Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Comparative Study of Addis Ababa City Light Railway project and Equivalent Bus Rapid Transit Mode of Transport

A Thesis submitted to Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the requirements of Degree of Master of Science in Civil Engineering

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ADDIS ABABA INSTITUTE OF TECHNOLOGY
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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled, "**COMPARATIVE STUDY OF ADDIS ABABA CITY LIGHT RAILWAY PROJECT AND EQUIVALENT BUS RAPID TRANSIT MODE OF TRANSPORT"** is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been properly acknowledged.

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ABSTRACT

In rapidly developing cities automobile ownerships and their utilization is increasing and accordingly the problem of traffic congestions quickly go from bad to worse. It is, therefore, necessary for these cities to construct and operate a transit system. The basic question that must be addressed in formulating an urban transport strategy for a given city is to decide on the type of public transit suited for the city.

Light rail transit is seen as a better choice for the cities than busways, perhaps because of their lack of image and knowledge of what is achievable using bus-based system. This document is a research product on comparative study of the Addis Ababa City Light Railway project and an equivalent Bus Rapid Transit (BRT) system. That is defined as a high quality bus-based transit system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated right-of-way infrastructure. The research is conducted to show whether or not the bus-based system's effectiveness and economic worth as compared to Light rail transit.

After examining the light rail and its equivalent BRT system in terms of performance, cost and impact, the research found out that the BRT system has capacity, commercial speed and quality of service which is not less than to the LRT system. Moreover, due to low cost and flexibility of BRT system they can cover more area and reduce or remove more small cars from street than LRT can do thereby reducing emission as compared to LRT.

The results of economic analysis show net present value of Birr -170 million, benefit-cost ration of 0.965, Internal rate of return of 9.45 % and more than 30 years payback period for LRT system, In case of BRT system; net present value of ETB 2.54 billion, benefit-cost ratio of 2.15, Internal rate of return of 27.4% and payback period of eighth years were calculated. Thus the BRT system gives maximum befit to the society for investment, due to low investment cost and shortage of implementation time, utilization of the existing infrastructures for the city which needs immediate solution to urban transport problems and ease of operation, construction, design with limited amount of budget. Therefore, the BRT system is a better transport option for the commuters in Addis Ababa.

Key Words
Light Rail Transit and Bus Rapid Transit

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Yassin Siraj

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ACRONYMS and ABBREVIATIONS

AACRA	Addis Ababa City Road Authority
AC	Asphalt Concrete
ASD	Automated Scheduling and Dispatch
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
CBA	Cost Benefit Analysis
CBD	Central Business District
CCTV	Central Business District
CNG	Compressed Natural Gas
CRGE	Climate-Resilient Green Economy
DFID	Department for International Development
ERC	Ethiopian Railway Corporation
ERA	Ethiopian Roads Authority
ESAL	Equivalent Standard Axel Load
ETB	Ethiopian Birr
FTA	USA Federal Transit Administration
GHG	Greenhouse gases (CO_2)
ITDP	New York-based Institute of Transportation & Development Policy
ITS	Intelligent Transport Systems
IRR	Internal Rate of Return
JCT	Junction
JICA	Japan International Cooperation Agency
LRT	Light Rail Transit
MRT	Mass Rapid Transit
NPV	Net Present Value
PPHPD	Passenger per Hour per Direction
PVR	Peak vehicle requirement
ROW	Right of Way
USD	United States Dollar
TCRP	Transit Cooperative Research Program
TOD	Transit-Oriented Development
TRL	Transport Research Laboratory, UK
TSP	Transit Signal Priority

1. INTRODUCTION

1.1 General

As cities move toward denser, more urban-style development, mass transit plays a crucial role in the process. Dense development requires access to transport that can efficiently move the people who live and work in the area. The alternative private automobile transport quickly leads to congested urban streets, neighborhoods, and cities, rendering the areas polluted, chaotic, and unlivable.

Shortage of public transport, traffic congestion and traffic accident are widely observed in Addis Ababa, more over due to population and economic growth of the City automobile ownerships and use are increasing from time to time than road network growth, accordingly the problem of urban transportation is quickly increasing.

As stated By JICA 2011 "It would be no longer possible to continue catching up with the pace of motorization by constructing more and more roads to maintain a favorable service standard for motorized traffic. The most fundamental issue is how to facilitate a shift in traffic demand from the private use of passenger cars to some public transit systems. However, in many large cities of the developing world, such modal shift is a vain issue because transit systems are either not available, or not up to the standard to take on the shift of passengers from private automobiles. It is, therefore, urgently necessary for the respective cities in the developing world to construct and operate a transit system. The basic question that must be addressed to formulate an urban transport strategy for a given city is to decide on the type of public transits suited for the city".

An urban public transportation project is usually proposed because of a perceived problem or need. A project to improve public transport on the city may be due to shortage of transportation and/or traffic congestion on the corridor. In most cases, there are more than one ways to solve the problem, and each solution or alternative will result in a unique outcome in terms of project cost and outcomes.

A public transportation improvement can be viewed as a mechanism for producing a result desired by society at a price. The question is, will the benefits of the project be worth the cost? In some instances, the results may be confined to the users of the mass transport whereas in other instances, those affected may include persons in the community who do not use the system such as private car users.

As mentioned by Kook, Lotshaw and Weinstock, 2013, the provision of specific forms of urban public transport should be guided by the level of demand to be served, the quality of service desired and budget and operational constraints faced by the transit agencies and regulatory authorities. A systematic assessment of public transport needs should also be placed within a framework that recognizes the strategic, tactical and operational elements of planning.

Prior to beginning an analysis to evaluate a transportation alternative, the planner should consider a number of basic questions and issues. These will assist in determining the proper approach to be taken, what data are needed, and what analytical techniques should be used. Transportation policy and planning decisions can have many economic, social and environmental impacts. It is important to consider all significant impacts when evaluating potential transport system options.

Bus rapid transit (BRT) is a high-quality, efficient mass transport mode, providing capacity and speed comparable with urban rail (light and heavy rail). Its insertion in urban transport systems is relatively recent and as a result there remains a need to introduce the concept to several audiences, particularly urban transport decision makers, and to better understand its cost, performance and impacts as explained by WRI EMBARQ, 2014.

Rail-based systems are able to solve transport shortage problems of the city and provide service environmentally friendly due to zero emission, but need an exclusive or separated right of way and have very high construction costs.

This thesis work will explores and compare the performances, cost benefit, environmental and social (development) impact of these two main options; Bus Rapid Transit (BRT) and Light Rail Transit (LRT) for a specific route.

1.2 Statement of Problem

The Addis Ababa light railway construction work was undertaken by the China Railway Engineering Corporation (CREC) from 2012-2015. The rail line consists of two lines running with the total distance of 31km. It has underground and elevated section and 39 stations. The 475 million dollar cost of the scheme is mostly being met by loan from China Exim Bank and the maintenance and operation of the Light Rail system is also given for two companies of Shenzo Metro Company Limited and China Railway Limited Company (CREC) for additional 116 Million Dollar contract agreement for four years. (ERC)

As mentioned above, the cost of rail construction is very high (USD 15 million per km 2009). As shown in Figure 1.1 the first Phase has enough route length along Eastern and Southern ends but on other two ends it does not have enough running length from CBD. The problem is that, due to high cost of LRT construction, it is challenging to start the implementation of Phase Two in the near future but there is shortage of transport services and enough passengers for mass transport especial on Western (Torhailoch- Ayertena - Jimma JCT) and Northern (Piassa - Shiromeda) end of the project. The transportation problem of the city can be solved if more area is covered by mass transit and the rate of growth of small cars can be controlled or reduced. It is possible when all major corridors have access to Mass Transit and the fee of the trip is affordable enough by all group of people without/with minimum subsidy but this is very difficult to make possible by cost intensive system.

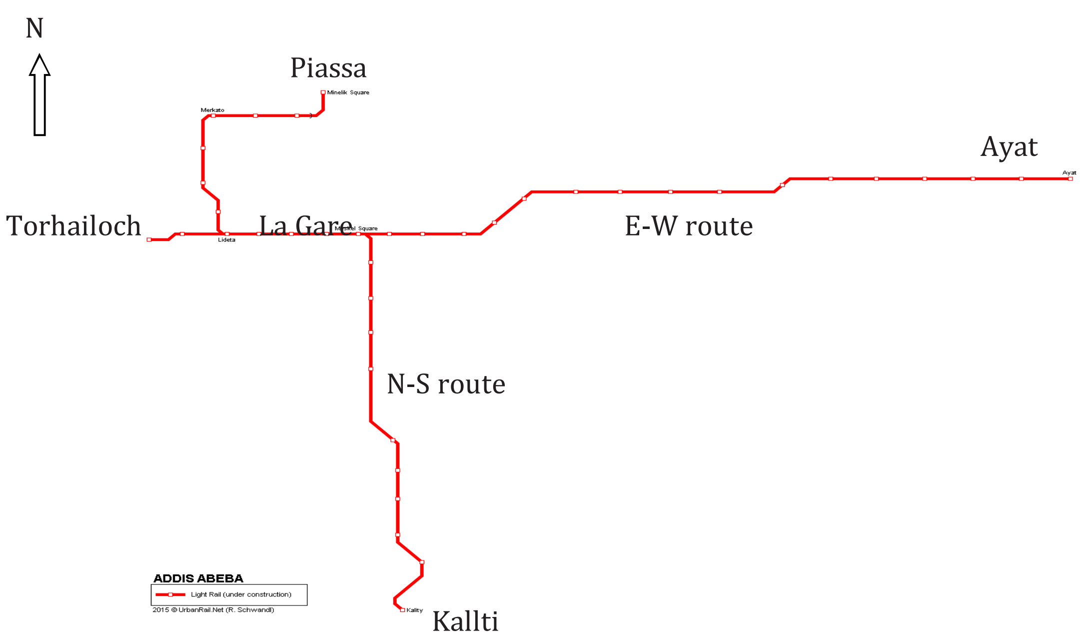


Figure 1.1: Phase one LRT Network

1.3 Objective of the Thesis

A significant reduction on shortage of public transport, congestion and accident and pollution on street is highly required from mass transit system that is affordable by the city and people, has more coverage area on major route of the city, enough capacity, good overall environmental result and short implementation time. The general objectives of the thesis is to compare LRT and its equivalent BRT in terms of cost effectiveness, system capacity, quality of service and environmental effect in order to find out which public transport systems have better potential to significantly improve the Addis Ababa city's transportation problem within short time. Therefore, the specific objective of this thesis is to provide a like-for-like comparison of cost-benefit and performance evaluation between LRT and its equivalent BRT systems on phase II selected route.

1.4 Research Question

The study has raised the following questions:

Which alternative:-

- is more cost effective, with adequate capacity and quality of service?
- can make the fee of trips as much as possible cheaper that is affordable by all people without or with minimum subsidy by the government?
- give maxim benefit to society?
- has good potential to reduce environmental impact of city transportation?
- is easy of construction, operation and maintenance thereby reducing the overall cost and solving the transportation problem of the city within short time before the situation goes from bad to worst?
- what can we learn from developing countries implementing the BRT or LRT as means of mass transportation?

1.5 Significance of the Study

The thesis output is envisaged to benefit the Addis Ababa City Transport Authority, Ethiopian Railways Corporation, Addis Ababa City Roads Authority, transport officials and for researchers that are involved in related study areas.

The benefits of the results are expected to be of wide and can be viewed from different directions. The most important benefits from the research are to indicate the comparative advantage of alterative technology that provide optimal mass transportation with affordable cost for the city that will be able to cover more area in the city thereby to increase efficiency of mass transport, reduce congestion, accidents, pollution and to control the growth of small vehicle.

2. Literature Review

2.1 General

Literature review is done to analyze and understand what were previously done on the comparison of LRT and BRT urban mass transport and also to investigate the application of the two options in different countries. This helps to identify the gaps of the previous works. The literature review and sources of data focused primarily on known institutions through books, internet, thesis, articles and journals and it was also done to find out the gaps in previous studies.

An urban public transportation project is usually proposed because of perceived problems or needs. A project to improve public transport on the city may be due to shortage of transportation and/or traffic congestion on the corridor. In most cases, there are more than one ways to solve the problem, and each solution or alternative will result in a unique outcome in terms of project costs and benefits. [Hoel and Garber, 2009]

Transportation alternative evaluation is viewed as a fact-finding process in which all outcomes are reported separately in a matrix format so that the decision maker has complete information about the project outcome. This information can be used in public forums for citizen input and the decision process can be extended to include public participation.

A transportation project is intended to accomplish one or more goals and objectives, which are made operational as criteria. For instance, in an urban public transportation problem, if the goal is to reduce travel time, the criteria can be measured as the amount of time saved for ridership expected to occur for each of the alternatives considered. If another goal is to reduce transport shortage, the criteria could be the number of minutes per passenger delayed when waiting for travel but this criteria must be evaluated based on other factors also such as at what cost and overall benefit. [DFID, 2000]

The initial cost of the project is the one main criterion for the decision maker; in many instances, this alone will determine the outcome. Another question may be, do the benefits justify the expenditure of funds for transportation, or would the money be better spent elsewhere? The decision maker also will want to know if the proposed project is likely to produce the stated result that is "How certain can we be of the predicted benefit?"[Randal, 2010]

It is necessary to carry out a sensitivity analysis that shows a range of values rather than a single number. Also, evaluations of similar projects elsewhere may provide clues to the probable success of the proposed venture. The decision maker also may wish to know if all the alternatives have been considered and how they compare with the one being recommended. Are there other ways to accomplish the objective, such as using management and traffic control strategies that would eliminate the need for a costly construction project? It may be that providing separate bus lanes results in significant increases in the passenger-carrying capacity of a freeway, thus eliminating the need to build additional highway lanes or railways. [Hoel and Garber, 2009]

The decision maker may want to know the cost to highway users as the result of travel delays during construction. Also of interest may be the length of time necessary to finish the project, since public officials are often interested in seeing work completed during their administration. The source of funds for the project and other matters dealing with its implementation will also be of concern. Thus, in addition to the fairly straightforward problem of evaluation based on a selected set of measurable criteria such as NPV, IRR, PBP and BCR, the transportation engineer must be prepared to answer all questions about the project and its implications. In the final analysis, the selection itself will be based on a variety of factors and considerations that reflect all the inputs.

Inputs to be considered for evaluating transportation project alternatives

- Capital costs
    - Design and Construction
    - Right of way
    - Vehicles
    - Depot and operation center
- Maintenance costs
- Facility operating costs
- Travel time
    - Total hours and cost of system travel saving
    - Accessibility of services
- Vehicle operating costs saving
- Social and environmental Impact
    - Air pollution
    - Construction impact
    - Construction time

2.2 Comparison of LRT and BRT

BRT and LRT, generally aim to achieve the same goals: an increase in speed, predictability, comfort, capacity and safety. The two modes can operate on surface streets and include important elements such as a dedicated running way, limited stops, off-board fare collection, minimized conflicts with traffic at intersections, safe, attractive and permanent stations, and high-capacity vehicles. If aligned to the central median in the road right-of-way, both technologies benefit from speed increases by avoiding conflicts with right-turning traffic and slow or stopped taxis, bicycles, delivery vehicles, and other causes of delay typically found in the curb lane. However, LRT requires tracks and overhead wires while BRT can operate more or less on normal roads.

As Stated by ITDP, 2007 "Unfortunately, the current state of public transport services in developing cities often does little to serve the actual mobility needs of the population. Bus services are too often unreliable, inconvenient and dangerous. In response, transport planners and public officials have sometimes turned to extremely costly mass transit alternatives such as rail-based metros. Due to the high costs of rail infrastructure, cities often can only construct such systems over a few kilometers in a few limited corridors. The result is a system that does not meet the broader transport needs of the population. Nevertheless, the municipality ends up with a long-term debt that can affect investment in more pressing areas such as health, education, water, and sanitation. Moreover, the probable need to subsidize the relatively costly rail operations can place a continuing strain on municipal finances."

2.2.1 Capital Costs

BRT systems found in African cities of Lagos, Johannesburg and Captown. Lagos' system, which opened in 2008, observed US$1.7 million per kilometer to build. But, it carries almost 200,000 passengers per day or a quarter of public transport trips along its corridor even though BRT vehicles make up just 4 percent of vehicles on the route as mentioned by ITDP, 2007

As stated by Cervero on Scientific Advisory Group Report, 2013, BRT system typically costs 4 to 20 times less than an LRT system and 10 to 100 times less than a Metrorail system. However, Adelaide's track in Australia guided bus cost over US$26 million per kilometer and Nagoya's in Nigeria exceeded US$45 million per km, considerably more than most LRT systems. The lowest Busway is found in Trans Jakarta Indonesia which cost just US$1.35 million per kilometer. To date, most BRT investments have come in well below US$10 million per kilometer. BRT's capital costs savings have been found across a variety of cities, whether in advanced western economy or a rapidly developing one.

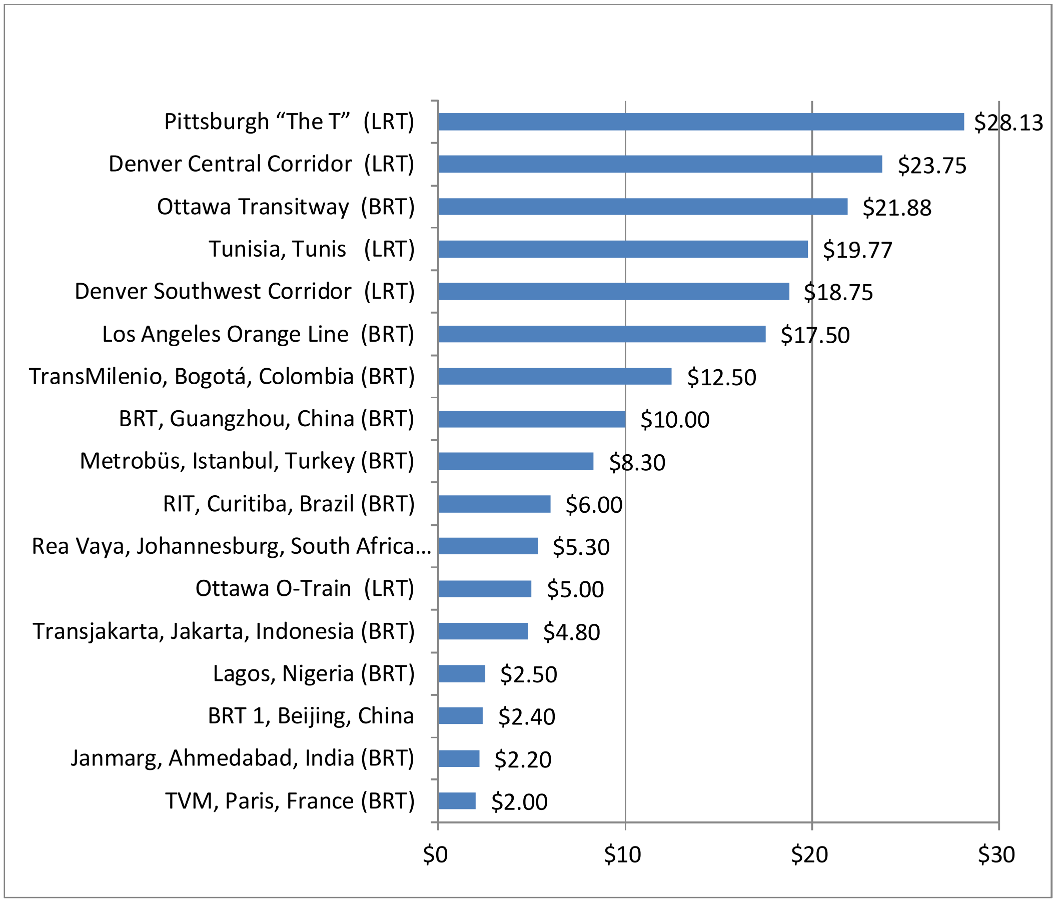


Figure 2.1: LRT & BRT Capital Cost/km USD:
Source: Kook, Lotshaw and Weinstock, 2013,WRI EMBARQ, 2014 and Jain 2012

According to Carvero, 2013, he per kilometer cost of building light rail systems has been placed in the $25-$35 million range compared to $10-$15 million for BRT in Europe. For developing countries, the capital costs of seven high quality BRT systems across seven countries to range from US$4 million to US$7 million per kilometer versus US$15 million to US$40 million for six at grade LRT systems in three countries. Elevated sky trains in southeast Asia ranged from US$40 million to US$100 million per kilometer and underground metrorail's cost S$45 million to US$350 million.

On ITDP collected capital cost data in 1999 on the six best BRT and LRT corridors in the United States, on average, the cost per mile of BRT infrastructure was less than one-half that of similar-quality LRT systems on. At the same time, BRT provided a similar or sometimes higher quality of service. The cost advantages of BRT were considerably greater than LRT in most cases.

