.

The above time interval values travelled by most students can be longer, similar or even shorter when they are compared to the one before LRT`s construction. The following table is very helpful for this important decision.

Table 35: Walking Time to School After LRT`s Construction

Mode choice	Walking Time to School			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	83.33	0.00	16.67	**100**
Walking + PT	70.27	0.00	29.73	**100**
Total	**72.83**	**0.00**	**27.17**	**100**

(Source: Own survey on 2020)

After the LRT is constructed, 83.33% of the students use walking only to reach to school travel longer time while the other 16.67% walks with similar time interval. None of the students responded that it takes shorter time currently to get to their school. 70.27% of those who use walking and public transportation also responded there is a longer time spend to walk and 29.73% responded that they walk with similar duration as they used to walk before LRT was constructed. Totally, 72.83% of the students walk for longer time and 27.17% walks for similar duration. Therefore, most students` time get to school is affected by the LRT infrastructure.

Out of the total respondents, 30 of them were neither students nor employees. So, the study has included these respondents in order to get the general perspective on the effect of LRT on the trips made to shops, religious places, social service centers and recreation centers.

Table 36: Walking Distance to Other Places after LRT`s Construction

Mode choice	Walking Distance to Other Places			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	85.00	0.00	15.00	**100**
Walking + PT	80.00	0.00	20.00	**100**
Total	**83.33**	**0.00**	**16.67**	**100**

(Source: Own survey on 2020)

Table 37: Walking Time to Other Places After LRT`s Construction

Mode choice	Walking Time to Other Places			Total (%)
	Longer	Shorter	Similar	
	Percent (%)	Percent (%)	Percent (%)	
Walking	85.00	0.00	15.00	**100**
Walking + PT	80.00	0.00	20.00	**100**
Total	**83.33**	**0.00**	**16.67**	**100**

(Source: Own survey on 2020)

The above two tables comprise the result on walking distance and time respectively for residents who travel from home to other places than work and school. The walking distance and time for 83.33% of these respondents is longer while for 16.67% of them it is similar to the one before LRT is constructed. These results show both who use walk only and walking plus public transportation modes to reach to other places walk longer distance for longer time than they used to do before.

On the following table most frequently used walking distance interval (>300m) by respondents and its proportion among respondents is presented.

Table 38: Percentage of Respondents with a walking distance of more than 300m

Mode	Walking Distance (>300m)	
	Frequency	Percent (%)
Walking	**53**	**68.83**
Walking + PT	**148**	**53.43**
Total	**201**	**57**

(Source: Own survey on 2020)

About 201 (57%) respondents walk more than 300m. 68.83% of those who use walking only walks more 300m while 53.43% of those who take public transportation modes after walking travel more than 300m. The following table shows the percentage of respondents whose walking time lies between 15-30 minutes since this time interval has the highest frequency from the others.

Table 39: Percentage of Respondents with a walking time of 15-30 minutes

Mode	Walking Time (15-13 min)	
	Frequency	Percent (%)
Walking	**49**	**63.64**
Walking + PT	**163**	**58.84**
Total	**212**	**100**

(Source: Own survey on 2020)

There are 212(60%) respondents that spend this amount of time to walk across the LRT line. 63.64% of the total respondents that prefer walking only and 58.84% of the respondents that prefer to use public transportation modes after walking spend 15 up to 30 minutes to get to work, school and other places. As the above results show, longer walking distances and times are encountered by the respondents who cross the LRT infrastructure. The following table summarizes how the longer walking distance and time category is distribute among the respondents.

Table 40: Respondents with Longer Walking Distance and Time

Destination	Walking only (%)		Walking + Public Transportation Modes (%)	
	Longer Distance	Longer Time	Longer Distance	Longer Time
Work	**76.27**	**76.27**	**68.47**	**62.07**
School	**77.78**	**83.33**	**70.27**	**70.27**
Other	**85.00**	**85.00**	**80.00**	**80.00**

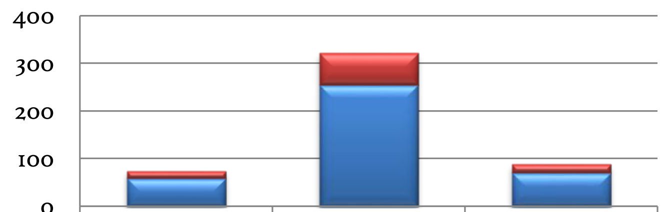
(Source: Own survey on 2020)

Out of the total respondents that use walking only to reach to work, school and other places, 76.27%, 77.78% and 85% walks longer distance respectively after LRT`s construction. On the other hand, 76.27%, 83.33% and 85% of them spends longer time while walking to work, school and other places. Among the respondents, those who use walking and public transportation modes together by crossing the LRT line are 287 in number. 68.47%, 70.27% and 80% of them walk longer distance to reach to work, school and other places because of the LRT. Their time expenditure on walking is also longer for 62.07% on work trip, 70.275 on school trip and 80% on other trips. So, longer walking time and distance is added to most surrounding residents who cross the LRT corridor.

4.6.4. The Effects of the LRT infrastructure on the Surrounding Built-up Activities

Different factors are provided by a variety of studies conducted on the barrier effect of LRT. This study has collected some factors from literature review that can cause longer walking times and distances on surrounding residents` activities. So, the selected factors are given responses from the selected residents who provided the above reactions.