2.2.2 Operation and Maintenance Costs

Some transit literature and research indicate that LRT systems are less expensive to operate then bus-based systems. Others have concluded that the opposite is true. According to Caevero 2013, many BRT systems in the developing world operate without a public operating subsidy, while few urban rail systems can lay claim to. For Porto Alegre city in Brazile, every passenger bus trip was subsidy free whereas the city's urban rail system required a 70 percent subsidy for each passenger carried. One US study found average operating costs of BRT to be less than that of LRT on both a revenue-kilometer and revenue-hour basis despite bus services being more labor-intensive. [Carvero, 2013]. Figure 2.2 below shows operation cost per vehicle mile on six US Cities.

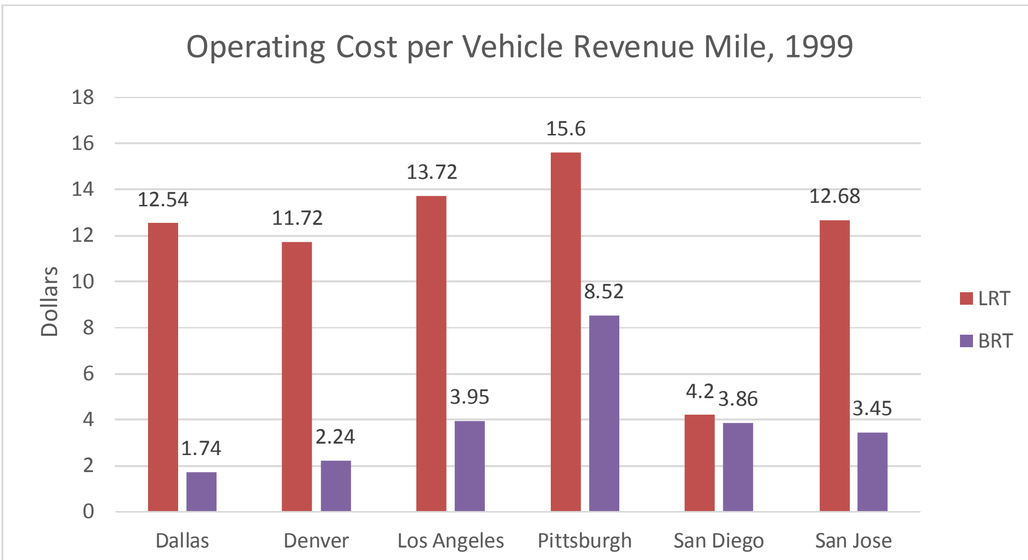


Figure 2.2: Operation Cost per Vehicle Mile
Source: U.S.A (GAO, 2001)

In the developing world, the operating cost advantages of BRT over LRT are greater than those in the US given relatively low labor costs in those countries. In the US and Canada, some project-specific data indicate that the operating costs of BRT are still lower than those of LRT. Although LRT operates at lower frequencies and therefore requires fewer drivers, maintenance costs for BRT are typically lower than LRT [Kubala & Barton, 2003]

It is commonly stated that LRT requires fewer operators for a given level of ridership based upon the ability of each LRV to carry about twice and even four times as many passengers. So, 700 passengers per train could be carried in Tunis vs. 270 passengers per bi-articulated bus in Curitiba and 160 passengers per articulated bus in Bogota, Quito. Although LRT costs per passenger km are often argued to be lower than for bus systems, these comparisons are usually spurious because they are based on theoretical capacity and not on actual patronage. [Kuhn, 2013].

"The World Bank has for many years been skeptical about urban rail systems on the grounds that: the fiscal burden of maintaining urban rail systems may be very damaging to the capability to finance other urban services. Peak hour peak directional flows of up to 20,000 passengers per hour could be effectively, and much more cheaply, accommodated by busway systems". [DFID, 2000]

"A counter-argument is that bus transit could provide equal benefits as rail at a lower cost. This does not appear to be the case. Rail offers greater benefits due to its ability to attract more discretionary travelers and provide a catalyst for more efficient land use. Costs per passenger-mile are often lower for rail than bus transit, and unit costs for all forms of transit tend to be lower in cities with large, well-established rail systems. This indicates that in appropriate conditions, rail can be the more cost effective transit option". [Litman, 2012]

2.2.3 Capacities

The first BRT system is opened in Curitiba (Brazil) in 1974 and cities were slow to adopt BRT because they believed that its capacity was limited to about 12,000 people per peak hour per direction (PPHPD) which was Curitiba's capacity at the time. With the introduction of Biarticulated bus this capacity increased to about 16,000 PPHPD. [Kubala & Barton, 2003]

The world view for limited BRT capacity was changed when the TransMilenio system in Bogotá, Colombia, opened in 1998 and attended practical capacity of 46,000 PPHPD by providing passing lane, multiple sub-stops at each station and introducing express services. While Light rail has a maximum theoretical capacity of about 20,000 PPHPD, that require very long multicar vehicles on fully grade-separated rights-of-way. On normal city streets, the highest-capacity LRT systems are in Europe, and they typically carry a maximum of about 9,000 PPHPD. There are conditions that favor LRT over BRT. If these specific conditions exist, light rail would have an operational advantage. [Kubala & Barton, 2003]. Figure 2.3 below illustrate public transport capacity for different mode.

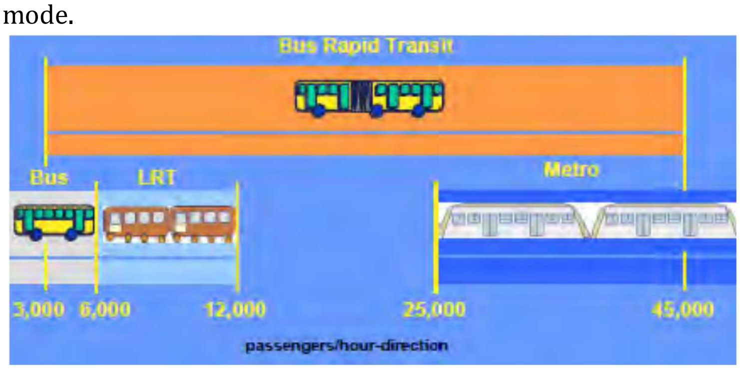


Figure 2.3: Public Transport Capacity Source:
Wright, 2007

We saw that LRT operates at a maximum flow of 28,000 passenger /hour/direction (phd) with two-car trains; in Manila three-car trains are operated on viaduct, the maximum flow should be over 28,000 phd. These systems, when operating at design capacities, will present characteristics usually found in metro systems. [Kuhn, 2013]

"LRT do not tend to carry large numbers of people at speed, which is the required role of MRT in larger developing cities. While much is known about them, the major issue concerns their ability to perform this role. After reviewing the evidence, and concluded that the performance is likely to be bounded by a capacity of about 12,000pphpd and an average operating speed of 20kph. This is lower than the capacity of many busways, and it may be wondered why this should be". [DIFD, 2000] Demand level exceeds the capacity of the BRT, use of LRT is preferred. [Jain, 2012]

2.2.4 Average Trip Speed.

Average trip speed affects the service that can be provided for passengers, and also determines the number of vehicles and drivers that will be needed. The average trip speed is also related to the maximum speed of the vehicle, to braking, acceleration characteristics and stopping distance. It might thus be expected that electric trains would be significantly faster than buses. [Kuhn, 2013]. Figure 2.4 & 2.5 shows average speed of different BRT and LRT System.

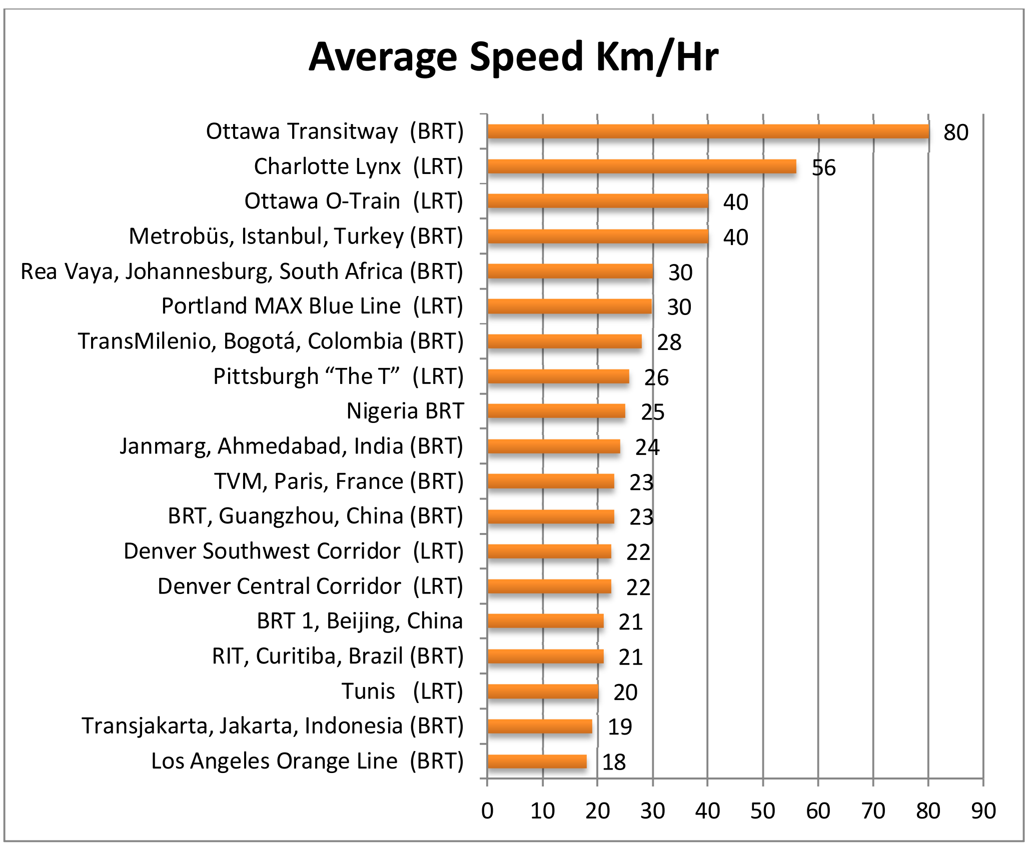


Figure 2.4: Average Speed of Transits

Source: Kook, Lotshaw and Weinstock 2013,WRI EMBARQ 2014 and Jain 2012

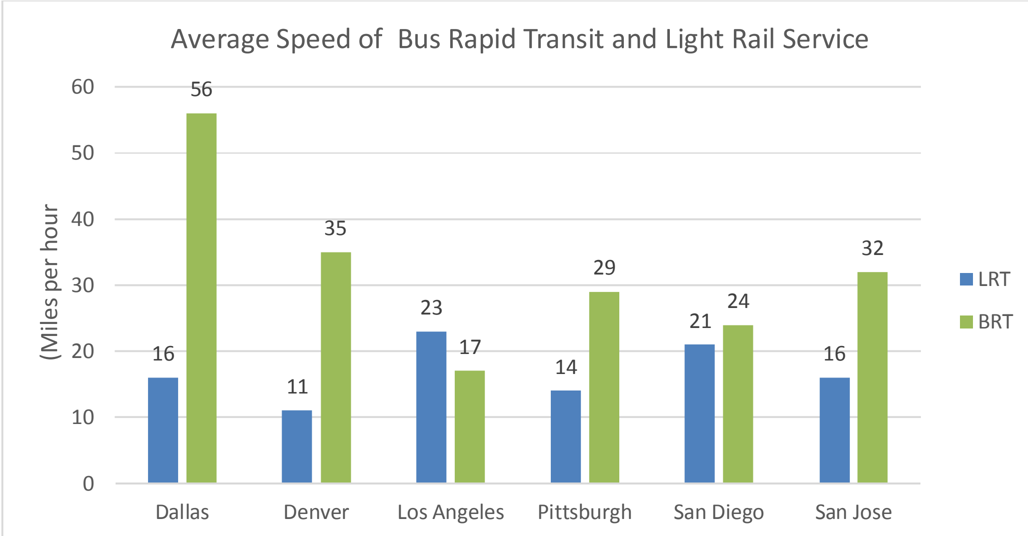


Figure 2.5: Average Speed
Source: U.S.A (GAO, 2001)

Providing passing lane at stations or the ability to pass in a general traffic lane at stations and limited stop is easier for BRT system, whereas rail-based transit systems require double-tracking throughout for express services. At an average cost of $41 million per mile, double-tracking rail is generally expensive. Bogotá's TransMilenio system's has attained high average speeds and capacities due to the introduction of a large number of express service. [Kubala & Barton, 2003]

"TRL field surveys revealed little difference and research using multiple regression analysis, to allow for factors such as station spacing suggests that the inherent difference between bus ways and LRT is not statically significant. LRT achieves high speed by using a signaling system to avoid bunching and by obtaining priority at traffic signals over other traffic; and it achieves high capacity by having large vehicle, which takes advantage of the signal cycles". [Kuhn, 2013]

2.2.5 Comparing Ridership

A route with high demand will likely have high ridership when a new mass transit system is opened. Providing service types that reduce total travel time for passengers encourages ridership. The BRT systems can have multiple express, limited, and local service options easily which attract ridership like Bogotá and Curitiba system while for LRT systems, it is difficult to offer multiple service types to alternative destinations, as services must remain on their tracks and cannot circulate around city that are not served directly by the LRT infrastructure. This limited service can result in lower system ridership. [Kubala & Barton, 2003]

If the total trip attributes of transit alternatives such as travel times, costs, ride quality, minimal transfers, and quality of stations and facilities are the same for LRT and BRT, both system able to generate equal number of ridership. [WRI EMBARQ, 2014]

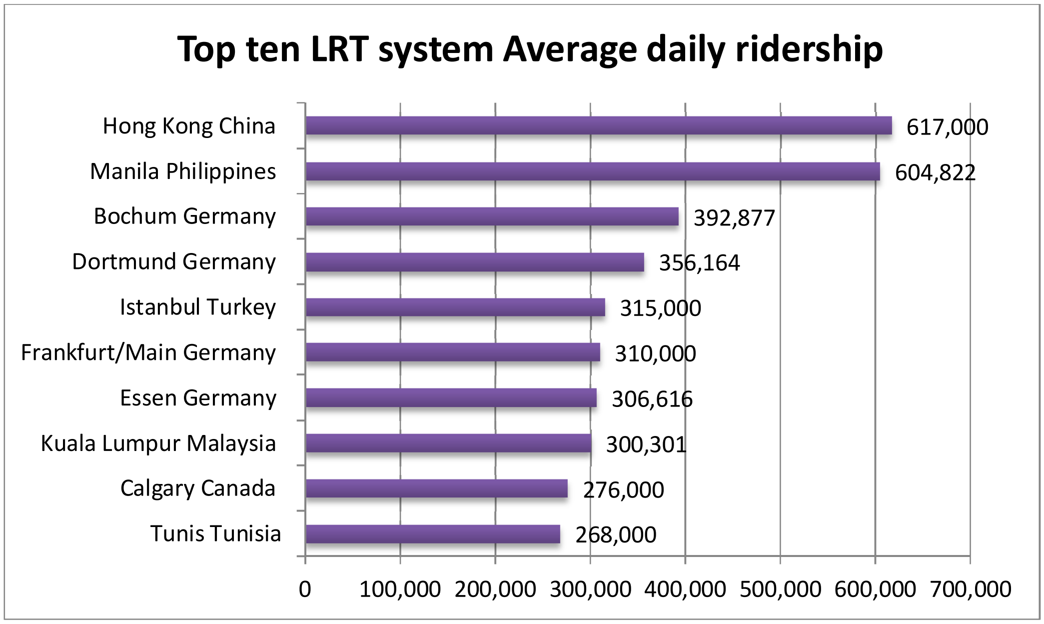


Figure 2.6: Average Daily Ridership of LRT
Source: UN Habitat, 2013

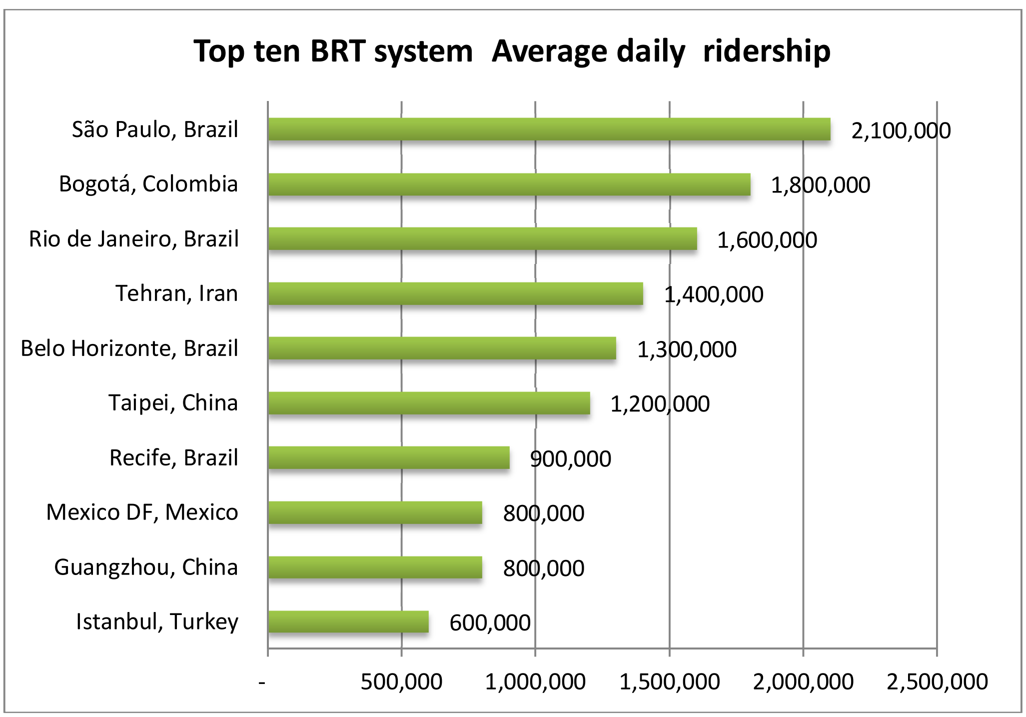


Figure 2.7: Average Daily Ridership of BRT
Source: UN Habitat, 2013

2.2.6 Financial Viability

In most BRT systems, average trip fares were below US$0.80 per trip as of 2009, with the exception of Curitiba and São Paulo whose fares are US$1.27 and 1.33 respectively. Most systems with fares below US$0.40 such as Beijing, Ahmedabad, Jakarta, Quito, and México City either received subsidies or were financially strained. If operational costs exceed fare box revenues, there is a need for an operational subsidy that is not allowed in most developing countries thus it is placing pressure on the transit system's finances. [WRI EMBARQ, 2014]

The trip cost in Curitiba BRT is 0.21 US$ 98 and in Tunis LRT it is 0.148 US$ 98. Tunis LRT shows a competitive vehicle-km and trip costs despite higher capital cost than BRT of Curitiba and Bogota. The high ridership all day long in Tunis is one reason for this cost effectiveness. [Kuhn, 2013]

"Public bus transport is the most affordable near term solution to urban mobility. Today buses meet more than 60 per cent of the travel demand in Delhi. This modal share of the bus transport will have to be enhanced to meet the increase travel demand in the cities and to reduce dependence on the personal transport. The immediate task of the government is to increase the number of buses and revamp the city bus system organization and operation". [Jain 2012]

"Some LRT system around the world fully meeting their operational costs and requires some form of ongoing governmental subsidy. What is clear from the evidence around the world, any city embarking upon a new LRT system must be prepared for the possibility of continually funding ongoing operation subsidies for the life of the system". [August, 1998]

2.2.7 Implementation Time and Phasing

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. The developers of high-quality BRT systems in cities such as Bogotá, Brisbane, Curitiba, Ottawa, Istanbul, Guangzue, South Africa and Nigeria demonstrated that the ultimate objective was to quickly, efficiently, and cost-effectively move people rather than many small cars. [ITDP, 2007].

A BRT can be designed and implemented within an extremely short time frame. Guangzhou BRT system went from a firm political commitment to implementation within eighteen months. In many cities around the world, a major selling point for BRT is that mayors are able to get the projects built and operational within a single term of office, as happened in Bogotá during the 1998–2001 term of Mayor Enrique Peñalosa. LRT projects tend to have much longer time horizons. It also means that the mass transit and land use benefits will be felt much more quickly with BRT than with rail-based modes. [Kubala & Barton, 2003]

BRT provides much flexibility in terms of phasing. A city can build high-quality BRT along just a segment of an existing bus route where the BRT infrastructure is most needed, then extend this BRT when the need for these measures increases. The Ottawa Transitway BRT and Pittsburgh's BRT corridors developed in this phased manner. [Kubala & Barton, 2003]

LRT requires a fully connected line before the first train can operate. LRT has some complicated design characteristics: such as electrification, train control, computerization, rail alignment requirements, weight, and specifications of LRVs. BRT generally has the advantage of having more flexibility than LRT, being able to phase in service rather than having to wait for an entire system to be built. [Kuhn, 2013]

"Surprisingly, although much studied, few well-designed busways have been implemented outside South America. The problems preventing the widespread, routine development of busways are primarily institutional rather than technical - they have no natural promoters, perhaps because of their lack of image and a lack of knowledge of what is achievable, even though their effectiveness and economic worth are demonstrable. Where they have been implemented widely, in Brazil, they are sometimes seen as a step towards LRT". [DFID, 2000]. Figure 2.8 below shows Guangzhou, BRT corridor completed within 18 months.