The first factor that needed the response of the sample residents is checking how much the width of the roadway has increased after the LRT corridor has been constructed. If the responses show there is a high increase in the width of the roadway, their walking distance and time is indirectly affected by it.



	Very Wide	Wider	No Change
Percent (%)	15.36	66.41	18.23
Frequency	59	255	70

Chart 1: Change in width of Roadway after LRT`s construction

The above figure summarizing the respondent`s perspective on the width of the roadway indicates that the road is wider and this affects their activity to travel. 66.41% has responded it is wider, 18.23% noticed no change in width at all and 15.36% responded that its very wide when compared to the width of the roadway before LRT is constructed. The following picture can also show the existing condition of a roadway width which includes the LRT line around Megenagna roundabout.

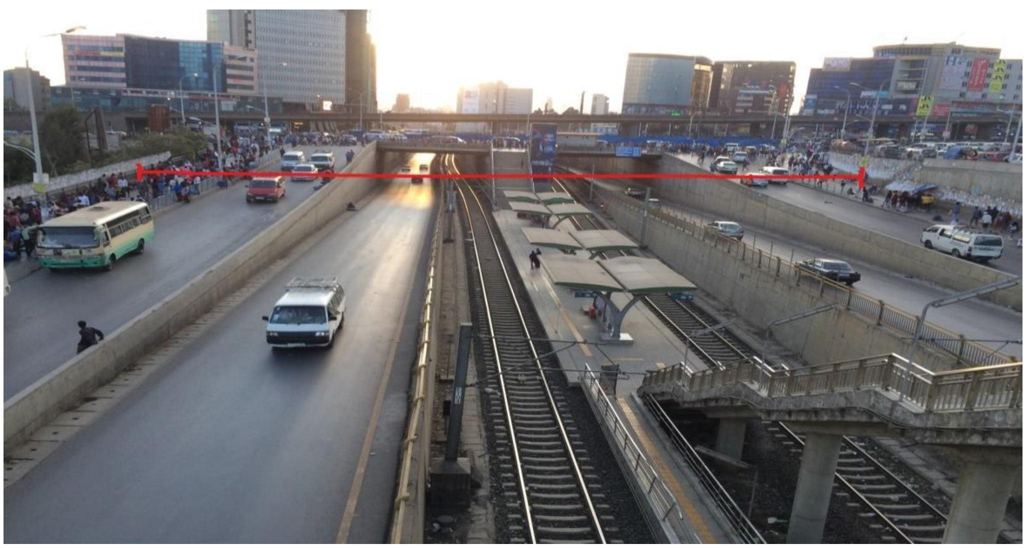
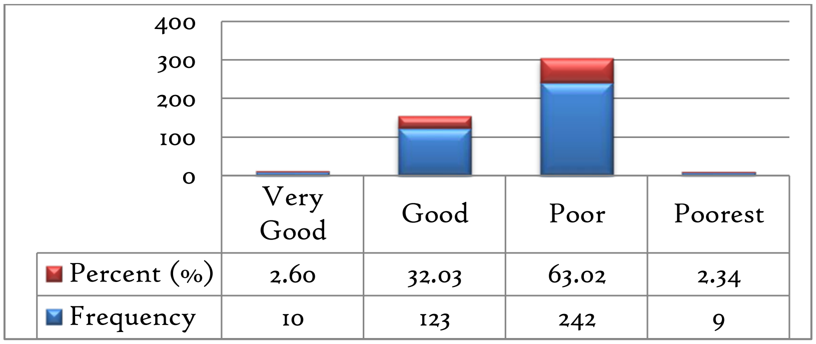


Figure 6: Sample Carriageway width with pedestrian crossing along the AA LRT corridor around Megenagna roundabout

(Source: Picture during survey)

Another important finding from the survey is about the feeling of respondents on the general condition of the LRT pedestrian crossing structures.



	Very Good	Good	Poor	Poorest
Percent (%)	2.60	32.03	63.02	2.34
Frequency	10	123	242	9

Chart 2: The Condition of Pedestrian Crossing along the LRT line

According to the survey results, 63% of the total respondents are feeling that the pedestrian crossing condition is poor while 32% take it as good. 2.6% and 2.3% responded that it is in a very good and poorest status. So, most respondents assume that it is in poor condition and their point of view may include reasons such as in-adequate space to walk and un-comfortability. Studies also support that there are a number of related to the condition of pedestrian crossings along the AA LRT (Imamoglu *et al.*, 2016; Nallet, 2018). Moreover the picture below taken at Gurd-Shola station by the author on 2020 can show the condition of at-grade pedestrian crossings.

Figure 7: The condition of at-grade pedestrian crossing along AA LRT line at Gurd-Shola station

(Source: Picture during Survey)

The distance between pedestrian crossings along the LRT line is assessed using the responses from the selected sample.

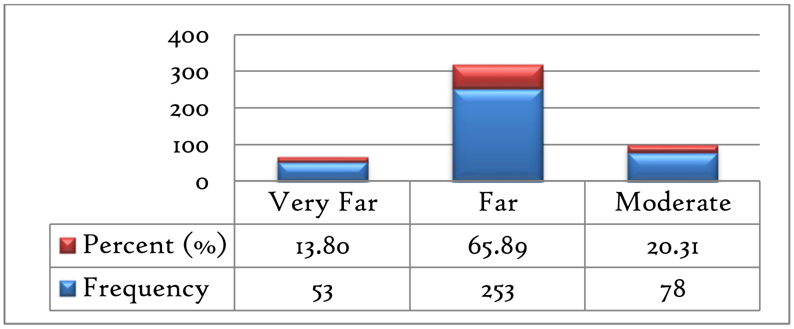


Chart 3: The Distance between Successive Pedestrian Crossing Structures along the LRT line

The figure clearly shows that about 65.89% of the respondents replied that the crossings distance is far while 13.8% replied very far to each other. The other 20.31% think that distance can be taken moderate. So, from this result, the interval between consecutive crossings is far which forces pedestrians to walk long distance for long time to cross.

The above three summaries collected from the respondents` perspective show that the higher width of the roadway, the poor condition of the existing crossings and the longer distance between pedestrian crossings along the LRT line has generated longer walking distance and time for the surrounding residents. Simultaneously, longer walking distance and time inhibited their day to day activities to work, school and other places. The final result from the survey is to inspect how the LRT line has affected the social interaction among neighbors living around the corridor.

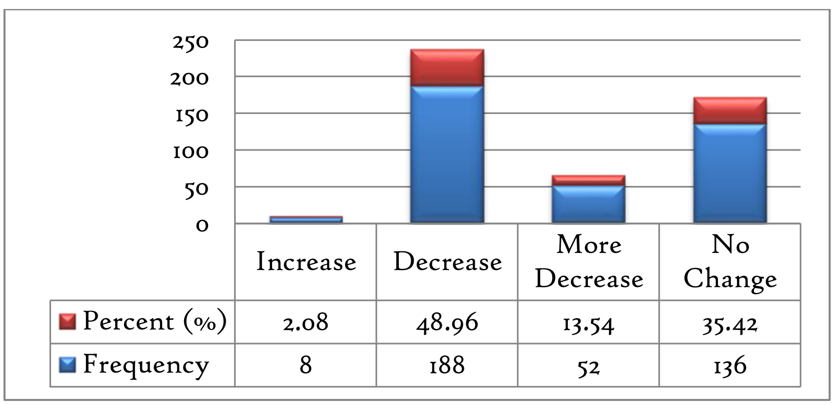


Chart 4: The Effect of AA LRT Infrastructure on Neighborhood Interaction

The neighborhood interaction among residents has decreased for most of the respondents as it can be seen in the above figure. 48.96% of them replied 'decrease' option, 35.42% replied 'no change', 13.54% replied 'more decrease', and 2.08% replied 'increase'. Totally, 62.23% of the respondents` neighborhood interaction is decreased after the AA LRT has been constructed.

Chapter Five
5. Conclusions and Recommendations

5.1. Conclusions

Based on the findings of the study, some major conclusions are drawn with regards to the examination of AA LRT and AA BRT projects. There were two ways of examining these recent mass rapid transit systems conducted under this study. The first was through comparison of the two modes using multifaceted life-cycle cost and benefit analysis while the second was through examining the effect of selected AA LRT corridor infrastructure on the movement of the surrounding

The conclusion taken from the estimation of NPV and BCR indicates that both projects are viable. But the comparison result shows that NPV of AA LRT is 12,752,547.77USD and that of AA BRT is 7,537,666.36USD. But the NPV of AA BRT with trolley has the highest NPV value which is 23,340,539.98USD/km. This shows that if AA BRT is operated with trolley buses, it will be more cost-effective. The BCR result also shows that AA BRT project is more cost effective than AA LRT whether it uses diesel or trolley buses. This is due to the higher value of BCR scored by AA BRT which is 2 and 1.5 for trolley and diesel buses respectively. This value for AA LRT is 1.24 which much less than that of both BRT options. Even if the life cycle benefit gained from the AA BRT is less than the LRT project, it can be incurred by increasing its flexibility, passenger number and environmental friendly aspect. So, according to this study and also based on other related studies, BRT is more preferable specifically with trolley buses for developing cities with an abundant percentage of low income society. The sensitivity analysis of AA LRT and AA BRT shows that both projects are efficient even if their sensitive cost and benefit inputs are altered by different percentage value. But there is a decrease in NPV and BCR value for both projects.

The analysis conducted to examine AA LRT`s effect on the movement of the surrounding built-up can be summarized as the following. The response from sample residents around the selected corridor indicates that the LRT infrastructure has increased their time and distance to cross the roadway. The waking distance and time for 57% and 60% of the respondents who use walking only and walking plus public transportation lie above 300m and between 15-30 minutes. Accordingly, among the respondents, more than 71% and 68% has taken that the corridor as a reason for longer walking distance and time respectively whether they use both walking only and/or other public transportation modes to reach to their destination from their home. About 82% and 80% of the respondents consider the excessive increase in roadway width and longer interval between pedestrian crossings are the causes for this situation respectively. The condition of the pedestrian crossing infrastructure has also been assessed using the view of the respondents. From the assessment, it has been concluded that the pedestrian crossing along the LRT infrastructure is poor. The interaction of neighborhood around the selected line for about

63% of the respondents has become decreased after LRT is introduced. It has also been concluded that the factors that inhibited the activities of residents across the line are the existence of limited numbers of pedestrian crossings along the line, excessively wide infrastructure to be crossed, high distance between consecutive pedestrian crossings along the line, low integration of LRT with the location of other facilities and service centers, and low consideration given to the access of other public transportation modes which are along the line of the LRT infrastructure.