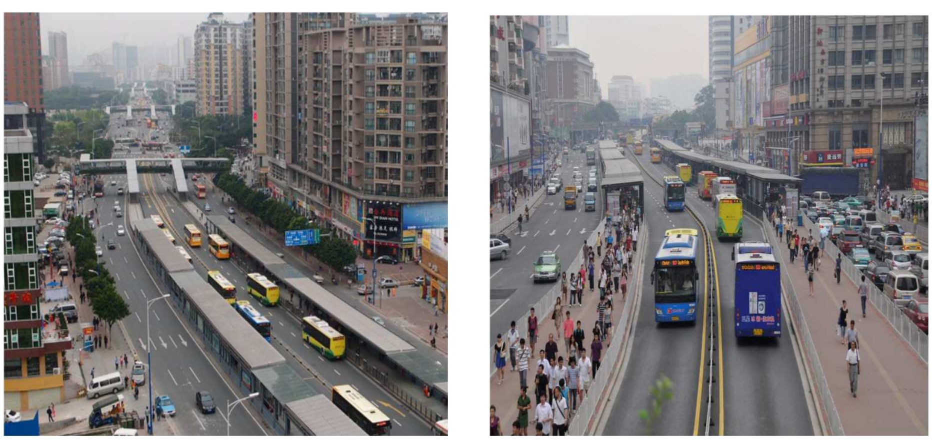


Figure 2.8: Guangzhou, BRT Corridor
Source: Carvero, 2013

2.2.8 Environmental Impacts

Ethiopia's current contribution to the global increase in GHG emissions of less than 2 tons CO_2 per capita are modest compared with the more than 10 tons per capita on average in the EU and more than 20 tons per capita in the US and Australia. Overall, Ethiopia's total emissions of around 150 Mt CO2e in 2010 represent less than 0.3% of global emissions. [ECRGE, 2011]

The Addis Ababa Greenhouse Gas Emission Inventory of 2012 was 4.8 million tons of carbon dioxide gas (Co_2) the city emits, transport vehicles account for 47 % of the total emission since 50 percent of the national vehicle stock in the city. Within the transportation sector the road transport account 1.4 million tons of co_2 emission while the aviation sector is responsible for remainder. About 34 percent of transport emissions originate from trips to and from the adjacent Oromia special zone as well as heavy duty cargo trucks incoming from seaports in Djibouti. Though Addis Ababa consumes 49 percent of Ethiopia electricity, high usage of kerosene and charcoal for domestic cooking and power needs is one of the largest and most significant sources for emission releasing 1.3 million tons of Co_2. The Industrial and Manufacturing sector emit about 0.21 million tons and Commercial and Institutional emission was 0.02 million tons of co_2. [Mekonnen, 2015]. Figure 2.9 below shows Addis Ababa Greenhouse Gas Emissions of 2012.

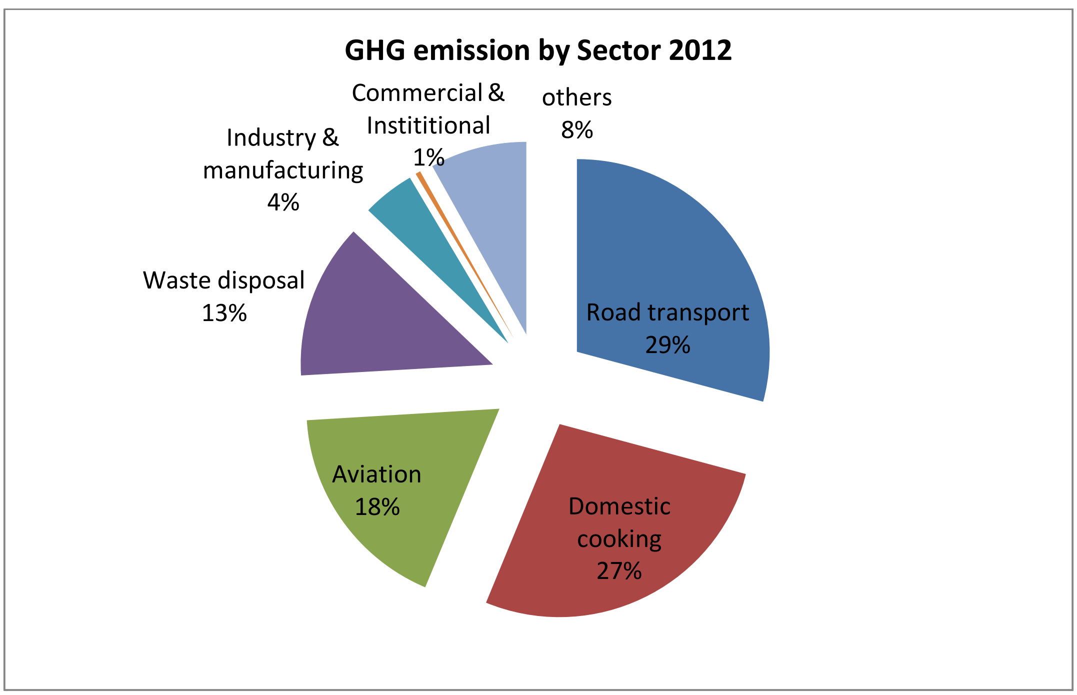


Figure 2.9: Addis Ababa Greenhouse Gas Emissions of 2012.
Source: [Mekonnen, 2015]

The emission reduction of LRT Phase I is estimated at 59,940 tons of Co_2 at opening year that is 1.25 % of city's emission in 2012 (4.8 million tons) and the emission share of Anbessa city bus is about 0.75% of the city emission for more than 600 buses in 2012.[ECRGE, 2011]

According to Kubala & Barton, 2003 "Because BRT systems tend to have catchment areas that are larger than those of LRT systems, they also tend to have greater modal shift. Curitiba is the only city in the world that maintained its share of public transit users for nearly three decades during the period of motorization".

LRT is seen and accepted as helping to reduce pollution and supported by environmentalists, but to date only BRT projects have been certified as greenhouse gas-reduction projects by the Clean Development Mechanism defined in the Kyoto Protocol. Buses are major producers of particulate emissions unless they use low-sulfur fuels, have particulate traps and clean engines, or run on some source of fuel that is an alternative to diesel. These particulate emissions are the main problem for BRT systems because the particles can become trapped in BRT stations and pose a significant health hazard. [Kubala & Barton, 2003]

Delhi has one of the largest CNG bus fleet in the world comprising 46,000 buses covering a road network of 31,200km running about 13 million km per day and transporting nearly 6 million passengers per day. It is interesting to note that private modes carry 31 % of vehicular trips and are responsible for 90% of emissions, while CNG powered buses carry 62 % of tripe and emit less than 4% of pollutant. [Jain, 2012]

"In Grenoble, prior to LRT, urban pollution from diesel buses was a problem in the city. In 1984, 201 diesel buses would enter the city during the evening in one direction. Since the advent of light rail in 1987, this number has been reduces to 57. The presence of light rail along with electrical bus in the city has helped to reduce pollution levels". [August, 1998]

Bus rapid transit systems can have positive environmental impacts by reducing greenhouse gases that contribute to global climate change as well as local air pollutants, which lead to citywide air pollution and smog. Emissions reductions can be achieved by reducing vehicle-kilometers travelled (VKT), and replacing older technology and smaller vehicles with newer, cleaner high-capacity BRT buses. [www.TRB.org, 2007]

2.2.9 Quality of Mass Transit

"While there is some ambiguity surrounding the definition of different rail-based mass transit systems, it is generally understood what makes an LRT an LRT. There has been far greater ambiguity surrounding the notion of what, exactly, constitutes BRT. The lack of a common definition for BRT has caused confusion in discussions about the technology since its inception. However, as a result of a rapidly growing body of experience with BRT, today the international BRT technical community has a much better understanding of the essential elements of a successful BRT than it did a decade ago". [Kubala & Barton, 2003]

The BRT Standard15 was introduced by a committee composed of the world's leading BRT experts in 2010. *The BRT Standard* lays out the essential elements of BRT and provides a framework for system designers, decision makers and the sustainable transport community to implement and identify top-quality BRT. Under *The BRT Standard*, a corridor of a BRT system can be certified as gold-standard, silver-standard, or bronze-standard [Kubala & Barton, 2003] Figure 2.10 below shows Interior of Tramcar and Bus.

Figure 2.10: Interior of AA-Tramcar and Bus

While busways and LRT provide equivalent levels of service in term of travel time and vehicle comfort, busways have an edge in that transfers to and from feeder bus are less likely to be required. BRT is essentially designed to eliminate delays and provide faster service on better vehicles. One of the challenges faced by BRT is the negative stigma potential riders attach to buses regarding their noise, pollution, and quality of ride. [Kuhn, 2013]

A 2008 survey by Center for Science and Environmental and Youth Climate Network recorded that while 83 % of all commuters support the BRT, with major endorsement coming from bus commuters' pedestrians and cyclist, 73% of car and two wheel drivers felt that the project should be continued. A subsequent survey in December 2008 by the students of the Indian Institute of Technology, Delhi, reinforced these finding by showing that 85 % of the bus travel quicker and 90% support the idea of implementing it in other places. [Jain, 2012]

2.3 Summary of Literature Review

Generally, the investment cost of BRT is less than LRT system but there is BRT system which has initial cost near to some LRT system. Even among the BRT system there is great variation. Many BRT systems have initial cost of less than $3 million per km and others have above $10 million per km (Figure. 2.1).

Some transit literature and research indicates that LRT systems are less expensive to operate than bus-based systems. Others have concluded that the opposite is true. One study on six cities in Figure. 2.2 shows that the operation cost of LRT is six times the BRT in Dallas and three or four times in other cities and on San Diego the LRT operation cost is comparable to BRT per vehicle mile.

In terms of directional per hour capacity one research say the LRT has capacity of above 20, 000 pphpd the other paper limit the capacity of LRT around 12,000 pphpd. While one BRT system has attained capacity 45,000 pphpd and few systems have attained above 20,000 pphpd.

Average trip speed of most LRT and BRT system is below 30 km/hr and above 20 km/hr. But there are systems from both MRT which attained upto 40 km/hr average trip speed. As shown in Figure 2.4, the maximum average speed is attained by BRT (80 km/kr) and the lowest is also attained by the BRT (18 km/hr). As shown in Figure 2.5 in Dallas the BRT speed is more than three times LRT, on another city the LRT average speed is greater than BRT or comparable.

As shown in Figure. 2.6 & 2.7 the top ten BRT systems in terms of average daily ridership have great capacity as compared to corresponding LRT systems but the BRT system has long network.

There is general believe that the LRT system has great capacity, high quality and environmental friendly mass transit while bus based system has low capacity, poor quality and pollutant to the environment.

3. Research Methodology

3.1 General

To compare rapid mass transit LRT and BRT options in terms of capital, operation costs, transportation system performance, environmental improvement potential and right-of-way requirements, the resumed methodology is set as follow, first, Related researches which were done before will be reviewed in respect of LRT and BRT. The network along the railway project was examined and data on the rail project were collected from contract documents. To provide equivalent transport services in terms of passenger per direction per hour and quality of service to that of LRT and BRT, system planning and operations in terms of running ways, rolling stock, route configurations, stations, fare collections, and the like are designed for the BRT transport system based on available design manuals.
Considering the above, the economic analysis of the LRT and BRT were conducted based on the costs - benefits identified and compared to find out the better feasible rapid transit. Then comparison of BRT's costs and performance relative to the LRT is examined. Finally, conclusions drawn based on the analysis result and recommendations are also forwarded at the end.

3.2 Data required

The data inputs required for the accomplishment of the thesis were design passenger capacity of LRT system, cost of LRT construction, operation and average speed of the trip, interval of service, capacity of train and cross-section of railway with system length. For BRT system, the required costs of different element of BRT were type of operation bus, bus capacity, performance of bus and traffic count. To evaluate the benefit of the MRT tariff of public transport, emission factor, value of carbon credit and Anbessa bus data were also required. In order to get those data, different data collection methods are employed. The methods of data collection and the overall step of the research are stated in the issuing paragraphs.

3.3 Data collection

3.3.1 Data collection from field survey and observation

Traffic counts were done manually on hourly basis to estimate public passenger demand on selected routes. Data about the performance of existing bus such as loading capacity, average commercial speed and dwell time at station were done directly from field. To understand practicality of the network of the LRT along with design document, field observation was also made on four directions along the route of the LRT. Trips were also taken on LRT to look at trip speed and dwell time at station on the train.

3.3.2 Data Collection from the Design Document.

Secondary data collection involved thorough analysis of contract documents of the LRT to obtain the cost of construction, supervision, design, and operation and maintenance costs. To estimate the cost of bus, depot and Intelligent Transport System (ITS) system and operation of BRT bus and maintenance cost of infrastructure data were collected from previously recorded data and works done related to the topic. To estimate the benefit of MRT from station rent and advertisement on vehicle data were collected from Anbessa city bus; carbon emission and credit data were collected from the ERC- Climate Finance Investment Plan.

3.4 System Cost and Benefit Analysis

Benefit-cost analysis is a method used to evaluate public expenditure decisions. The analysis involves identifying and quantifying all the benefits and costs that will accrue to society. Cost-benefit analysis examines from LRT and BRT that maximizes the net benefit to society from an allocation of resources. This involves estimating a value for benefits to users of the facility, a value for social benefits, and comparing these benefits to project capital, operations, and maintenance costs. Finally, total discounted costs are subtracted from total discounted benefits to calculate the net benefit. The purpose of a cost-benefit analysis is to determine the project alternative that would provide the greatest net benefit to the society, by comparing the monetary value of benefits and costs of each alternative.

The costs of the system include; initial investment, operation and maintenance. The initial costs are distributed in the first three years of implementation and the operation and maintenance cost are distributed throughout the project life of 30 years. The operation and maintenance costs increase from initial year according to traffic growth. Similarly, the initial and operation costs of LRT were estimated from phase I on per km base. The costs of the BRT infrastructure system were estimated from similar works on the city and the operation costs were acquired from the Anbessa city bus.

The benefits of the mass transits includes: travel time saving, carbon credit and vehicle operating cost saving (VOC). Travel time saving cost is calculated from total travel time saving and hourly cost of passenger time. The carbon emission factor and carbon credit saving are estimated from the ERC data. VOC cost savings are estimated from the Anbessa city bus data. The benefits will increase after initial year in proportion to passenger growth.

Benefits and costs often occur at different times over the lifespan of a project and so they must be adjusted according to when they occur. Because many costs usually occur in the early stages of a project, while benefits are spread out over a number of years, discounting is used to bring both costs and benefits to the same year, Due to the time value of money and the value placed on immediate consumption, future benefits and costs are worth less than those incurred immediately. To account for this, future benefits and costs are discounted and then summed to arrive at the present value. A project selection is then made by comparing the present value of the discounted stream of benefits to the present value of the discounted stream of costs. The discount rate is applied to the benefits and costs incurred in each year of the project's life cycle.

The steps in conducting cost/benefit an analysis include the following

1. Determine relevant categories of benefits and costs that will be measured;
2. Analyze changes in travel time savings, emission and vehicle km traveled;
3. Monetize travel activity impacts to estimate benefits and costs;
4. Discount future steam of benefits and costs to present value;
5. Estimate net benefits and cost/benefit ratios;
6. Conduct sensitivity analysis to assess changes in net benefits based on values of key input variables; and
7. Evaluate the economic parameters (NPV, IRR, BCR) and make recommendations

3.5 Comparison of the two systems

Based on present values costs and benefits the economic comparisons were examined based on Net present value, benefit cost ratio, internal rate of return and payback period of the investments. For economic analysis, the national discount rate of 10% is considered for infrastructure projects according to ERA. The research conducted a risk analysis by altering the values of key variables such as initial cost, fare revenue and operation cost.

The LRT and the BRT transportation systems performance such as average speed of trip, frequency of service, capacity, the potential to afford environmental improvement and right-of-way advantage were compared based on the outcomes.

Finally, conclusion and recommendation were drawn based on the outcome of the result for the two mass transit system options.

$$NPV = \frac{B_0 - C_0}{(1+i)^0} + \frac{B_1 - C_1}{(1+i)^1} + \ldots + \frac{B_T - C_T}{(1+i)^T}$$

Where: NPV= net present value, t = year, B = benefits, C = cost, i=discount rate.

$$B/C = \left[\frac{B_0}{(1+i)^0} + \ldots + \frac{B_T}{(1+i)^T}\right] \div \left[\frac{C_0}{(1+i)^0} + \ldots + \frac{C_T}{(1+i)^T}\right]$$

Where: B/C = Benefit to Cost ratio, t = year, B = benefits, C = cost, i=discount rate.

The main actions that will be carried out during the study are summarized in Figure 3.1.

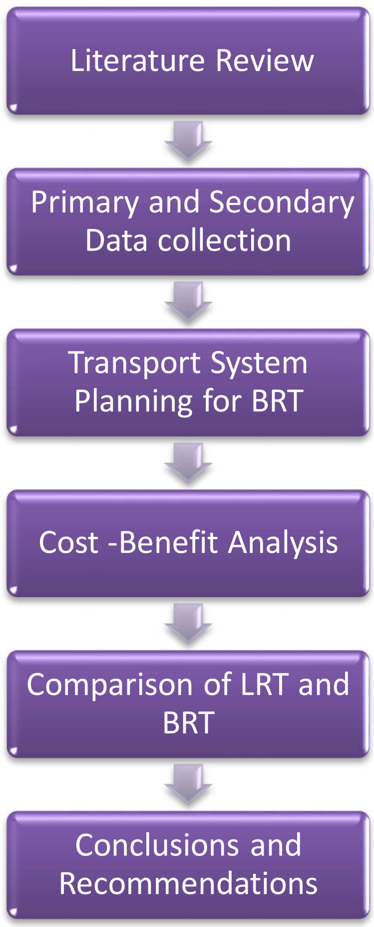


Figure 3.1: Research Methodology

4. Addis Ababa Light Rail Transit (AA-LRT) and BRT

4.1 Addis Ababa Light Rail Transit (AA-LRT)

4.1.1 General

To solve the problem of urban transportation, that of the downtown area, the government of Ethiopia decided to build a light rail in the city of Addis Ababa. The Addis Ababa Light Rail Transit (AA-LRT) Project consists of E-W & N-S lines, with the total length of 31.025 km. These two lines operate on the same rail in downtown area for a total length of 2.662 km. The ground line mode is mostly applied in rail laying for 22 km, while elevated line of 8km and underground line of 1km are also applied in some sections.

The entire line has 39 stations, consisting of 9 elevated stations (including 5 in the section that uses the same rail, 1 on E-W line, and 3 on S-N line), 2 underground stations, 1 semi-underground, and the rest are all ground stations. [15][16] Figure 4.1 below shows AA- LRT network and future connections.

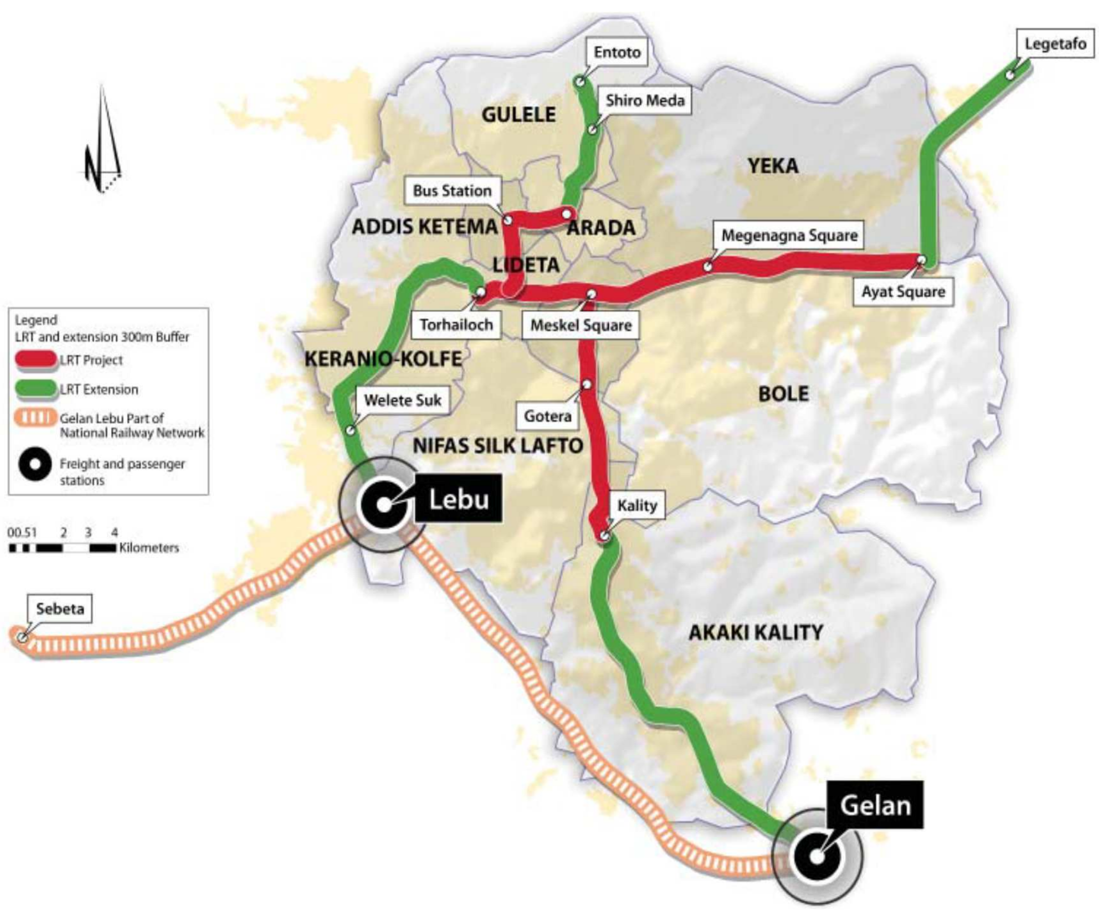


Figure 4.1: AA LRT network and Future Connections
Source: ERC, 2012

Phase I East-West (E-W) line project starts from Ayat and ends at Torhailoch with a length of 17.4 km. There are 22 stations, among which 6 are elevated stations, 1 underground station and 15 ground stations. The depot is located at the West ends of the project. The control center is temporarily considered to be placed inside the depot.

Phase I South-North(S-N) line phase I project starts from Menelik II Square and ends at Kaliti. The total length is 16.97 km. There are 22 stations, among which 8 are elevated stations （5 common stations at the common line, 2 underground station and 12 ground stations. The depot located at the south end of the project. The control center (commonly used by both lines） is considered to be placed inside the parking yard at Southern end (Kality).

4.1.2 Design and Construction of LRT

The design and construction of the Light Rail Transit project is awarded to the China Railways Engineering Corporation (CREC) and the supervision contract is also given originally to Swedish National Road Consulting AB (SWEROAD), work covers all systems of the East-West and North-South line, which mainly includes: rolling stock, marshalling, passenger flow forecast, route, clearance limit, track, station construction, subgrade structure, elevated structure, underground structure, power supply, communication, signal, automatic fare collection, ventilation and air condition, water supply and drainage and firefighting, depot, control center, environmental protection and cost estimate.

Figure 4.2 Light Railways Transit of Addis Ababa

4.1.2.1 Traffic Forecasting

According to Line E-W construction plan, the forecasting scope is from Sebeta station to Legetafo station with the total length of 37.75 km. The section from Ayat to Torhailoch is the first phase of this project. For the Line N-S planned alignment, the forecasting scope is from Shiromeda station to Akaki Campus station with the total length of 36 km.

One-day and peak hour passenger flow forecast of each rail section in Lines E-W and N-S are as shown in table 4.1:

No	Section	Unidirectional Passenger Flow Forecast (Persons/day)		
		Initial Stage 2014	Short-Term 2021	Long-Term 2036
E - west Line	Sebeta-Jimma JCT		6,069.0	9,962.0
	Jimma JCT-Torhailoch		11,631.0	19,092.0
	Torhailoch-Lideta Light	15,885.0	29,031.0	47,646.0
	Lideta Light-La Gare	38,462.0	70,308.0	115,385.0
	La Gare-Adwa Square	19,262.0	35,208.0	57,777.0
	Adwa Square-CMC	7,031.0	12,846.0	21,085.0
	CMC-Ayat	5,531.0	10,115.0	16,600.0
	Ayat-Legetafo		5,062.0	8,300.0
S-North Line	Shiromeda-Menellk ll Square		12138	19923
	Menellk ll Square-Merkato	11623	21246	34862
	Merkato-Lideta Light	13008	23777	39015
	La Gare-Gotera	17708	32369	53123
	Gotera-Kallti	16323	29846	48977
	Kallti-Akaki		12646	20754
	Akaki-Akaki Campus		5562	9131
	Total passenger /day/direction	144,833.0	264,746.0	434,470.0
	Total passenger /day/both direction	289,666.0	529,492.0	868,940.0

Table 4.1 One-Day Unidirectional Passenger Flow Forecast Unit:
Source: China Railway Group Ltd (2009). Addis Ababa LRT Project: Project Study Report.

It is estimated that the maximum unidirectional section passenger flow of Line E-W in peak hours will take place on the road section from Lideta to La Gare shared with Line N-S. The total unidirectional section passenger flows in initial stage, short-term and long-term are 38,462 persons/day, 70,308 persons/day and 115,385 persons/day respectively. The maximum passenger flows of initial stage, short-term and long-term in peak hours are 5,000 persons/hour, 9,140 persons/hour and 15,000 persons/hour/direction respectively. [Project Study

Report, 2009]. Table 4.2 below shows Unidirectional Passenger Flow Forecast in Peak Hours based on traffic growth rate of 9% up to 2021 and 4% growth rate after 2021.

No	Section	Unidirectional Passenger Flow Forecast (Persons/h)		
		Initial Stage 2014	Short-Term 2021	Long-Term 2036
	Sebeta～Jimma JCT		789.0	1,295.0
	Jimma JCT～Torhailoch		1,512.0	2,482.0
	Torhailoch～Lideta Light	2,065.0	3,774.0	6,194.0
	Lideta Light～La Gare	5,000.0	9,140.0	15,000.0
	La Gare～Adwa Square	2,504.0	4,577.0	7,511.0
	Adwa Square～CMC	914.0	1,670.0	2,741.0
	CMC～Ayat	719.0	1,315.0	2,158.0
	Ayat～Legetafo		658.0	1,079.0
	Shiromeda～Menellk ll Square		1578.0	2590.0
	Menellk ll Square～Merkato	1511.0	2762.0	4532.0
	Merkato～Lideta Light	1691.0	3091.0	5072.0
	La Gare～Gotera	2302.0	4208.0	6906.0
	Gotera～Kallti	2122.0	3880.0	6367.0
	Kallti～Akaki		1644.0	2698.0
	Akaki～Akaki Campus		723.0	1187.0

Table 4.2: Unidirectional Passenger Flow Forecast in Peak Hours Unit.
Source: Addis Ababa LRT Project Study Report. China Railway Group Ltd (2009)

4.1.2.2 Ground, Elevated & Underground Section of the Railway

E-W route has the total length of 17.4 km, about 14 km of which are occupied by ground section, and the length of elevated section is about 3 km and the rest are underground section. The total length of the grade sections is 14.1461 m, which account for 81.3% of the full length. N-S route has the total length of 16.970 km; the length of underground structure is 700 m, which occupies 5% of the full line and about 5 km of which are elevated section. Around 2.7 km of the elevated section is shared by both routes. [AA-LRT Project Study Report, 2009]. Figure 4.3 below shows Elevated and Underpass section of the railway.

Figure 4.3: Elevated and Underpass Section of the Railway.

4.1.3 LRT Stations

Twenty-two LRT stations are placed along Phase One of E-W route project, five of which are shared with N-S route. Average interval between two adjacent stations is 0.815 km. The longest interval is 1.210 km and the shortest interval is 0.525 km. Five of the 22 E-W stations are elevated shared with N-S route, 1 of which is underground station. The rest 16 stations are ground stations.

E-W & N-S lines are 31.025 km long, and the ground laying mode is mostly applied. Ground stations are designed on ground line section, including 27 ground stations along the line (13 ground stations on N-S line, and 14 ground stations on E-W line). The light rail lines are laid along the center of the road; ground stations are designed into the ones with side platforms; the stations are set in the road center along the light rail line, and the clear width of station platform is 2.5m and length is 60 m.

Overpasses to rail station are constructed on both sides of each elevated station. For the sake of investment cost, pedestrian overpass is not considered on the ground section; the passengers cross the street directly on ground at zebra crossing. The escalators for the disabled people are being equipped from the ground to both sides of platform in underground stations and elevated stations. At Both ends of ground station platform built ramps for the disabled people. Figure 4.4 shows AA - LRT station.

Figure 4.4: Stations of AA - LRT

4.1.4 Ticketing System

The Addis Ababa LRT will use combined method of fare collection such as manual fare collection (ticketing) and electronics card system.

The electronics card system adopts contactless card technique and rechargeable card. This system adopts metered ticket and timing ticket. Ticket system adopts fare collection and manual fare collection. The center computer system for fare collection installed route should be responsible for the whole line ticket management. [AA-LRT Project Study Report, 2009]

The tramcar for E-W route of the Addis Ababa LRT has 4 doors each side. Passengers should be onboard and alighting on one side of the tramcar in the station. And the rechargeable cards should be read by card readers near the doors at both ends of the tramcar after passengers got onboard. The card reader records the time and place for the passenger. When passengers are to get off the tramcar, the rechargeable cards should be read near the two middle doors. The card reader can charge the passenger according to ridership distance and time. [AA-LRT Project Study Report, 2009]

4.1.5 Depot and Integrated Base

Based on the route network plan, one rolling stock base shall be set up for East-West Line. Combining with the step-by-step construction plan, one rolling stock base shall be set up in order to satisfy the requirement of operation and inspection and repairing of the train. Rolling stock base have been be set up near the EW21 station of East-West Line. The rolling stock base shall serve the whole LRT system as the guarantee of using, inspection and repairing, material as well as logistic of the rail transport system. [AA-LRT Project Study Report, 2009].

4.1.6 Operation Control Center

Operation control center is the place to comprehensively manage the LRT. It is able to monitor, schedule and make command to train travelling, power supply system operation, to comprehensively maintain electromechanical equipment, and to train operators. In special cases it is also commanding center to handle special events. Therefore, operation control center is eventually the communication hub, information exchange and dealing center for the whole line of LRT.

In order to realize unified coordination and commanding and the share of human resource and equipment among LRT lines, it is suggested that E-W route and N-S route share the same operation control center. Based on LRT project characteristics, it is suggested that operation control center be set up in either E-W route depot or N-S route depot in order to facilitate the construction of operation center and the introduction of different equipment. This scheme temporarily determines to place the operation control center into E-W route depot. This operation control center can also make reservation for other route in the future in Addis Ababa. [AA-LRT Project Study Report, 2009]

4.1.7 Rolling Stocks

The vehicles for LRT are operated in two directions, and are 6-axle double-articulated 70% low-floor Light Rail tramcar. The proposed rolling stocks are estimated to be used for 30 years. Each modular articulated tramcar with 6-axles has four doors along the carriage. The doors are electric sliding doors. The effective opening of the door is 1.2 m and its effective height is about 1.8 m. [AA-LRT Vehicle Specification CRGL, 2013]. Figures 4.5 below shows the AA - LRT tram car.

Figure 4.5 AA-LRT Tramcar

4.1.7.1 Tramcar Performance

- The Highest Speed: 80 Km/h
- Average Travelling Speed: 18 km/h
- Weight of Tramcar: 44t (empty)
- Rated passenger capacity (59.24t),
- Overload capacity (63.02t), Axle load ≤11（1+3%）t
- Load: axis weight of the tramcar is not more than 11 tons
- The total length of one unit marshalling of the train is about29 meters
- Tramcar Body Width: 2650 mm
- The Distance between Floor and Track Top: 365 mm
- Platform Height （to the track top）: 380mm

4.1.7.2 Loading Capacity

1、Seats: 65

2、Rated Passengers: 6 persons/m^2, 254 persons in one tramcar in total. [AA-LRT Vehicle Specification CRGL, 2013]

The number of rail cars included on the contract document is 41 and the cost of one rail car is 2.6 million USD in 2009, the total amount to 103.3 million.

4.1.8 Design and Construction Cost of LRT

Table 4.3 below shows the design and construction cost of LRT

Item No.	Work Items Description	Contract Amount (USD 2009)	Contract Amount (USD 2012)
1	Temporary facilities construction	12,591,943.98	
2	Station	30,339,884.33	
3	Section	186,873,654.19	
4	Track work	39,125,294.72	
5	Communication and signal system	16,323,948.68	1$2009=1.07$2012*
6	Power supply	41,058,248.41	
7	Ventilation and AC system	811,792.97	
8	Water supply and drainage, Fire protection	2,246,498.64	
9	Escalator and Elevator	9,500,894.33	1$2012=17.777 birr
10	Ticketing System	1,665,933.35	
11	Depot and integrated Base	27,937,316.07	
12	Rolling Stock (41)	106,524,589.50	
Total Contract Amount		**475,000,000.0**	**508,250,000.0**
Total Contract Amount (2012 birr)			**9,035,160,250.0 birr**
Supervision cost			**101,098,456.8 birr**
Total Cost (2012 Birr)			**9,136,258,706.8 birr**
Total Cost/km(2012 birr)			**294,718,022.80**
Total Cost/km (2012 USD)			**16.58 million**

*** US Bureau of labor statistics**

Table 4.3 Design and Construction Cost of LRT (the project is duty- free)

Source: - Project Contract document (ERC)

4.1.9 Operation and Maintenance of the LRT Project

The operating cost is that arising from the day-to-day operation of rail transit. This cost includes maintenance, operator and administrative salaries, power, materials and supplies.

The operation and maintenance works are also given for two companies which perform the following activities during the contract period.
Operation and management of the whole system and training of local staff, to deploy its executive management for four years to provide technical assistance for the LRT system management by Ethiopian managers after handover. The cost of technical assistance for the seven months in the 4th year (seven) months after completion of the 41 months contract period is also included in the contract price. Table 4.4 shows Operation and Maintenance cost summery of AA-LRT for the contract period.

Operation and Maintenance cost	2015	2016-2018	2015-2018	
In 2014 USD	19,831,919	105,046,125	124,878,045	
In 2012 USD	19,235,615	101,887,610	121,123,225	
In 2012 Birr	341,951,528	1,811,256,036	2,153,207,564	
For each year (birr)	341,951,528	603,752,012		
Per train/year in 2012 USD		828,354.55		
Per train/year in 2012 birr		14,725,658.8		

Table 4.4 Operation and Maintenance Cost Summary
Source: - Operation and Maintenance of Addis Ababa LRT Contract Document (ERC)

4.1.9.1 Operation Indices

Table 4.5 below presents the AA- LRT operation summary Indices.

Indices		E-W Initial Stage 2015	E-W Long-Term 2036	S-N Initial Stage 2015	S-N Long-Term 2036
Operation Length （km）		17.1	37.7	16.8	36
Type		75% at grade		60% at grade	
Design Average speed (km/Hr)		18		18	
Total cycle time (min)		114		112	
Tramcar Marshalling (Unit)		1	2	1	2
Rated Passengers (6p/m2)Persons/tramcar)*		254	508	254	508
Number of Station		22		22	
Average distance between station (km)		0.8		0.8	
Operated Trains in Peak Hours (couple/hour/direction）	Shared-rail Section	20	30	20	30
	Other sections	10	15	10	15
Minimum Travelling Interval （Minutes）	Shared-rail Section	3	2	3	2
	Other sections	6	4	6	4
Capacity thousand passengers/hour/direction)	Shared-rail Section	5.08	15.24	5.08	15.24
	Other sections	2.54	7.62	2.54	7.62
Train Allocation (train)	Operated Tramcars	19	59	18	56
	Spare Tramcar and Maintenance Tramcar	2	6	2	6
	Total	21	65	20	62

Table 4.5: LRT Operation summary

Source: Conceptual design report, 2009

* Project Technical Specifications of Vehicles, 2013

4.1.10 Tunis LRT

Similar project in Africa which is found in many literatures with full information is the Tunis LRT in Tunisia presented below for comparison.

The Tunis LRT, 5 lines network, 31 km in total length at grade ROW type (200 m tunnel only), a 121 vehicles fleet, has a cost of 19.77 Million USD in 2012 per km. Table 4.6 below presents LRT data comparison between Tunis LRT and AA – LRT.

Parameter	Tunis	Addis Ababa
Year of operation	1998	2015
Type	At grade Shared ROW only 200m tunnel	72 % at grade, 25% Elevated 3% underground
Route Length	31	31
No. stop	10	39
Average Station Spacing (km)	2.97	0.8
Fare (US$) one way trip	1.5	0.43
Avg. speed km/hr	20	18
Ridership/day	268,000	160,000
Capital Cost(2012 Million US$)	613	508
Cost per Km (2012 Million US $)	19.77	16.58
Operation cost per veh-km (2012 US $)	3.52	

Table 4.6: LRT in Different City
Sources: AA-LRT Project Study Report, 2009 & Jain 2012

4.2 Bus Rapid Transit (BRT)

4.2.1 Definition of BRT

As defined by Levinson et al., in 2003, Bus Rapid Transit (BRT) is "a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and Intelligent Transportation System (ITS) elements into an integrated system with a strong positive identity that evokes a unique image."

As defined by Thomas, 2001, "BRT is high-quality, customer-orientated transit that delivers fast, comfortable and cost effective urban mobility." (Wright, 2003) BRT is "a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses".

The USA 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."

A high-quality bus service with similar performance of a subway but at a fraction of the cost (Cervero, 1998). In terms of service quality and costs, then, BRT is often thought of as occupying the middle ground between urban rail and traditional bus systems. In ways, it offers the best of both worlds: the speed and reliability of rail, and the operating flexibility and lower cost of a conventional bus (Deng and Nelson, 2011).

New York-based Institute of Transportation & Development Policy (ITDP), which has emerged as one of the technology's strongest proponents, defines BRT as "a high-quality bus-based transit system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service" (Wright and Hook, 2007).

BRT systems are currently being added at a geometric rate, gaining particular favor in the developing world, following on the heels of widely publicized BRT successes in Curitiba, Bogotá, Mexico City, Istanbul, Ahmedabad, and Guangzhou. (Cervero, 2013)

4.2.2 Elements of BRT

As stated by Transportation Research Board. The following sections present the major elements of a BRT system such as bus ways, stations, vehicles, fare collection and intelligent transportation systems.

4.2.2.1 Running Way

Busways are separated roadway facilities for the exclusive use of buses, either within an overall roadway right-of-way or in a separate right-of-way. Busways especially when off-street and grade-separated are the most effective BRT running way option in terms of operating speed, service reliability, and BRT identity.

BRT services operate across four different lane configurations as provided by TRB:
(1) Running in mixed traffic with signal priority at intersections
(2) Operating in dedicated shoulder or curb lanes
(3) Running in dedicated median lanes and
(4) Using exclusive bus lanes, also called busways.

Mixed traffic systems are the slowest. Those using dedicated shoulders or curb lanes typically rely on markers and physical barriers to separate regular traffic from BRT buses.

Running ways impact the travel speeds, reliability and identity of a transit system. In the case of a BRT system, options range from mixed traffic lanes to fully grade separated BRT transit ways. Signal priority is often used in conjunction with BRT running ways in order to further improve BRT operation. Different types of running ways can be used along different segments of a BRT corridor depending on right-of-way costs and other factors. This flexibility is one of the characteristics that make BRT such an attractive transit alternative.

The most common type of running way which provides reliability and travel time savings for BRT systems is the designated lane. This type of running way provides BRT with a separate lane over a long distance which it typically shares with high occupancy and emergency vehicles. Designated lanes allow the BRT to move faster and more reliably along the corridor. Parking lanes and shoulders are typically used or converted to designated lanes.

Transit ways can either be at-grade or grade-separated. Either way they are designed to physically separate BRT from general traffic and are often restricted to the exclusive use of BRT vehicles. Transit ways are typically located in the median or adjacent to general traffic roadways. Transit ways allow BRT to move freely along the corridor providing the most reliable service and avoiding most traffic delays. Transit ways represent the most costly BRT running way alternative. Figure 4.6 below shows dedicated median BRT running way.

Figure 4.6 Dedicated median BRT running way.
Source: WRI EMBARQ, 2014

4.2.2.2 Stations

Bus Stations form the interface between the BRT system and passengers. They are also locations where the brand identity that distinguishes the BRT system from other public transit services while integrating with and enhancing the surrounding urban environment.

BRT systems have limited number of stops and the number of customers using each BRT station will be higher than would be the case for a typical local bus line. Accordingly, BRT stations are more significant than a sign on a pole as is typically the case for conventional local bus services. They range from simple stops with basic shelters to complex intermodal terminals with amenities such as real time passenger information, coffee bars, parking, pass/ticket sales and level boarding.