5.2. Recommendations

Following the outcome of the analysis conducted under this study, the following recommendations for consideration in attempt to examine the different impacts of mass rapid transit systems in Addis Ababa especially BRT and LRT.

As, results from life cycle cost analysis dictates the introduction of BRT should be given priority since it needs less investment cost initially less operating and maintenance cost annually especially for developing cities with most of its population under low income status. It also provides more benefit by saving travel time for passengers through high frequency. The only drawback of the AA BRT operated with diesel is its less benefit by reducing fuel usage and reducing air pollution, since it is operated with diesel based buses. So, BRT vehicles operated with diesel should be removed after in the coming years, since it reduces the contribution of the project for the environment. Purchasing electrically operated vehicles may need more investment but will be compensated by its higher benefit as it can be seen from the experience of different cities` experience mainly Bogota. BRT operated with electricity can double up the benefit of the project through increasing its contribution air pollution reduction and fuel saving. The AA LRT on the other hand needs high investment cost initially and operating and maintenance cost annually. But to benefit from it in the long run, it is better to decrease the headway of the LRT in order to save passengers travel time, to increase its speed and efficiency along its line.

The savings from reduction of road traffic crashes can be increased by promoting both BRT and LRT, since they both decrease the occurrence of crashes. But consideration should also be given to reduce the severity of crashes occurred by LRT and BRT. Since both are categorized under heavy vehicles, their crash severity may increase if the appropriate precautions are not taken by their operating offices. On the hand, the increase in crash severity may add up more crash cost on the project which affects the life cycle cost of the project negatively.

Moreover, enhancing these mass rapid transit modes` flexibility will help to attract other public transportation mode users and even private vehicle users. This indirectly will help to increase its passenger number. Reducing the fare will also make it more affordable for low income passengers and will also attract other users. This indirectly helps to reduce the number of private vehicles and other public transportation vehicles. Therefore, the negative impact of transportation system in general on air pollution or the environment through increased fuel usage and emission will be reduced. Attracting more passengers will also consequently increase the benefit gained from passenger collected fare and reduce the number of private vehicle users which leads to solving the main challenges of urban transportation such as congestion. This can also be seen from the experience of other metro cities.

Allowing other ordinary Anbessa or Sheger buses to use the segregated lane after one year of the BRT`s operation may help to reduce the congestion of other ordinary roadways along the BRT routes. This also enhances the operation of the BRT project by benefiting the non-users (external) of the BRT bus. Providing parking area for other cars is also recommendable to increase the AA BRT revenue from parking fees. This way, it is possible to increase the source of revenue for the agency and increase its profitability.

The sensitivity analysis during this study indicates that more benefits should be provided by both projects otherwise they may not be viable if addition costs are incurred during their life time. This indirectly means saving more time for passengers, using more environmental friendly vehicles, reducing the fare, increasing flexibility, reducing crash and so on. So further expansion of the projects should include a way of increasing travel time saving, saving from passenger revenue through lower headway, higher frequency, more flexibility, and more passenger number.

The LRT infrastructure consumes more space than BRT which creates a negative impact on non-motorized travelers and others public transport users by increasing more crossing distance and time on the road. In order to solve the problem of long distance between consecutive pedestrian crossings, additional overpasses should be provided for pedestrians. This is recommendable than at grade crossings since those would affect the speed and headway of the LRT. The pedestrian crossings should be replaced or maintained in order to facilitate the movement of all kinds of pedestrians such as old users and physically disabled users. So, barrier effects of both projects should also be given priority and considered before implementation.

5.3. Recommendations for Further Research

A variety of recently published journals, articles, reports and books are used as references and inputs for the completion of this study. Most of these materials were from developed countries and few from developing countries. Especially in Ethiopia, the efforts accomplished are very less on this specific area of research. So, the following research areas should be noted as urgent issues to solve the current challenges of urban transportation.

There is no standardized tool to conduct the life cycle cost and benefit analysis of the existed and recent public transportation modes in Addis Ababa. The tool should comprise relevant platforms to insert local input values that are contextual economic, environmental, and social parameters. Institutions in developed and a few developing countries have their own tool for this purpose. But, these tools are not relevant to be applicable for the case of Addis Ababa since the context is very different. So, a research that comprises the development of a tool to analyze and compare life-cycle costs and benefits of public transportation modes in Addis Ababa should be done in the coming years.

An in depth study that can embrace more wide and comprehensive examination of mass rapid transit modes in Addis Ababa is also another recommendable area. Since mass rapid transportation is on the verge of its growth, this kind of researches can be used as an important input for urban transport policy makers

Another area that needs further investigation is analysis of non-monetary impacts of Addis Ababa`s public transportation modes in general. Some impacts to be assessed could be monetary or non-monetary. Among the transport cost and benefit components, most of them comprise elements that cannot be monetized but have a significant impact on external and internal users. So, it is better to research on which non-market impacts are weighty and what kind of method is appropriate to measure them.

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Appendices

Appendix 1: Capital, Operating and Maintenance Costs

A. Capital costs of AA BRT infrastructures in Million Birr (Oct 2010g.c./2003e.c.)

Components	Estimated cost in Million Birr (2010)
Preparatory works	9.50
Public utilities	86.50
BRT platform	216.10
Stations infrastructure platforms	7.50
Stations equipment	8.90
Sidewalks, car lanes, car parks, roundabouts	36.50
Barriers	24.20
Traffic lights	31.10
Road signs and markings	3.40
Bus interchange / Park and ride	24.90
Rolling stock	223.49
Depot/maintenance area	40.00
Risks and uncertainties	58.70
Total	**770.79**

Source: Feasibility study of AA BRT, 2010

B. AA BRT operational staff and their salary structure

Staff	Numbers	Average Salary / Person / Month (in Birr)
Depot Supervisor	1	5000
Drivers	70	3528
Conductors	65	1510
Maintenance Staff – Mechanics	20	2225
Operation Officers	10	2500
Administration staff	7	2500
Bus Cleaning Staff	15	1300
Station Cleaning staff	13	1300
Security manpower	52	2500
Other staff - ITS: CC & DC	18	2225
Total	**271**	

(Source: DIMTS Analysis, 2014)

C. Annual Operating and Maintenance cost of AA LRT for 30 years

Year	Operating and Maintenance Cost				
	Electricity	Staff	Contract Management Fee	Other Operating Expenses	Maintenance Cost
2017	0	0	0	0	0
2018	6,829,881.98	82,829,973.95	977,563,012.05	280,646,566.17	906,779.72
2019	7,171,376.08	86,971,472.65	977,563,012.05	280,646,566.17	906,779.72
2020	7,529,944.88	91,320,046.28	977,563,012.05	280,646,566.17	906,779.72
2021	7,906,442.13	95,886,048.59	977,563,012.05	280,646,566.17	906,779.72
2022	8,301,764.23	100,680,351.02	195,512,602.41	280,646,566.17	906,779.72
2023	8,716,852.45	105,714,368.57	195,512,602.41	280,646,566.17	906,779.72
2024	9,152,695.07	111,000,087.00	195,512,602.41	280,646,566.17	906,779.72
2025	9,610,329.82	116,550,091.35	195,512,602.41	280,646,566.17	906,779.72
2026	10,090,846.31	122,377,595.92	195,512,602.41	280,646,566.17	906,779.72
2027	10,595,388.63	128,496,475.72	195,512,602.41	280,646,566.17	906,779.72
2028	11,125,158.06	134,921,299.50	195,512,602.41	280,646,566.17	906,779.72
2029	11,681,415.96	141,667,364.48	195,512,602.41	280,646,566.17	906,779.72
2030	12,265,486.76	148,750,732.70	195,512,602.41	280,646,566.17	906,779.72
2031	12,878,761.10	156,188,269.34	195,512,602.41	280,646,566.17	906,779.72
2032	13,522,699.15	163,997,682.80	195,512,602.41	280,646,566.17	906,779.72
2033	14,198,834.11	172,197,566.94	195,512,602.41	280,646,566.17	906,779.72
2034	14,908,775.82	180,807,445.29	195,512,602.41	280,646,566.17	906,779.72
2035	15,654,214.61	189,847,817.56	195,512,602.41	280,646,566.17	906,779.72
2036	16,436,925.34	199,340,208.43	195,512,602.41	280,646,566.17	906,779.72
2037	17,258,771.60	209,307,218.86	195,512,602.41	280,646,566.17	906,779.72
2038	18,121,710.18	219,772,579.80	195,512,602.41	280,646,566.17	906,779.72
2039	19,027,795.69	230,761,208.79	195,512,602.41	280,646,566.17	906,779.72
2040	19,979,185.48	242,299,269.23	195,512,602.41	280,646,566.17	906,779.72
2041	20,978,144.75	254,414,232.69	195,512,602.41	280,646,566.17	906,779.72
2042	22,027,051.99	267,134,944.32	195,512,602.41	280,646,566.17	906,779.72
2043	23,128,404.59	280,491,691.54	195,512,602.41	280,646,566.17	906,779.72
2044	24,284,824.82	294,516,276.12	195,512,602.41	280,646,566.17	906,779.72
2045	25,499,066.06	309,242,089.92	195,512,602.41	280,646,566.17	906,779.72
2046	26,774,019.36	324,704,194.42	195,512,602.41	280,646,566.17	906,779.72
2047	28,112,720.33	340,939,404.14	195,512,602.41	280,646,566.17	906,779.72

(Calculated by the author)