As explained by Transportation Research Board Stations have five primary characteristics:

Station Type – There are different BRT station types, in increasing size and complexity: simple stop, enhanced stop, designated station, and intermodal transit center. BRT stations can be designed to convey a brand identity that distinguishes the BRT system from other public transit services, while integrating with the local environment. The BRT station adopted the LRT Enhanced stations which include enhanced shelters, to provide additional features such as more weather protection and lighting. This BRT station type incorporates additional design treatments such as walls made of glass or other transparent material, high quality material finishes.

Enhanced stop Designated station [8]

Figure 4.7 BRT Stations

Source: WRI EMBARQ, 2014

Platform Layout and Height – Platform layout, which describes the length and extent of width assignment, is a major element of station design. It affects how many vehicles can simultaneously stop at station and how passengers must position themselves along a platform to board a given service**.** For BRT the station length is 40mx3m to accommodate two 18m articulated bus for all stations except at elevated section the width can be from 3-2.5m and the length can up to 50m. Passengers on city bus service board vehicles by stepping from a low curb up to the first step on the vehicle, then climbing additional steps. Adoption of low-floor vehicles make boarding and alighting easier for all passengers. Platforms at the same height as vehicle floors can enhance customer experience and reduce dwell times if some approach to providing no-gap, no-step boarding and alighting is adopted through provision of drop ramps or precision vehicle docking. To create the safest, easiest, and efficient manner of customer boarding and alighting, platforms level with BRT vehicle floors (approximately 40cm above the pavement for low floor vehicles) are the preferred station platform treatment. Level station platform boarding and alighting platforms enhances the customers traveling experience by creating smooth transition between station and vehicle.

Passing Capability – When service on a bus way is so dense that vehicles operate in quick succession, the ability of vehicles to pass each other can maximize speed and reduce delay, especially at stations. Passing lanes at station stops are critical to allow both express and local services. They also allow stations to accommodate a high volume of buses without getting congested with buses backed up waiting to enter. While more difficult to justify in low-demand systems, passing lanes are a good investment, yielding considerable passenger travel-time savings and allowing for flexibility as the system grows. Passing capability can be accommodated through a number of means including multiple lanes or passing lanes at stations. For BRT system passing lane is provided on the ground section.

The cost of the station for BRT is taken as 2/3 of the AA-LRT station since the proportion of length of BRT station is 2/3 LRT (40/60).

Access to Bus Stop – Station access describes how the passengers get into the bus stop. Pedestrian can access to bus stops on surface crossing which is controlled by at grade zebra crossings or grade separated crossings (under pass tunnel/ over Pass Bridge). The type of parking facility and the number of spaces should be tied to the nature of the market that the station serves and the adjacent physical environment. Station is accessed to the passenger at grade on the ground section and by Overpass Bridge on the elevated section.

4.2.2.3 Vehicles

BRT vehicles have important bearing on speed, capacity, ridership attraction, system performance, environmental effect and comfort. BRT vehicles are also the element of BRT that most passengers and non-customers associate with the BRT system's identity. As the BRT element in which rider ships spend the most time, passengers derive much of their impression of the BRT system from their experience with vehicles. For non-passengers, vehicles and station are the system elements that are most visible.

As mentioned by Transportation Research Board, four main characteristics define BRT vehicles:

- **Vehicle Configuration** – The basic configuration of BRT vehicles is a function of the combination of size, floor height, and body type. Transit vehicles in the Ethiopia have traditionally been high-floor vehicles with steps. Vehicles in the city range from high - floor two-axle 12m to three-axle 18m articulated buses. Conventional Articulated 18m longer, bus have be selected for BRT with passenger carrying capacity of 160 passengers (4 person /meter square) based on local experience.

- **Aesthetic –** Vehicles should have strong passenger appeal and should be environmentally friendly, easy to access, and comfortable. Desirable features include air conditioning, bright lighting, large windows, and real-time passenger information. Aesthetic treatments, including also paint schemes and styling options affecting the appearance and configuration of the vehicle body contribute to BRT system identity.

- **Passenger board and alight Enhancement** – Enhancements can be added to vehicles in order to facilitate circulation to board and alight. These include the provision of wider door channels on both side of the vehicle. Vehicles should be Low floor heights of 30cm or less above the pavement are desirable Sufficient passenger circulation space on buses can lower dwell times and allow better distribution of passengers within the bus. Seating arrangements, floor height, and door configuration impact dwell time at stations, BRT travel time and passenger comfort.

- **Propulsion** – Propulsion systems determine the acceleration, maximum speed, fuel consumption and emissions characteristics of BRT vehicles. They also affect the noise and smoothness of operation and have impact on over-all BRT system revenue, service times, emissions, and operating and maintenance costs. Diesel buses currently used in city bus operations. Internal Combustion Engines Euro diesel III is selected for its low cost and ease of operation rather than Trolley buses.

Figure 4.8 Sample of BRT Bus
Source: Huang, King Long

4.2.2.4 Fare Collection

Fare Collection forms an important influence on the design of the passenger facilities within the BRT station. Fare collection systems for BRT can be electronic, mechanical, or manual. Fare payment has a large influence on dwell time and speed of service. Fares may be collected in a number of ways, either on or off the vehicle at each transit station. Off board fare collection policy reduces the dwell time at bus stations and enables rapid boarding and lighting. The use of more advanced payment methods such as electronic smart cards increases boarding speed and can contribute to a considerable decrease in dwell time. Factors include fare policies, fare collection practices, and payment media.

Characteristics of Fare Collection as explained by Transportation Research Board.

- **Fare Collection Process** - refers to the use of different devices to validate payment; these can be on-board or off-board the vehicle depending on the BRT design. The fare collection process is how the fare is physically paid, processed, and verified. It can influence a number of system characteristics including service times, fare evasion and enforcement procedures, operating costs, and capital costs.

- **Fare Media** - Fare media are the type of payments that are accepted, such as passes, cash, prepaid tickets, or smart cards. The fare media helps to process transactions associated with a given fare collection process. The choice of fare transaction media includes the instruments associated with the selected equipment, technologies, and fare collection processes.

The choice and design of fare media can also influence the service times, auxiliary uses, as well as the capital and operating costs of the fare collection system. The fare media both smart card and ticketing system will be used.

- **Fare Structure** – Fare structure refers to the system wide structure for fare collection, such as using one payment valid for the entire trip, charging by distance traveled, or providing free transfers. BRT fare structures greatly influence the choice of fare processes and technologies. Transit agencies may consider a number of design factors including their size, network, organization, customer base, as well as financial and management-related variables. The two basic types of fare structures flat fares and differentiated fares.

4.2.2.5 Intelligent Transportation Systems (ITS)

ITS is a variety of advanced technologies to collect, process and disseminate real-time data from vehicle and roadway sensors. The data are transmitted via a dedicated communications network and computing intelligence is used to transform these data into useful information for the operating agency, driver and ultimately the customer.

Combinations of technologies form different types of ITS systems. For example, automatic Vehicle Location (AVL) in combination with Automated Scheduling and Dispatch (ASD) and Transit Signal Priority (TSP) can improve schedule adherence and hence reliability as well as revenue speed.

Intelligent Transportation Systems (ITS) have increased: safety, operational efficiency and quality of service. The remote monitoring of transit vehicle location, status and passenger activity also improves passenger safety and security. ITS also can be used to assist operators in maintaining vehicle fleets.

Characteristics of ITS as explained by Transportation Research Board.

There are many technologies and operational features that can be utilized for BRT systems. The various ITS applications that can be integrated into BRT systems are discussed below such as:

- Vehicle Prioritization
- Assist and Automation Technology
- Operations Management
- Passenger Information
- Safety & Security

Vehicle Prioritization

This technology group includes methods to provide priority to BRT services. The goal is not only to reduce the overall traffic signal delays (thus greater operating speed and shortened travel time) of in-service transit vehicles, but also to achieve greater schedule adherence and consistency (thus enhanced reliability and shorter waiting times). Signal Timing / Phasing and Signal Priority help BRT vehicles minimize delay caused by having to stop for traffic at intersections.

Driver Assist and Automation Technology

Automation and driver assist systems include components such as vehicle collision warning systems, precision docking assistance, and vehicle guidance systems. Guidance systems can be used either throughout a bus route or only when the bus approaches a station. The guidance systems can be physical, optical, or electronic. Physical systems use a guide way that may connect to the bus through guide-wheels or guide-rail, in which case the driver only needs to control acceleration and braking. Optical systems use painted stripes on the road to control lateral distances and guide the bus forward. Electronic control systems can fully automate the control of the bus through differential GPS and magnetic markers. All assist and automation technologies help to reduce frequency and severity of crashes and collisions and reduced running and station dwell times.

Operations Management Technology

Use of Automated Scheduling Dispatch System and a Vehicle Tracking method assists BRT management to best utilize the BRT vehicles. Use of Vehicle Mechanical Monitoring and Maintenance assists in minimizing downtime of the BRT vehicles. AVL technology is used to track the location of vehicles in real time through the use of GPS devices. Information about the vehicle location is transmitted to a centralized control center. All Operations Management functions improve operating efficiencies, supporting a reliable service and reduced travel times.

Passenger Information

Passenger Information technologies rely on a communication system that is able to track individual vehicles, transmit vehicle location data to a central processing center and disseminating processed vehicle data to the transit customer. For BRT systems, information about the vehicle schedule can be provided to the transit customer at the station or on the vehicle.

Safety and Security Technology

The typical technologies used for transit safety and security include alarms, closed-circuit television (CCTV) systems, call boxes, vehicle monitoring systems, pager systems, and driver assist technologies such as rear- or side-view cameras.

5. Comparative Analysis of LRT & BRT on the Envisaged Expansion of LRT

5.1 Route of LRT

The future LRT expansion has a length of 20 km along E-W line and on S-N route also has additional length of 20 km. The route map of AA-LRT project is shown in Figure 5.1.

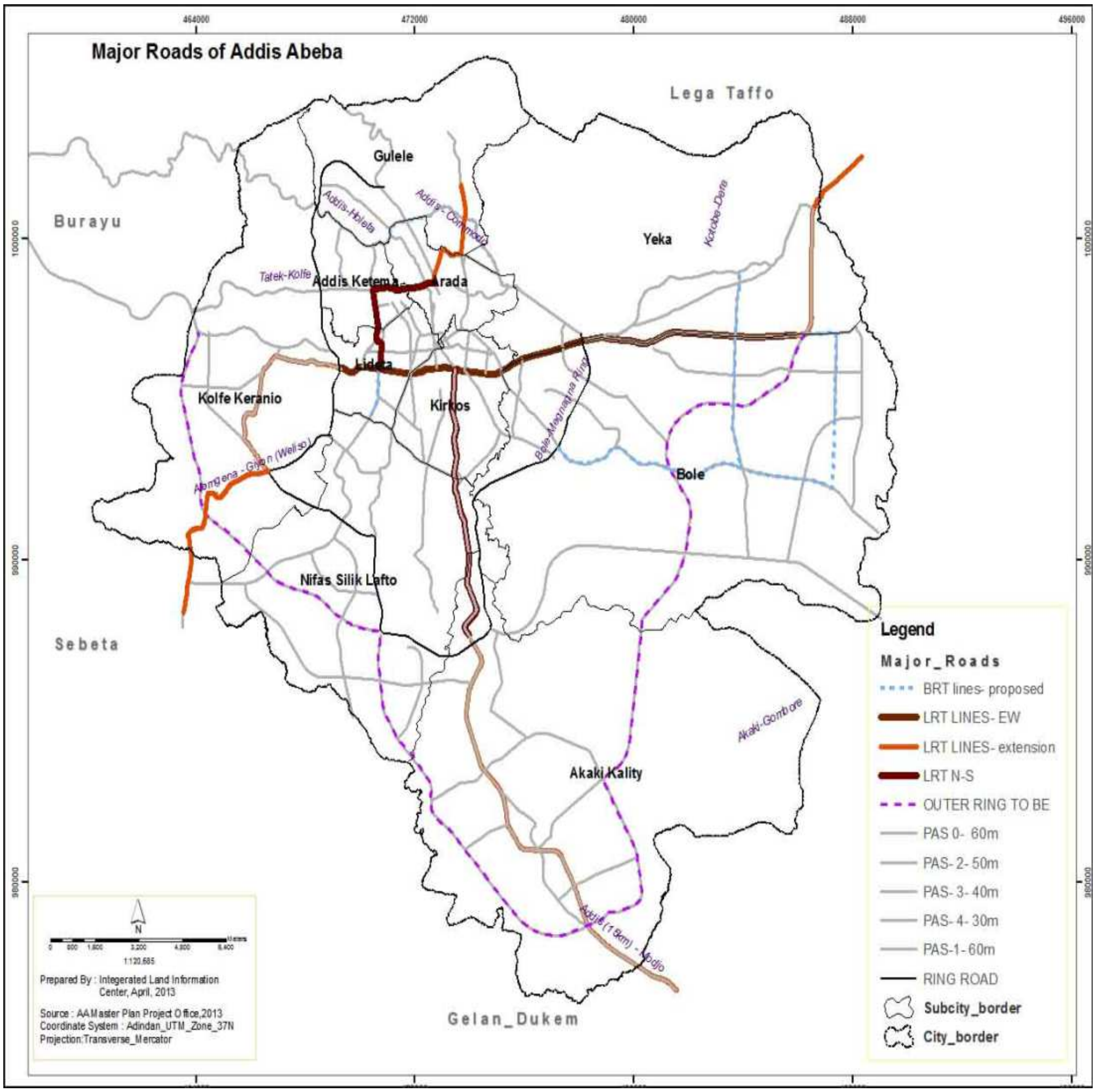


Figure 5.1: Route Map of LRT (ERC)
Source: Ethiopia Railways Corporation

The Phase I project has gone enough length for more than 10 km in two directions i.e on East (Ayat) and South (Kality) ends but on Western (Torhailoch) and Northen (Sheromeda) ends, it runs for less than 3 km from the Central business district, but does not have enough coverage on the western and northern direction, even if there is currently enough passengers for mass transport on both sides and shortage of public transport. According to the Anbesa City bus data, the highest number of passenger demand is on route from Sheromeda to Leghare and the second highest is from Piassa to Ayertena. Especially the route from Torhailoch to Jimma JCT is found on the highest populated sub-city according to population statistic of the city as shown in Figure 5.2. Ayer Tena identified is as one of the major strategic site not implemented.

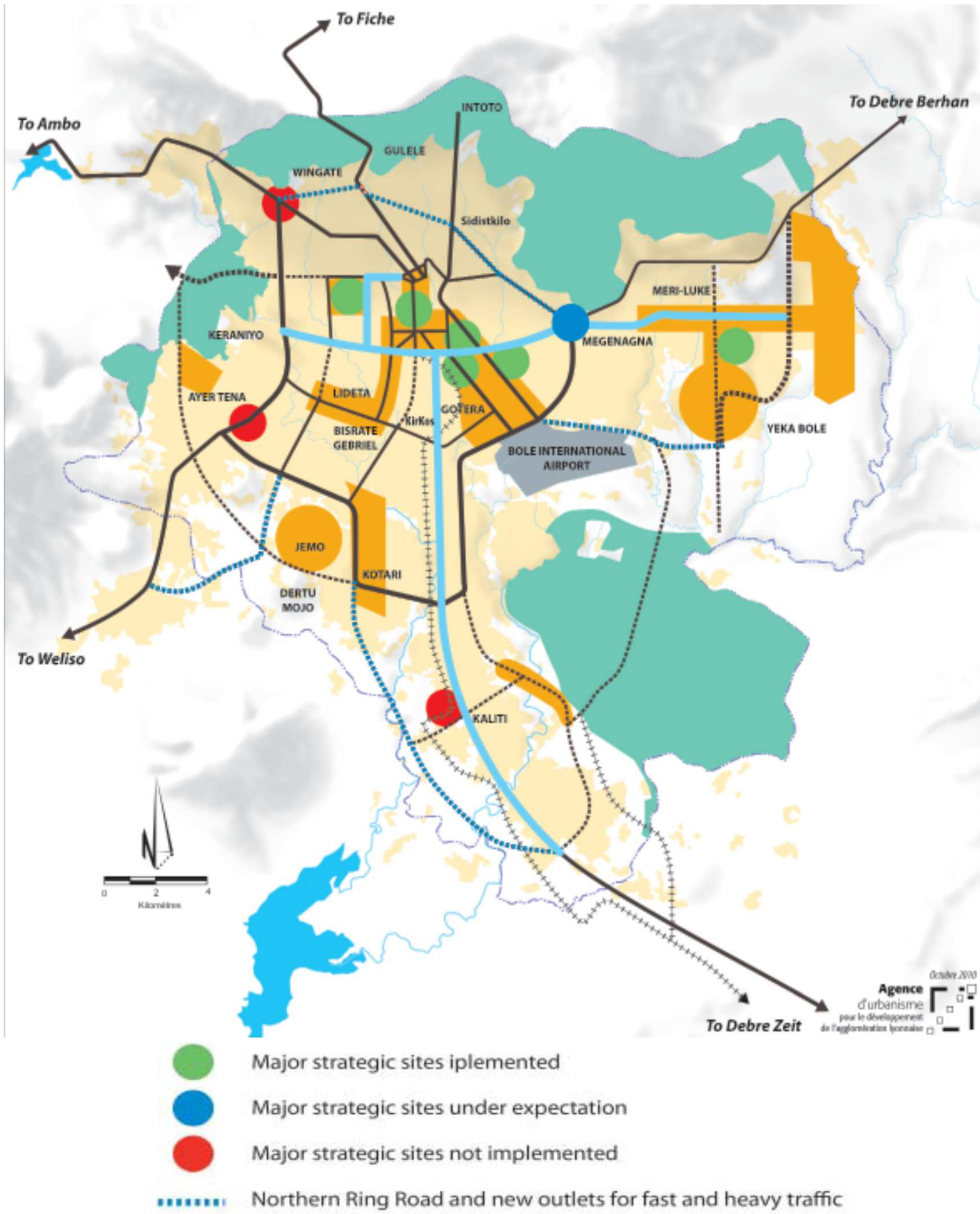


Figure 5.2: Project Location Map

Source: From Addis Ababa City Development Plan (2000-2012)

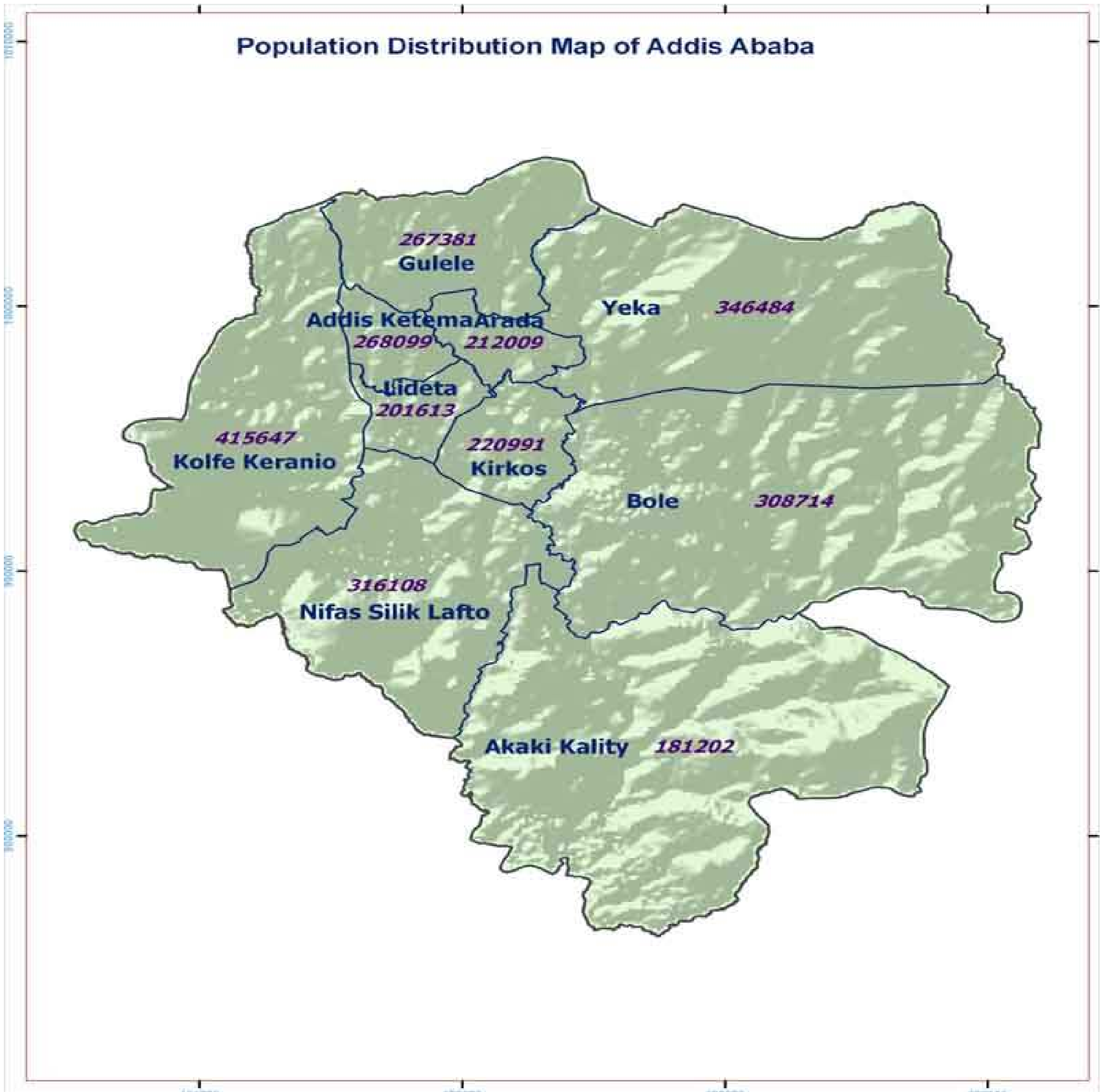


Figure 5.3: Population Distribution Map of Addis Ababa
Source: Central Statistical Agency (CSA, 2007)

As shown in Figure 5.2 and 5.3, the project is located along high population density area and is identified as a strategic site. According to traffic survey data their exist enough public passengers on the route; thus, alterative form of mass transport were analyzed and compared on western end along Torhailoch- Ayertena - Jimma JCT route with length of 12km.

5.2 Traffic Count

Traffic count was done on the route for seven days for mass transit from 04/05/2015 to 10/05/2015 at midpoint of the route at Ayer Tena. The traffic count was done on hourly based manually from 6am to 10pm and for five weekdays. The maximum was observed on Monday as shown in Table 5.1 and the peak traffic is also from 7:30-8:30Am. On Saturday, 70% of weekday traffic was observed, on Sundays and Holidays, 50% of the weekday was observed according to the traffic count and is presented in Appendix–I.

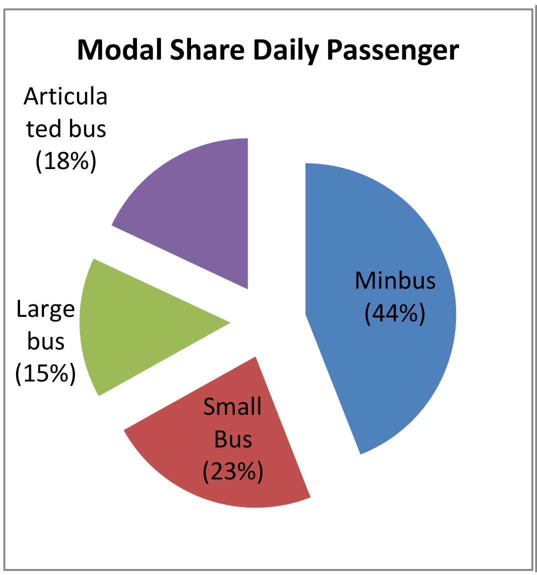
Current Demand: Daily public Passenger Flow uni- direction (6am – 10pm).

Weekday maximum daily uni - direction passenger traffic on Torhailoch -Jimma Jct from 6am-10pm

No	Vehicle	No. of vehicle	Passenger capacity /Veh	Average load Factor	Total Passenger	Peak hour traffic	
1	Minibus	3132	12	1	37,584	3,840	
2	Small bus	650	30	1	19,500	2,400	
3	Large bus	143	100	0.9	12,870	1,560	
4	Articulated bus	113	160	0.85	15,368	1,600	
				Total	85,322	9,400	

Table 5.1: Public Transport Traffic Count

Source: Traffic Count Surveys



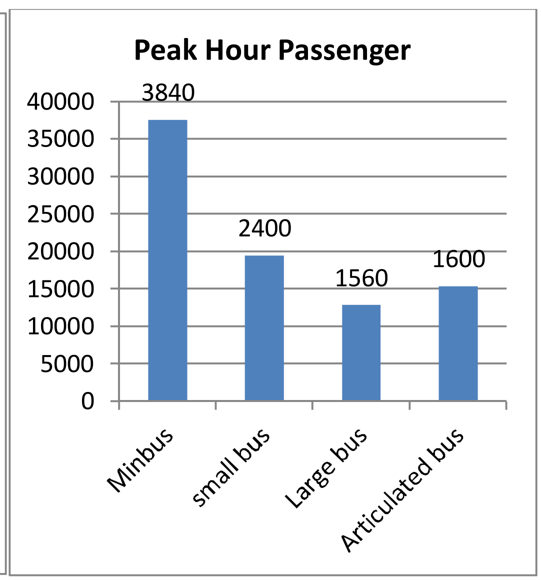


Figure 5.4 Daily Passenger & Modal Share

Source: Traffic Count Surveys

5.3 Design Traffic

As shown in Figure 5.4, there is enough passenger demand. In this regard, if the mass transit to work with the existing systems it will have a modal share of around 45 % (appendix I) which is above 4,000 passenger per hour per direction. If the normal buses are replaced; it can be designed for 6000 pphpd. But, to integrate with the Phase I and there is also a shortage of public transportation with an average of 52% according to the Addis Ababa City Transport Authority. The rapid transit will be designed for passengers' capacity of 5000 ppdph at the initial stage and with traffic growth rate of 9 % per year up to 2021 and 4% per year afterwards according to LRT traffic growth forecast as shown in table 4.2.

5.4 Service Plan

Based on the forecast demand levels and outline of the proposed route, an indicative service plan is proposed which provides the required levels of passenger capacity to meet that demand. The design average speed of LRT is 18 km/hr which was as well consider for BRT to calculate the number of buses, interval of services and average speed. Number of station, based on average station distances of 800m from Phase I for 24 km cycle length was estimated at 30. The average design speed of 18 km/hr can be attained with the following arrangements as presented in Table 5.2 below.

Total cycle length (km)	No. of stations	Dwell time at station (s)	Layover time at both end (min)	Avg travel speed b/n stations excluding dwell time (km/hr)	Total cycle time (min)	Average speed km/hr
24	30	60	12	40	78.0	18

Table 5.2: Trip Time
Source: Calculated

5.4.1 Fleet Required

The vehicle requirement is functions of: peak hour demand, capacity of cars, and the round trip times. Vehicle layover is required to provide for driver breaks and to enable the reestablishment of vehicle headways in order to prevent vehicle congestion and a layover period of 12 minutes was considered for both ends. Table 5.3 shows the total service time and Peak Vehicle Requirement based on bus capacity of 160 passenger per bus (4 passenger/m^2) for 18m long*2.5m width bus and 254 passengers per LRT for 30 m long rail car (6 passenger/m^2) based on the vehicle specification. The number of cars required /hour was calculated by dividing the product of peak hour passenger flow and total cycle time (in hour) by car capacity. Table 5.3 below shows the required number of fleet for the design passenger.

Mode Type	Peak hour passenger flow /direction			Car capacity (psngr)	Total cycle time (min)	Number of cars required/ Hr/ (10% additional for maintenance)		
	2015	2024	2035			2015	2025	2035
Peak Hour								
BRT	5000	10000	15000	160	78.0	45	89	134
LRT	5000	10000	15000	254	78.0	28	56	84
70% off peak								
BRT	3500	7000	10500	160	78.0	31	63	94
LRT	3500	7000	10500	254	78.0	20	39	59
50% off peak								
BRT	2500	5000	7500	160	78.0	22	45	67
LRT	2500	5000	7500	254	78.0	14	28	42

Table 5.3 Required Number of Fleet
Source: Calculated

Figure 5.5: BRT Bus
Source: King Long

Fleet requirement is PVR (peak vehicle requirement) plus 10% allowing for vehicles which may be out of service due to break down or the need for routine maintenance. The 10% Figure assumes that vehicle will be fully maintained and not permitted to leave the depot if they do not pass daily inspections. The complete cycle of the route is 24 km.

The fleet requirement to support the service plan set out above is estimated at 45 articulated buses and 28 LRT cars. As the system passengers increase, additional train will be purchased. The service life of the buses are 10 years. The cost of the bus is around ETB 4, 000, 000 million in 2012 with Air condition (AC) as provided by (sources King Long 227 USD 2014) with additional ETB of one million for shipping cost and others. For comparison, the cost of Anbessa Articulated bus is round ETB 3.5 million birr in 2012 as provided by Anbessa City Bus.

5.4.2 Service Interval

Vehicle frequencies based on peak hour demand and car capacity were calculated as shown in Table 5.4. In addition, vehicle frequencies are also provided for the Inter-peak and Off-peak periods (which are 70% and 50% of the peak period, respectively as observed during traffic count). Interval of service was calculated by dividing the product of car capacity and number of minute per hour by peak hour passenger flow per direction. The time-table for the three periods based on demanded from traffic survey and easy of operation can be summarized as follow:

- Peak – 8 hrs on weekdays (06:00-10:00 and 16:00-20:00)
- Inter-peak – 6 hrs on weekdays (10:00-16:00), 12hrs on Saturdays (08:00-20:00)
- Off-peak – 2 hrs on weekdays (20:00-22:00), 4 hrs on Saturday (06:00-08: 00 and 20: 00-22:00) and 16 hrs on Sundays and Public Holidays.

Mode	Peak hour passenger flow /direction			car capacity (psngr)	Interval of the service during peak hour (min)		
	2015	2024	2035		2015	2025	2035
Peak Hour							
BRT	5,000	10,000	15,000	160	1.92	0.96	0.64
LRT	5,000	10,000	15,000	254	3.05	1.52	1.02
70 % off peak					off peak hour		
BRT	3,500	7,000	10,500	160	2.74	1.37	0.91
LRT	3,500	7,000	10,500	254	4.35	2.18	1.45
50% off peak							
BRT	2,500	5,000	7,500	160	3.84	1.92	1.28
LRT	2,500	5,000	7,500	254	6.10	3.05	2.03

Table 5.4 Interval of Service
Sources: Calculated

5.5 Infrastructure Cost

5.5.1 Estimating Ground Section

In order to estimate capital costs associated with the route corridor, the cost of BRT lane for ground section is designed for traffic class of 56 Million Equivalent Standard Axle Load (ESAL) and is presented in Appendix A for design period of 30 years and subgrade class of S2 CBR = 3%. According to ERA Design manual, the pavement structure is as shown Figure 5.6 below. The design period of the pavement is 30 years and overlay of pavement will be done at the middle of design period. Due to similarity in pavement structure unit price is taken from Addis Adam Expressway. The Per km quantity is estimated based on pavement structure in Figure 5.6 & Figure 5.7 BRT Running way below.

	layer	Thickness (mm)
Wearing		40
Binder		60
Base (High module Asphalt Macadam)		220
subbase		225
capping		200

Figure 5.6: Pavement Structure of BRT Running Way

No	Activity	Unit	Quantity/km	unit R.	Amount (Birr)
1	General				1,000,000.0
2	Site clearance	Hr	1.0	50,000.0	50,000.0
3	Cut to spoil				
	soft excavation to the depth of 800mm	m3	8,000.0	134.1	1,073,040.0
	intermediate excavation to depth of 1100 mm	m3	3,000.0	243.3	729,765.0
	hard excavation to depth of 1300mm	m3	2,000.0	352.4	704,760.0
4	Road bead preparation	m2	10,000.0	64.4	643,700.0
5	Cut and borrow to fill				
	Common fill	m3	3,000.0	145.0	435,000.0
	Rock fill	m4	2,000.0	298.9	597,780.0
6	Capping 200mm thick	m3	2,813.5	310.0	871,875.0
7	Sub base 225mm thick	m3	2,000.0	540.0	1,080,000.0
8	Prime	lt	8,800.0	35.7	313,896.0
9	High modul Asphalt Macadam 220mm	m3	1,760.0	5,500.0	9,680,000.0
10	Tack coat	lt	8,800.0	35.7	313,896.0
11	Wearing course 40mm	m2	8,000.0	265.0	2,120,000.0
12	Binder course 60mm	m2	8,000.0	365.0	2,920,000.0
13	C25 Kerb	m3	480.0	4,016.6	1,927,958.4
14	Road marking with yellow and white line	m2	600.0	500.0	300,000.0
15	Others (5 %)			1,200,000.0	1,200,000.0
16	Fence or Barrier (from phase I LRT)	km	2.0	4,594,807.0	9,189,613.9
	Total cost per km for ground section				**35,151,812.3**

Table 5.5 Cost Estimation for Ground Section

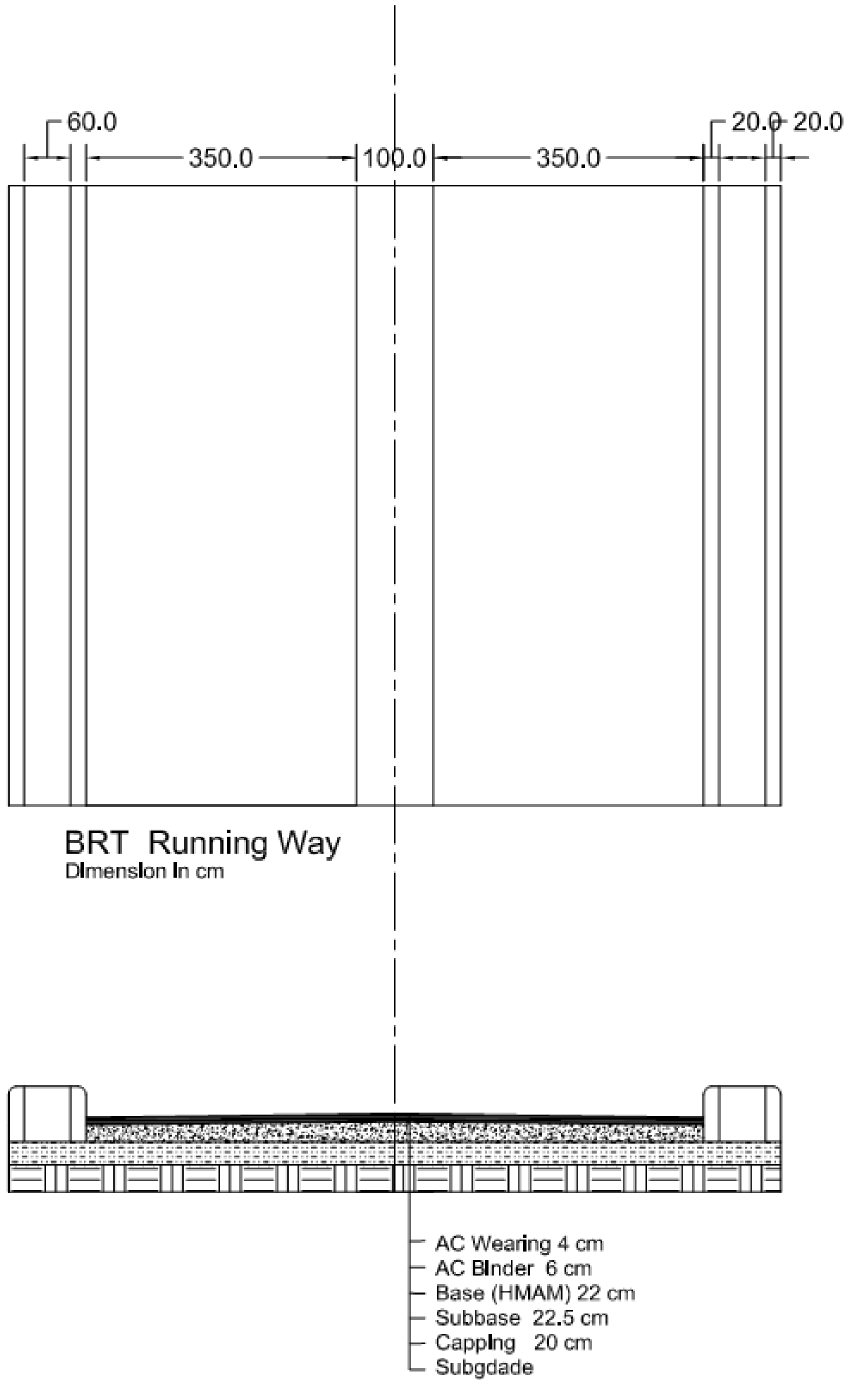


Figure 5.7: BRT Running Way
Source: Own

5.5.2 Elevated Section (Overpass Bridge)

The cost of elevated section is estimated based on Highway Bridge on road projects in Addis Ababa. The cost of super structure constructed using precast bridge and the substructure is estimated from the Addis Ababa Adama express Way interchange and the insitu casted continues bridge portion from Overpass Bridge located between Lideta to Meskel Flower at around global hotel located on AA-LRT route across the railway. Even if the axle loads of BRT bus is smaller as compared to the design vehicle used for design of Highway Bridge, it is taken as it is to be on the safe side. The elevated section of AA- LRT Phase I has a total length of 7.31 km and around 810m of it is constructed from continues beam of span length 30m (27 beam). The cost of a 30 m beam of width 11m is ETB 4,052,000.00 and total cost for 810m calculated at ETB 109,404,000.00 = 27*4,052,000. The cost of precast bridge includes production, installation and bearing. The elevated section of the road cost is estimated and depicated in Table 5.6. Electric installation for lighting and drainage facilities are built with the general traffic road to be included in it; thus, on both LRT and BRT their cost is not included. Along the route on five major intersection points overpass section is considered which will have total elevated potion of 1 km i.e. 200m for each overpass and the quantity of the structure is taken from Phase I elevated portion in order to estimate per km cost.

No	Superstructure	Unit	Quantity	Unit Rate (ETB)	Amount (ETB)	Remark
1	Type 20m of simply supported beam	Pcs	153.00	741,197.71	113,403,249.55	Estimated from Addis Adama Expressway interchange
2	Type 23m of simply supported beam	Pcs	6.00	852,377.37	5,114,264.20	
3	Type 25m of simply supported beam	Pcs	522.00	926,497.14	483,631,505.44	
4	Type 25m of simply supported beam for 9 station length on each side 50m	Pcs	36.00	926,497.14	33,353,896.93	
5	Insitu caste beam	Pcs	27.00	4,052,000.0	109,404,000.00	Lideta-meskel Flower
6	**Substructure**					
	Cost of excavation, pile, cap and pier	m	6500	84,953.04	628,652,500.92	Estimated from Addis Adama Expressway interchange
7	**Retaining walls**		1200	24,452.4	29,342,857.51	
8	**Design and Supervision**					
	Design and Supervision (5%)				66,322,226.9	
				Total cost	**1,392,766,764.8**	
				Cost/km	**190,789,967.8**	

Table 5.6: Cost Estimation for Elevated Section.

5.5.3 Stations

The platform layout of stations for the BRT system is similar to Phase one LRT expect its length which is two-third of the LRT that is required to park two 18 m BRT bus and passing lane is provided at station which enable buses to pass each other thereby maximize speed and reduce delay. The station length is 40mx3m to accommodate two 18m articulated bus. The cost of the station is taken as 2/3 of the LRT since the proportion of length of BRT station is 2/3 LRT (40/60). Typical station layout is shown in Figure 5.8 below for BRT system.

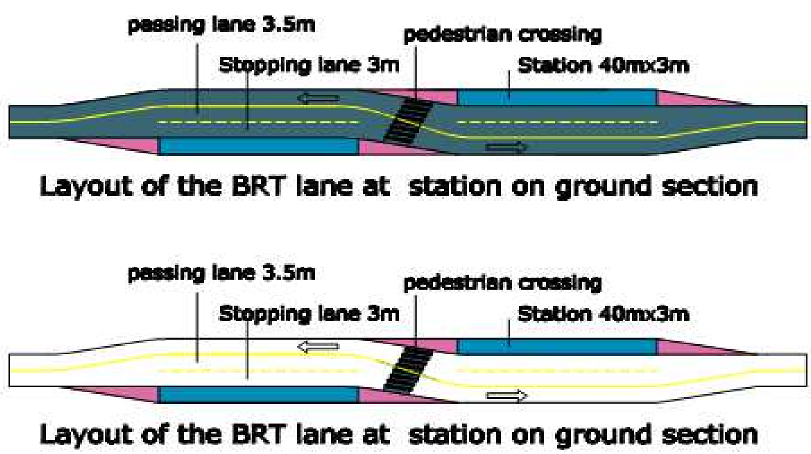


Figure 5.8: BRT Station Layout.
Source: Own

5.5.4 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) is used to increase safety, operational efficiency and quality of service. ITS includes a variety of technologies to collect, process and disseminate real-time data from vehicle and roadway sensors. The data are transmitted via a dedicated communications network and computing intelligence is used to transform these data into useful information for the operating agency, driver and the customer. The cost of the ITS for the BRT system is estimated as follow for 45 buss and 15 stations. Table 5.7 below shows Cost of ITS Equipment for 45 buses and 15 intersections.