D. Annual Operation and Maintenance Cost of AA BRT with Diesel Buses

Year	Variable Operating Costs					Staff Related Costs		Maintenance Costs	Total
	Fuel Cost	Lubricant Cost	Tire Cost	Spare parts	Misc. Cost	Employee Remuneration	Overtime & Allowances		
2013	0	0	0	0	0	0	0	0	-
2014	19,399,020.00	1,506,720	8,616,555	1,804,925	3,452,900	11,928,200.00	3,295,950	22,349,680	72,353,950.00
2015	20,368,971.00	1,506,720	8,616,555	1,804,925	3,452,900	12,524,610.00	3,295,950	22,349,680	73,920,311.00
2016	21,387,419.55	1,506,720	8,616,555	1,804,925	3,452,900	13,150,840.50	3,295,950	22,349,680	75,564,990.05
2017	22,456,790.53	1,506,720	8,616,555	1,804,925	3,452,900	13,808,382.53	3,295,950	22,349,680	77,291,903.05
2018	23,579,630.05	1,506,720	8,616,555	1,804,925	3,452,900	14,498,801.65	3,295,950	22,349,680	79,105,161.71
2019	24,758,611.56	1,506,720	8,616,555	1,804,925	3,452,900	15,223,741.73	3,295,950	22,349,680	81,009,083.29
2020	25,996,542.13	1,506,720	8,616,555	1,804,925	3,452,900	15,984,928.82	3,295,950	22,349,680	83,008,200.95
2021	27,296,369.24	1,506,720	8,616,555	1,804,925	3,452,900	16,784,175.26	3,295,950	22,349,680	85,107,274.50
2022	28,661,187.70	1,506,720	8,616,555	1,804,925	3,452,900	17,623,384.02	3,295,950	22,349,680	87,311,301.73
2023	30,094,247.09	1,506,720	8,616,555	1,804,925	3,452,900	18,504,553.23	3,295,950	22,349,680	89,625,530.31
2024	31,598,959.44	1,506,720	8,616,555	1,804,925	3,452,900	19,429,780.89	3,295,950	22,349,680	92,055,470.33
2025	33,178,907.41	1,506,720	8,616,555	1,804,925	3,452,900	20,401,269.93	3,295,950	22,349,680	94,606,907.35
2026	34,837,852.79	1,506,720	8,616,555	1,804,925	3,452,900	21,421,333.43	3,295,950	22,349,680	97,285,916.21
2027	36,579,745.42	1,506,720	8,616,555	1,804,925	3,452,900	22,492,400.10	3,295,950	22,349,680	100,098,875.52
2028	38,408,732.70	1,506,720	8,616,555	1,804,925	3,452,900	23,617,020.10	3,295,950	22,349,680	103,052,482.80
2029	40,329,169.33	1,506,720	8,616,555	1,804,925	3,452,900	24,797,871.11	3,295,950	22,349,680	106,153,770.44
2030	42,345,627.80	1,506,720	8,616,555	1,804,925	3,452,900	26,037,764.67	3,295,950	22,349,680	109,410,122.46
2031	44,462,909.19	1,506,720	8,616,555	1,804,925	3,452,900	27,339,652.90	3,295,950	22,349,680	112,829,292.09
2032	46,686,054.65	1,506,720	8,616,555	1,804,925	3,452,900	28,706,635.54	3,295,950	22,349,680	116,419,420.19
2033	49,020,357.38	1,506,720	8,616,555	1,804,925	3,452,900	30,141,967.32	3,295,950	22,349,680	120,189,054.70
2034	51,471,375.25	1,506,720	8,616,555	1,804,925	3,452,900	31,649,065.69	3,295,950	22,349,680	124,147,170.93
2035	54,044,944.01	1,506,720	8,616,555	1,804,925	3,452,900	33,231,518.97	3,295,950	22,349,680	128,303,192.98
2036	56,747,191.21	1,506,720	8,616,555	1,804,925	3,452,900	34,893,094.92	3,295,950	22,349,680	132,667,016.13
2037	59,584,550.77	1,506,720	8,616,555	1,804,925	3,452,900	36,637,749.67	3,295,950	22,349,680	137,249,030.44
2038	62,563,778.31	1,506,720	8,616,555	1,804,925	3,452,900	38,469,637.15	3,295,950	22,349,680	142,060,145.46
2039	65,691,967.23	1,506,720	8,616,555	1,804,925	3,452,900	40,393,119.01	3,295,950	22,349,680	147,111,816.23
2040	68,976,565.59	1,506,720	8,616,555	1,804,925	3,452,900	42,412,774.96	3,295,950	22,349,680	152,416,070.54
2041	72,425,393.87	1,506,720	8,616,555	1,804,925	3,452,900	44,533,413.70	3,295,950	22,349,680	157,985,537.57
2042	76,046,663.56	1,506,720	8,616,555	1,804,925	3,452,900	46,760,084.39	3,295,950	22,349,680	163,833,477.95
2043	79,848,996.74	1,506,720	8,616,555	1,804,925	3,452,900	49,098,088.61	3,295,950	22,349,680	169,973,815.35

(Source: Calculated by the Author)

Appendix 2: Questionnaires

Addis Ababa Institute of Technology, School of Civil and Environmental Engineering
Road and Transport Engineering Department
Questionnaire for Residents

Dear Sir/ Madam, My name is Endashu Tekalign. I am undertaking a study on the examination of selected Public Transportation Modes in Addis Ababa city. Under this study, there is an objective to estimate the Effect of Addis Ababa Light Rail Transit on the Surrounding Residents` Spatial Accessibility to their destinations along the selected stations. In order to accomplish the work, I need to get information from you. I would kindly request you to answer the following simple questions honestly; the information you give is for academic purpose and will be treated with maximum confidentiality. Dear respondents: to achieve the objective of the paper and deeply investigate the case, your response to the questionnaire given below has a crucial value. Thank you very much!

Instruction: Circle the letter of your choice or fill the blank spaces for the following questions. You may respond more than one answer if it is necessary.