No.	Equipment	Unit	Unit Price (ETB)	Quantity	Amount (ETB)
1	Fare collection	Per vehicle	429,360	45	19,321,200.00
2	Traffic Signal Priority	per intersection	691,294	15	10,369,402.97
3	Passenger on-board information	Per vehicle	279,176	45	12,562,922.84
				Total	42,253,525.81

Table 5.7: Cost of ITS Equipment for 45 Buses and 15 Intersection.
Source: TCRP Report 118, BRT Practitioner's Guide, 2007

5.5.5 Depot and Operation Center

Depot Area

To operate the BRT line, a workshop / depot should be created. The depot will be the BRT operating base. It will provide parking accommodation, servicing and maintenance facilities for vehicles, an administrative function, and facilities for staff.

The maintenance part of the depot requires the following functionalities:

- Oil station;
- Washing plant;
- Painting;
- Overhaul;
- Quick repairs;
- Big repairs; and
- Vehicle lifting,

In order to accommodate for all these functions, up to three htrs are required for 100 buses. The Figure below is a possible layout for the depot area. Its layout will depend on the characteristics of the piece of land available. The concept design illustrates 45 degree ‘sawtooth’ parking bays, which makes each bus accessible without the need to move others. This is important to enable drivers to be assigned to buses, and overcomes operationally difficulties if certain buses, for example, cannot be started.

The depot design conceptual layout, which is shown in Figure 5.9 below is capable of accommodating up to 100 buses. The estimated fleet size required at launch for the corridor is 45 vehicles. The size of the depot is designed as 200mx150m = 3 htrs, and will be constructed at the end of the route and its cost was estimated at 80 million birr from Similar project. [AA –BRT Feasibility Study Lyon Town Planning Agency, 2010].

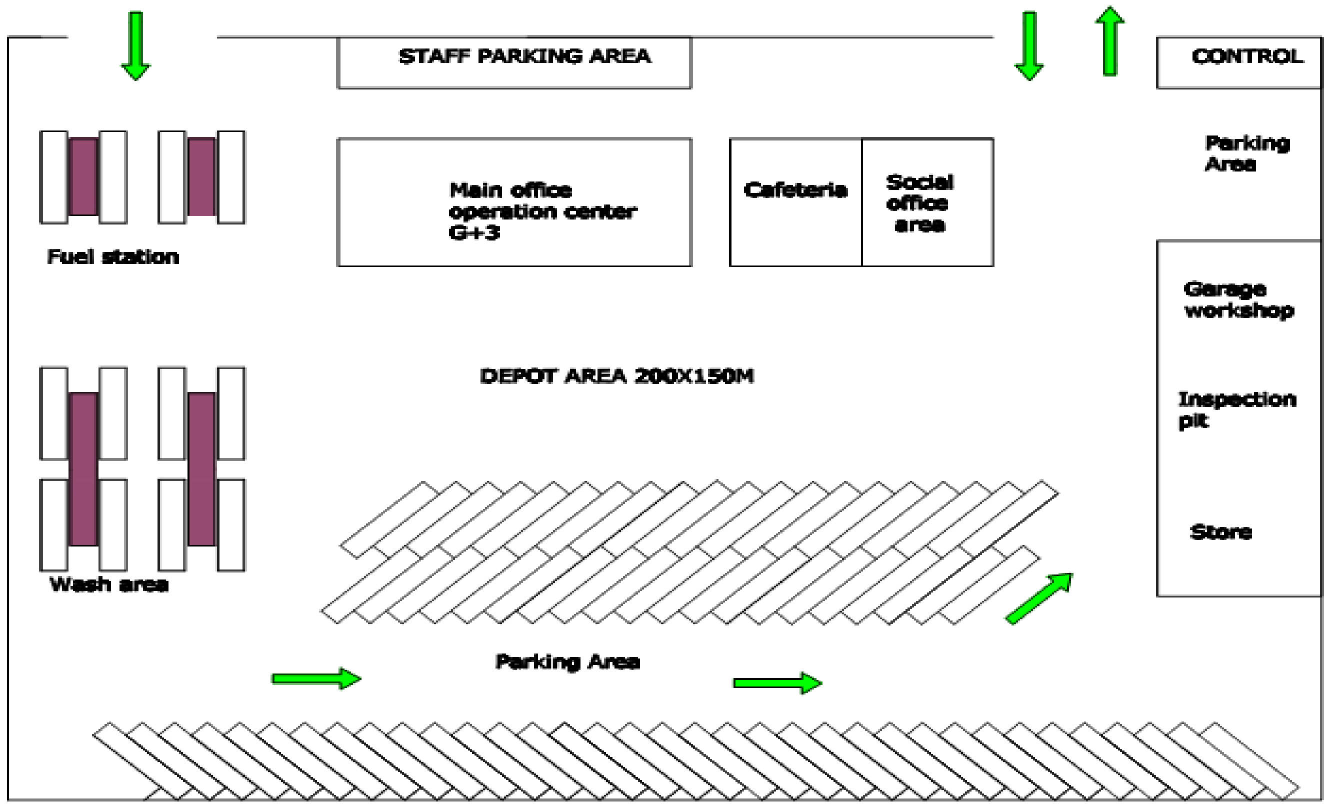


Figure 5.9: Depot and Operation Center
Source: Own

5.5.6 Capital Cost Estimation

Capital cost includes the cost of infrastructure (running ways, stations...), equipment (passenger information, fare collection) and fleet. The route has a total length of 12 km from which around one km is an elevated portion. The cost is typically measured on a per kilometer basis. The cost of LRT system is estimated based on Phase I and the BRT cost were estimated from similar projects of Addis Adam Expressway (Lebu-Akaki IT Park Outer Ring Road Project). Table 5.8 shows the estimated costs of LRT and BRT.

No.	Description (LRT)	Unit	Unit Rate (2009 USD)	Quantity	Amount (USD)	Remark
1	Ground Section	km	2,494,887.52	11	27,443,762.70	
2	Elevated Section	km	14,876,444.6	1.0	14,876,444.65	
3	Track work	km	1,222,665.46	12	14,671,985.52	
4	Power Supply	km	1,283,070.26	12	15,396,843.15	
5	Station	No	359,846.04	15	5,397,690.60	1 station /800m
6	Communication and Signal syt.	km	510,123.40	12	6,121,480.76	
7	Ticketing System	N. car	40,632.52	28	1,137,710.58	
8	Rolling Stock	No	2,598,160.72	28	73,137,201.36	
9	Depot and Integrated base	km	873,041.1	12	10,476,493.53	
10	Design and Supervision (5%)				1,642,072.67	
			Total (2009 USD)		170,301,685.51	USD/km
			Total in 2012 birr		3,239,374,777.67	15,185,234
No	**BRT**	**Unit**	**Unit Rate (2012 Birr)**	**Quantity**	**Amount (Birr)**	
1	Running way on ground section	km	35,151,812.3	11	386,669,935.7	
2	Running way on elevated section	km	190,789,967	1	190,789,967.79	
3	BRT Bus	No	5,000,000.0	45	223,437,500.00	
4	Station	No	7,006,028.9	15	105,090,434.22	
5	ITS Equipment	No. bus	938,967.2	45	42,253,525.81	
6	Depot & Operation center				80,000,000.00	
7	Design and Supervision (5%)				51,490,193.18	USD/km
					1,081,294,056.7	5,068,788

Table 5.8 Infrastructure Cost Summary

Note: Per km cost of similar road projects in the city; for example the cost of the from Paster – Sansusis River Bridge (2.8km) was ETB 65 million in (2012) for three lane per direction and ETB 22 million per lane per direction. The project contractor is foreign company and as we compare the BRT running - way cost of ETB 35 million per lane per direction it is not underestimated. The overall cost of the BRT is 5.07 million (2012 USD) per km which is greater than the Legos BRT which is first in Africa with USD 2.5 per km.

5.6 Operation and Maintenance Costs

Operation and maintenance costs of the BRT estimated from Anbessa City Bus Enterprise ETB 25 birr/vehicle-km in 2011/12 year without bus deprecation and infrastructure maintenance of ETB half million per km per year is taken(sources AACRA). For LRT, operation and maintenance is around ETB 70.57(USD3.97) per vehicle-km as observed from economic analysis of the ERC. Sensitivity analysis was conducted considering the operation and capital cost and assuming that fare revenue would be increased or decreased by 20% and the financial feasibility would be cross checked. The BRT buses will travel a total of more than three million km per year and the LRT tramcars around two million km per year at opening year for the design service plan as shown in Appendix-A. The expenditure is 17.05 birr/km for a normal bus, based on fuel consumption per km and the corresponding value for an articulated bus was 23.45 birr/km as shown in Table 5.9.

No	Bus Operation	Year		Remark
		2012/13	2012/11	
	Expenditure (000 birr)			
1	Salary	76,252	60,778	
2	Overtime	30,235	20,692	
3	Benefits	20,873	7,391	
4	Training	181	597	
5	Fuel	202,497	182,715	
6	Benzene	107	69	
7	Oil & Lubricant	7,967	8,142	
8	Spare parts	36,415	30,017	
9	Tyre and Tubes	9,087	6,734	
10	Consumable items	3,358	2,014	
11	Small vehicle Maintenance	3,847	586	
12	office Furniture	642	347	
13	Insurance	8,766	6,033	
14	Stationary & Sanitary	1,175	854	
15	Tickets	5,846	7,007	
16	Printing Materials	971	184	
17	Administration Expenses	2,770	8,871	
18	Uniform	3,075	3,002	
	Total Expenses	**414,064**	**346,033**	
	Number of bus	604	460	
Total thousand km per year		26,855	20,292	
Operation and Maintenance Cost birr/km		**15.42**	**17.05**	

Table 5.9: Operation & Maintenance Cost of Anbessa City Bus

5.7 LRT and BRT System Revenues

Fare levels vary based on the journey length and journey time. Currently, the Anbesa city bus and minibus fares are 0.25 birr/ km and 0.55 birr/km respectively and the average of the two, 0.4 birr/km is taken for initial analysis. In the case sensitivity analysis, fare variation up to 20% (from 0.32 - 0.48 per km were tested) other revenues from advertisement and renting stations were accounted for. Advertisement on vehicle revenue was adapted from Anbessa city bus which is 900 birr/bus/month and station advertisement and rents were estimated as 4,000 birr/month/station (based on city price). For Design, 112,000 passengers /day for 330 working days per year and for initial fare price of 0.4 birr/km on 12 km route will have fare revenue of 177.41 million birr/year. For following years, the revenue will increase in proportion to passenger growth rates. For 30 - year time horizon, both systems will generate ETB 12,099 and 58 million from fare collection and advertisement respectively. Additionally, from carbon credited, ETB of 150.5 and 245.2 million for BRT and LRT respectively accounted. Details of calculation are presented in Appendix B & C. Table 5.10 below shows revenues from LRT and BRT systems.

Type	Revenue (Million Birr)	
	LRT	BRT
Fare revenue	12099	12099
advertisement on Vehicle	36.6	36.6
advertisement & rent on station	21.60	21.60
Carbon credit	245.2	150.5
Total	12,402.7	12,308

Table 5.10: Estimated Revenues of LRT & BRT

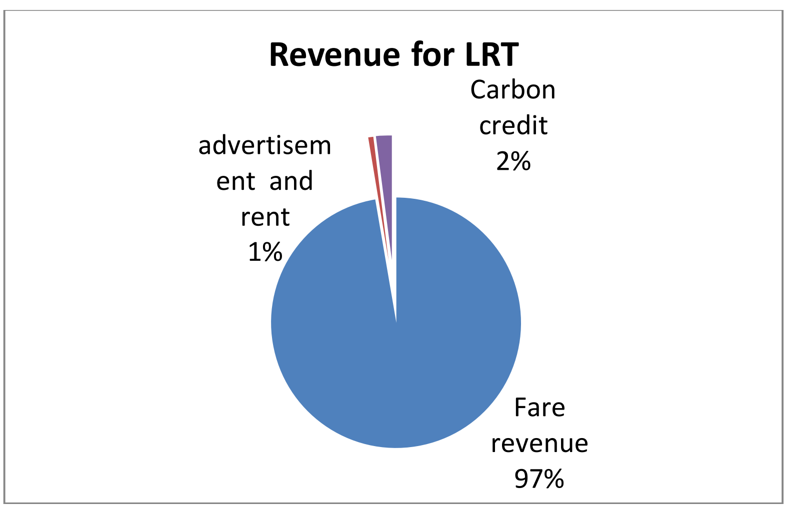


Figure 5.10: Estimated Revenue for LRT

5.8 Financial Analysis

Comparing system revenues to the operation and maintenance costs provides a basis for assessing the commercial viability of running the BRT and LRT systems. System costs and operational revenues for the time horizon of 30 year are shown in Table 5.11. Costs and benefits are in net present values below and the detail calculation is attached in Appendix D & E.

No	Capital Costs	Operations and Maintenance	Total cost (Birr)	Benefit Categories			Total Benefit (Birr)	NPV
				Fare revenue	Carbon Credit	Advertisement & rent		
LRT	5840	8780	15860	12099	245	58	12402	-3457
					B/C	0.78		
BRT	2248	6062	8313	12099	151	58	12308	3995
					B/C	1.48		

Table 5.11: Annual MRT Systems Financial Analysis

NPV = Net present Value (Present value of benefit minus present value of costs)

B/C = benefit– cost ratio (Present value of benefit divided by present value of costs

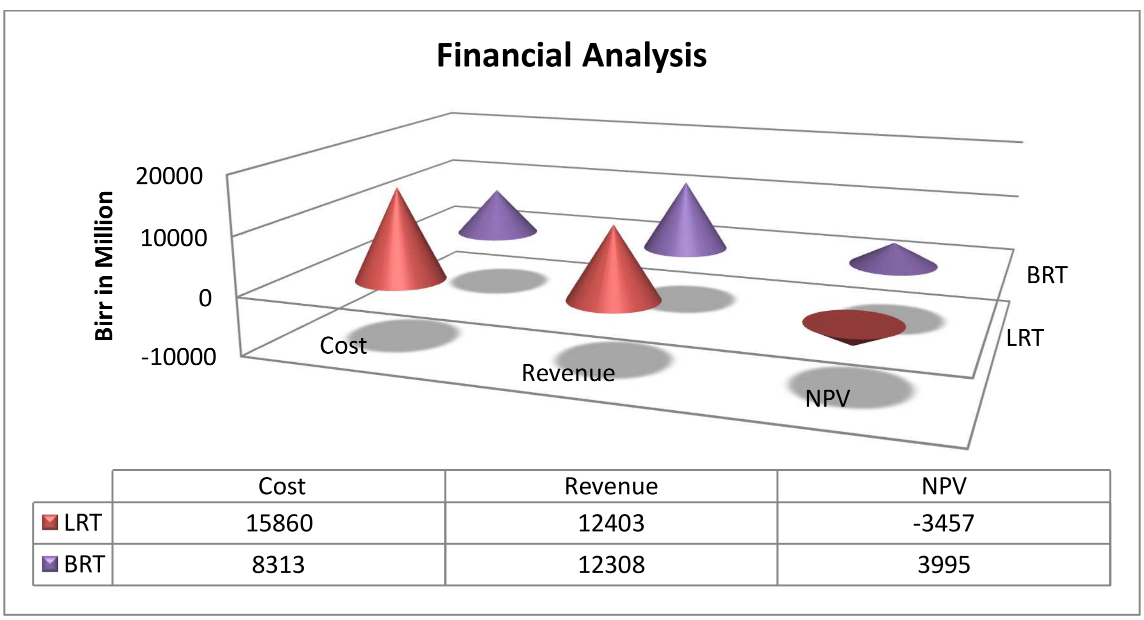


Figure 5.11: Annual Systems Financial Analysis

5.8.4 Sensitivity Analysis

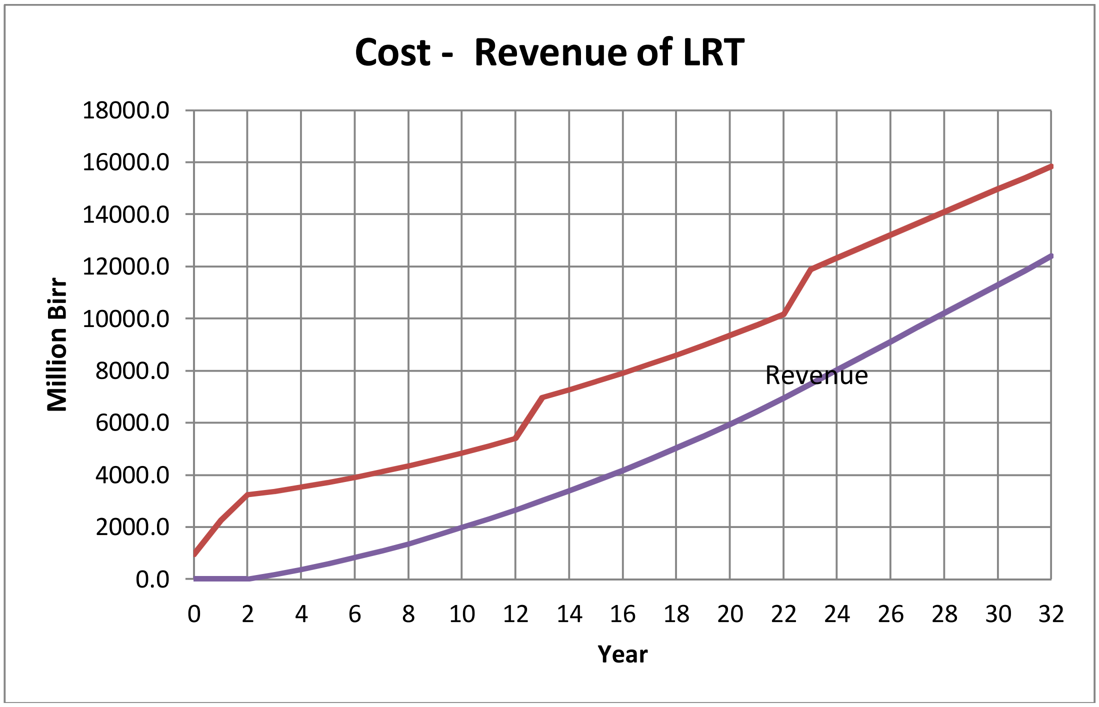
To test the sensitivities of LRT and BRT, up to 20% reduction or increases of major items have been analyzed and the net present value (NPV) results were calculated and summarized in the table 5.12.

Item	-20%	-10%	0%	10%	20%
BRT	Net value (Birr)				
Fare revenue	1574.82	2784.76	3994.69	5204.63	6414.56
Project Investment	4445.00	4219.85	3994.69	3769.53	3544.38
Operating Cost	5207.04	4600.87	3994.69	3388.51	2782.34
LRT					
Fare revenue	-5877.22	-4667.29	-3457.35	-2247.42	-1037.48
Project Investment	-2289.41	-2873.38	-3457.35	-4041.32	-4625.29
Operating Cost	-1453.28	-2455.32	-3457.35	-4459.39	-5461.42

Financial Net Present Value percentage as of total cost.

Item	-20%	-10%	0%	10%	20%
BRT	%				
Fare revenue	18.94	33.50	48.05*	62.61	77.16
Project Investment	53.47	50.76	48.05	45.34	42.63
Operating Cost	62.63	55.34	48.05	40.76	33.47
LRT					
Fare revenue	-37.06	-29.43	-21.80	-14.17	-6.54
Project Investment	-14.44	-18.12	-21.80	-25.48	-29.16
Operating Cost	-9.16	-15.48	-21.80	-28.12	-34.44

***(NV*100/Total cost)**
Table 5.12: Financial Sensitivity Analysis



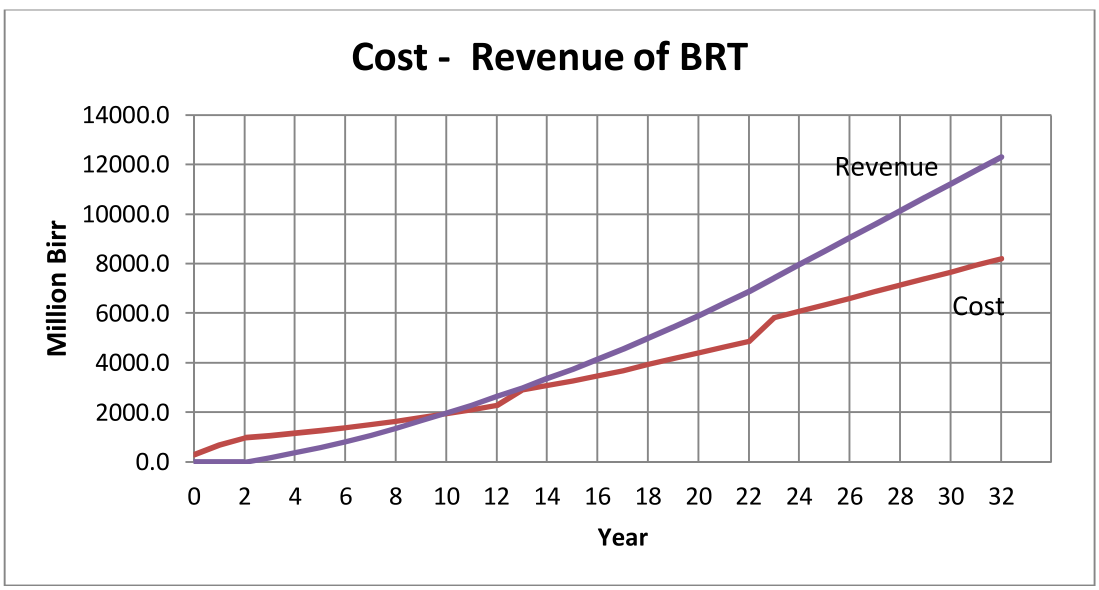


Figure 5.12: Cumulative Costs – Operation Revenue of LRT & BRT

5.9 Economic Analysis

Rapid transit projects have the potential to provide travel time, public health, environmental, land use, and other benefits to society. However, like all transport options, systems can also impose social costs from construction, operation, and maintenance. In order for policymakers to make an informed decision regarding the development or expansion of a project, the project should be evaluated in terms of total benefits compared to total costs. Cost-benefit analysis (CBA) is used to capture both public and private costs and benefits for society as a whole (Harberger and Jenkins 2002; Gramlich 1997; Boardman et. al. 2006). In addition to the financial or market costs, it also considers externalities and indirect or intangible costs to capture social effects. Cost-benefit analysis therefore provides policymakers with a valuable tool for comparing net benefits (benefits minus costs).