<u>Part One</u>: Socio-demographic information of residents

1. Your gender? A. Male B. Female
2. Your age in years?
   A. Below 18 B. between 19-30 C. between 31-50 D. 50 above
3. What is your level of education?
   A. Illiterate B. primary school C. high school D. above high school
4. What is your employment/work status?
   A. Government B. Self-employed C. Private sector
   D. Student E. Unemployed F. Other ______
5. How much is your monthly income?
   A. 1000—2000Etb B. 2001 –3000Etb C. 3001-4000Etb D. 4001-5000Etb E. Above 5000Etb

Part Two: Information about Trip Purpose, distance, and time of the Residents crossing LRT infrastructure

6. What is the main purpose of your trip?
   A. Work B. School C. Other place
7. If your answer is "Work" for question number 5, which mode of transportation do you use currently for your home to work trip?
   A. Walking only B. Walking plus Public transportation mode

8. What is the distance you walk currently across the LRT infrastructure to reach to your first destination?

Transportation Modes	Distance Travelled			
	1-100m	100-200m	200-300m	>300m
Walking Only				
Walking plus Public Transportation				

9. How do you compare this distance you travel with the distance you take before LRT?

   A. Shorter B. Similar C. Longer

10. How much time does it take you to reach to your first destination by crossing the LRT infrastructure?

Transportation Modes	Time			
	0-15min	15-30min	30-45min	>45min
Walking Only				
Walking plus Public Transportation				

11. How do you compare the duration with the time taken while you used to travel before LRT?

    A. Shorter B. Similar C. Longer

12. If your answer is "School" for question number 5, which mode of transportation do you use currently for your home to school trip?

    A. Walking only B. Public transportation mode

13. What is the distance you travel currently across the LRT infrastructure to reach to your first destination?

Transportation Modes	Distance Travelled			
	1-100m	100-200m	200-300m	>300m
Walking Only				
Walking plus Public Transportation				

14. How do you compare this distance you travel with the distance you take before LRT?

    A. Shorter B. Similar C. Longer

15. How much time does it take you to reach to your first destination by crossing the LRT infrastructure?

Transportation Modes	Time			
	0-15min	15-30min	30-45min	>45min
Walking Only				
Walking plus Public Transportation				

16. How do you compare the duration with the time taken while you used to travel before LRT?

    A. Shorter B. Similar C. Longer

17. Which mode of transportation do you use mostly for trips other than work and school?

    A. Walking only B. Public transportation mode

18. How do you compare the distance you travel to reach to these destinations with the one before LRT?

    A. Shorter B. Similar C. Longer

19. How do you compare the duration with the time taken while you used to travel before LRT?

    A. Shorter B. Similar C. Longer

Part Three: General Information about LRT Crossing Infrastructure

20. How would you evaluate the width of the roadway before and after LRT?

    A. Shorter B. No change C. Wider D. Very Wide

21. How do you evaluate the current condition of pedestrian crossing along the LRT line?

    A. Excellent B. Very Good C. Good D. Poor E. Poorest

22. How do you put the difference in distance between pedestrian crossings along the LRT line?

A. Close distance B. Moderate distance C. Far D. Very Far

23. How does the LRT affect the interaction of the surrounding residents with their neighborhood?

A. More Increase B. Increase C. No change D. Decrease E. More decrease

መጠይቅ

ክፍል አንድ - አጠቃላይ መረጃ

1. ፆታ ሀ. ሴት ለ. ወንድ

2. እድሜህ/ሽ ስንት ነው?

ሀ. ከ 18 አመት በታች ለ. ከ 19- 30 ሐ. ከ 31-50 መ. ከ 50 አመት በላይ

3. የትምህርት ደረጃ

ሀ. ያልተማረ ለ. የመጀመሪያ ደረጃ ሐ. ሁለተኛ ደረጃ መ. ከሁለተኛ ደረጃ በላይ

4. የሥራ ሁኔታዎ ምንድን ነው?

ሀ . በመንግስት ለ . የግል ሐ . የግል ቅጥር መ. ተማሪ ሠ. ስራ አጥ

5. ወርሃዊ ገቢዎ ስንት ነው?

ሀ. 1000-2000 ብር ለ. 2001 -3000 ብር ሐ. 3001-4000 ብር

መ. 4001-5000 ብር ሠ. ከ 5000 ብር በላይ

ክፍል ሁለት - ነዋሪዎች የፈጣን ባቡሩን መንገድ ሲያቋርጡ ያለው የጉዞ ዓላማ ፣ ርቀት እና ሠዓት

6. ሀዲዱን በማቋረጥ የእግር ጉዞውን የምታደርጉት ለምንድንነው? ሀ. ስራ ለ. ለትምህርት ሐ. ሌላ
7. ለጥያቄ ቁጥር 5 መልስዎ “ሥራ” ከሆነ ለስራ ጉዞዎ የትኛውን የትራንስፖርት አይነት ይጠቀማሉ?
   ሀ. የእግር ጉዞ ለ. የእግር ጉዞ በተጨማሪም የህዝብ መጓጓዣ
8. ከቤት ወደ ስራ ቦታዎ ለመድረስ የባቡሩን ሀዲድ በማቋረጥ በእግር የሚጓዙት ምን ያህል ርቀት ነው?

የመጓጓዣ ሁኔታዎች	ርቀት			
	1-100ሜትር	100-200ሜትር	200-300ሜትር	>300ሜትር
የእግር ጉዞ				
የህዝብ መጓጓዣ እና የእግር ጉዞ				

11. አሁን የሚጓዙትን ርቀት የባቡሩ ሀዲድ ከመገንባቱ በፊት ከነበረው ርቀት ጋር እንዴት ያነፃፅሩታል?

ሀ. አጭር ለ. መካከለኛ ሐ. ረዥም

12. ከቤት ወደ ስራ ቦታዎ ለመድረስ የባቡሩን ሀዲድ በማቋረጥ በእግር ሲጓዙ ምን ያህል ግዜ ያጠፋሉ?

የመጓጓዣ ሁኔታዎች	ሰዓት			
	0-15ደቂቃ	15-30ደቂቃ	30-45ደቂቃ	>45ደቂቃ
የእግር ጉዞ				
የህዝብ መጓጓዣ እና የእግር ጉዞ				

12. አሁን የሚጓዙበትን ሰአት የባቡሩ ሀዲድ ከመገንባቱ በፊት ከነበረው ጋር እንዴት ያነፃፅሩታል?

ሀ. አጭር ለ. መካከለኛ ሐ. ረዥም

13. ለጥያቄ ቁጥር 5 መልስዎ “ት / ቤት” ከሆነ ከቤትዎ ትምህርት ቤት ጉዞዎ በአሁኑ ጊዜ የትኛውን የትራንስፖርት አይነት ይጠቀማሉ?

ሀ. የእግር ጉዞ ለ. የእግር ጉዞ በተጨማሪም የህዝብ መጓጓዣ

14. ከቤት ወደ ት/ቤት ለመድረስ የባቡሩን ሀዲድ በማቋረጥ በእግር የሚጓዙት ምን ያህል ርቀት ነው?

የመጓጓዣ ሁኔታዎች	ርቀት			
	1-100ሜትር	100-200ሜትር	200-300ሜትር	>300ሜትር
የእግር ጉዞ				
የህዝብ መጓጓዣ እና የእግር ጉዞ				

15. አሁን የሚጓዙትን ርቀት የባቡሩ ሀዲድ ከመገንባቱ በፊት ከነበረው ርቀት ጋር እንዴት ያነፃፅሩታል?

ሀ. አጭር ለ. መካከለኛ ሐ. ረዘም

16. ከቤት ወደ ት/ቤት ለመድረስ የባቡሩን ሀዲድ በማቋረጥ በእግር ሲጓዙ ምን ያህል ግዜ ያጠፋሉ?

የመጓጓዣ ሁኔታዎች	ሰዓት			
	0-15ደቂቃ	15-30ደቂቃ	30-45ደቂቃ	>45ደቂቃ
የእግር ጉዞ				
የህዝብ መጓጓዣ እና የእግር ጉዞ				

17. አሁን የሚጓዙበትን ሰአት የባቡሩ ሀዲድ ከመገንባቱ በፊት ከነበረው ጋር እንዴት ያነፃፅሩታል?

ሀ. አጭር ለ. መካከለኛ ሐ. ረዥም

18. ከስራ እና ከት/ቤት ውጭ ለጉዞዎ ብዙውን ጊዜ የትኛውን የትራንስፖርት አይነት ይጠቀማሉ?

ሀ. የእግር ጉዞ ለ. የህዝብ መጓጓዣ

20. የባቡሩ ሃዲድ ከመገንባቱ በፊት እና በኋላ የመንገዱን ስፋት እንዴት ይገመግሙታል?

ሀ. ጠባብ ነው ለ. ለውጥ የለም ሐ. ሰፊ ነው መ. በጣም ሰፊ ነው

21. በባሩ ሃዲድ ለማቋረጥ የተቀመጡትን የእግረኛ መንገድ ማቋረጫ ሁኔታ እንዴት ይገመግሙታል?

መ. እጅግ በጣም ጥሩ ለ. በጣም ጥሩ ሐ. ጥሩ መ. ደካማ ሠ. በጣም ደካማ

22. በባቡሩ ሀዲድ መስመር ላይ ያሉትን እግረኛ መንገድ ማቋረጫዎች መካከል ያለውን ርቀት እንዴት ያዩታል?

ሀ. ይቀራረባል ለ. መካከለኛ ርቀት አለው ሐ. ይራራቃል መ. በጣም ይራራቃል

23. የባቡሩ ሀዲድ መገንባት በዙሪያዉ በሚኖሩ ነዋሪዎች መካከል ያለውን መስተጋብር እንዴት ይነካዋል?

ሀ. የበለጠ ጨምሯል ለ. ጨምሯል ሐ. ምንም ለውጥ የለውም

መ. ቀንሷል ሠ. የበለጠ ቀንሷል

ስለ ትብብርዎ በጣም እናመሰግናለን !!

Appendix 3: Classification of Walking Distance and Time

A. Classification of walking distances collected from respondents

Mode	Walking Distance (meter)									
	>300		200-300		100-200		1-100		Total	
	Frequency	Percent(%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Walking	53	68.83	18	23.38	3	3.90	3	3.90	77	22
Walking + PT	148	53.43	70	25.27	34	12.27	25	9.03	277	78
Total	201	57	88	25	37	10	28	8	354	100

(Source: Gathered from field survey and compiled by the Author)

B. Classification of walking distances collected from respondents

Mode	Walking Time (minutes)									
	0-15		15-30		30-45		>45		Total	
	Frequency	Percent(%)	Frequency	Percent(%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Walking	7	9.09	49	63.64	19	24.68	2	2.60	77	22
Walking + PT	92	33.21	163	58.84	22	7.94	0	0.00	277	78
Total	99	28	212	60	41	12	2	1	354	100

(Source: Gathered from field survey and compiled by the Author)