Three indicators are used in the cost- benefit analysis:

• **Net present value**. It is the difference between discounted benefit and discounted costs over the analysis period. 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.

$$NPV = \frac{B_0 - C_0}{(1+i)^0} + \frac{B_1 - C_1}{(1+i)^1} + \ldots + \frac{B_T - C_T}{(1+i)^T}$$

Where: NPV= net present value, t = year, B = benefits, C = cost, i=discount rate.

• **Benefit-cost ratio**. A ratio of discounted benefits over discounted costs and should be greater than one to indicate that the total benefits to society exceed the costs.

$$B/C = [\frac{B_0}{(1+i)^0} + \ldots + \frac{B_T}{(1+i)^T}] \div [\frac{C_0}{(1+i)^0} + \ldots + \frac{C_T}{(1+i)^T}]$$

Where: B/C = Benefit to Cost ratio, t = year, B = benefits, C = cost, i=discount rate.

• **Internal rate of return (IRR).** The IRR is the discount rate at which the net present value of costs equals the net present value of the benefits and indicates the attractiveness of the investment. The IRR of investment should exceed the cost of capital. Component of costs and benefits are stipulated below.

Costs

• Planning and design cost;
• Construction cost;
• Equipment (fleet acquisition, ITS) ;
• Bus operations and maintenance;
• Infrastructure maintenance;
ETC

Benefits

- Changes in travel time;
- VOC Savings;
- Changes in CO_2 emissions;
- Noise and accident reduction;
- ETC

5.9.1 LRT and BRT System Cost

The primary costs associated with mass rapid transit projects are implementation costs (including planning, construction, and equipment costs) and operating costs. The costs of LRT were estimated from Phase I and the BRT were estimated from the most expensive road project which is Addis Adama Expressway (Lebu-Akaki IT Park Outer Ring) Road Project. The costs of LRT were about ETB 267 (USD 15) million per km and the BRT is about ETB 89 (USD 5) Million per km in 2012. Operating time horizon of 30 years is considered and national discount rate of 10% is also taken for analysis. (Source ERC). Detailed costs of MRT are shown in Appendices F & G. Figure 5.13 below shows the cost of LRT and BRT system.

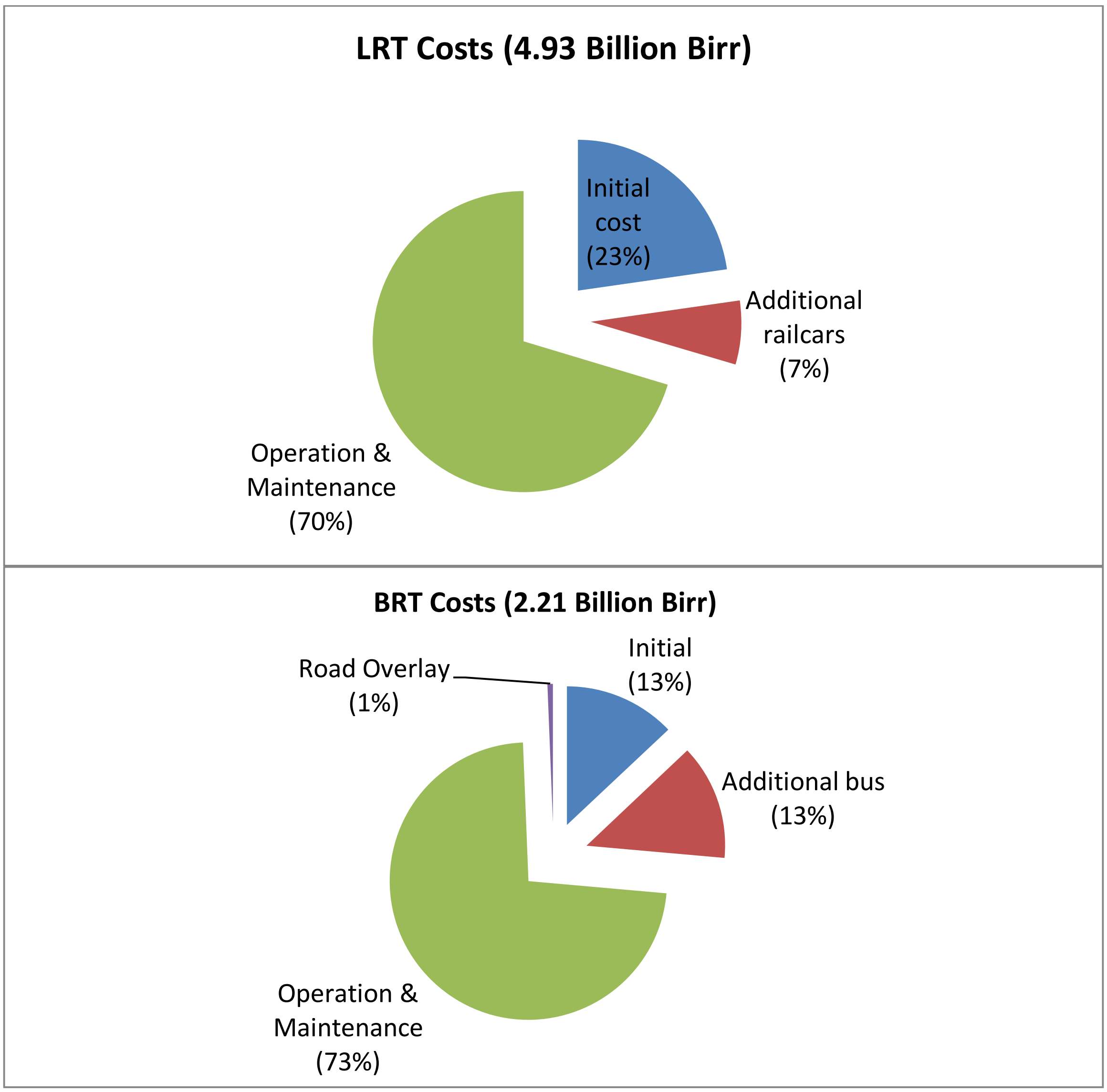


Figure 5.13 Discounted Cost of LRT & BRT in 30 Year Project life.

5.9.2 LRT and BRT Benefits

Benefits identified for mass transit system are:

- Mass transit user travel time savings;
- Public transport fleet operation savings; and
- Savings due to avoided greenhouse gas emissions.

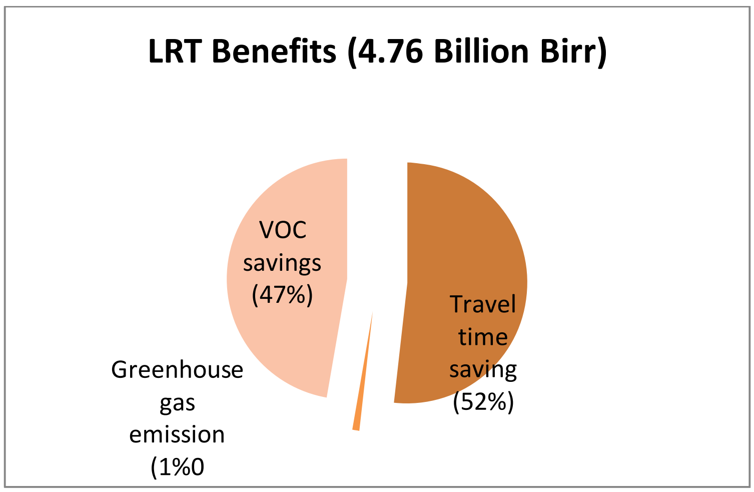
Transit User Travel Time Savings: These are the results of changes in trip speeds and station access times. Travel time savings are calculated from design average speed of LRT and BRT 18 km/hr and general traffic average speed during peak hour of 10 km/hr as observed on the roadway. Travel time cost saving of 10 birr/hr is taken based on the average income of the passenger from field survey (2400 birr/month). For one-way trip of 12 km route length, the time saving is 32 minutes which will be Birr 5.33 travel time cost saving. For 112,000 trips per day, the travel time saving cost will be Birr 197 million per year (330 working days per year).

Vehicle Operation Cost Savings: without the rapid mass transit the modal share of the public passenger is 25% for normal bus, 25% for small bus and 50% for minibus (GCRC 2011). The replacement of these form of public transport by BRT or LRT will have operating cost savings. The elimination of vehicles results in fuel cost savings of Birr 89,921,947.50 and considering the fuel cost as 50 % of total operation cost according to the Anebesa City Bus Enterprise data, the total VOC saving will be Birr 179,843,895.0 Birr at the opening year as shown in Appendix H.

Reductions in Greenhouse Gases

Mass rapid transit systems can have positive environmental impacts by reducing greenhouse gases that contribute to global climate change as well as local air pollutants, which lead to citywide air pollution and smog. Reductions in vehicle emissions can be achieved in several ways, including reducing vehicle kilometers travelled (VKT) and improving the fuel efficiency and technology of the buses or using electric energy in case of LRT. Passengers shifting from single-occupancy vehicles to high occupancy transit vehicle reduce overall VKT in the city. The social cost of carbon is an estimate of the monetized value of damages caused by an increase in greenhouse gas emissions; it reflects the benefit of reducing greenhouse gas emissions now to avoid the cost of those damages in the future (Greenspan Bell and Callan 2011). A benefit of a LRT or BRT project due to reducing greenhouse gas emissions is avoiding the future cost of those damages. The social cost of carbon is taken as 15 USD per ton of CO_2 and 0.002487 ton of CO_2 emission per liter of fuel is considered during analysis (source CRGE 2011). During the opening year of the project 13,391.68 and 8,186.81 ton of Co_2 emission is reduced due to LRT and BRT system respectively.

Over the time horizon of the projects lives, the present value of benefits aggregate to ETB 25.96 billion in 2012 for LRT and ETB 25.86 billon for BRT. The benefits associated with MRT are dominated by travel time reductions for users which cost ETB 13 billion of benefit. Benefits from reduced vehicle operating costs contribute an additional ETB 12.27 billion, ETB 245.2 and 150.5 million were estimated as benefits from CO_2 emissions reduction for LRT and BRT respectively. Discounted benefits of the LRT & BRT shown below at 10% discount rate. Figure 5.14 shows generated benefits for LRT & BRT. Figure 5.15 below shows cumulated cost-benefits of the same.



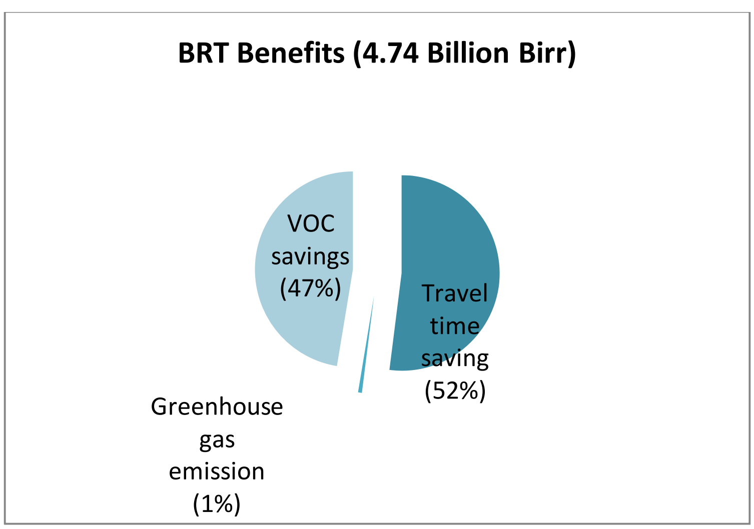


Figure 5.14: Discounted Benefit of the system in 30 year Project life.

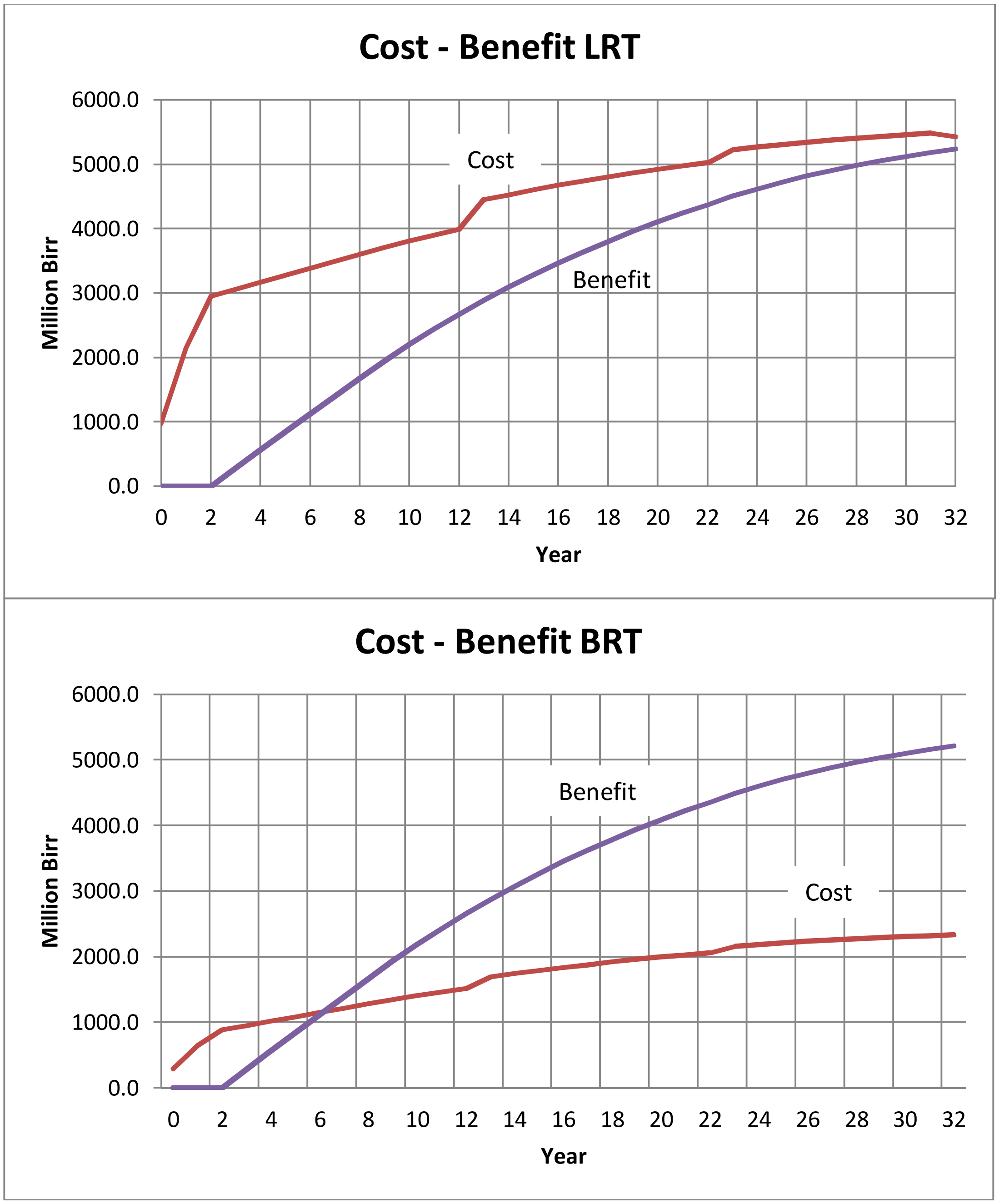


Figure 5.15: Cumulative Discounted Costs –Benefit

Note:

NPV (LRT) =discounted (benefit – cost) = 4762.33-4932.11 = -0.170 Billion Birr

NPV (BRT) =4744.97-2207.58 =2.5374 Billion Birr

BCR (LRT) = benefit/cost = 4.76/4.93=0.97

BCR (BRT) =4.74/2.21=2.15 from Figure 5.13 & 5.14

6. Discussion and Comparison of the Result.

6.1 Cost Benefit Analysis

For the time horizon of 30 years and at discount rate of 10 % the NPV of LRT was estimated at ETB -170 million while for BRT the NPV was estimated at ETB 2537 million. The IRR of the LRT was estimated as 9.5 % and for BRT the IRR was estimated as 27.4%. The payback period (PBP) of the BRT is about eight years and the LRT is above thirty years. Therefore, the attractiveness of the BRT system is very high. Initial investment cost of the BRT is around ETB one billion while the LRT is more than ETB three billion. BRT systems cost considerably less to build than their urban rail counterparts. This makes BRT the preferred option for budget constrained cities. Detail calculations are shown in Figure 5.15 and Appendices F & G.

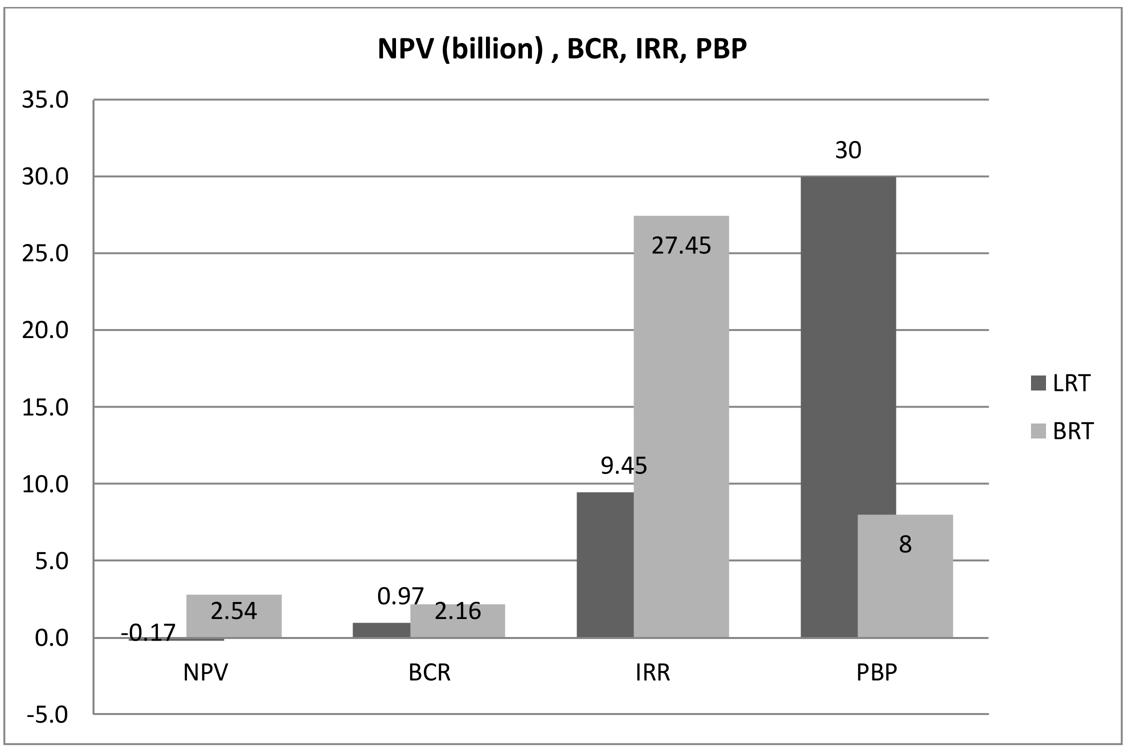


Figure 6.1: Graphical Presentation of the Economic Indicators

The initial cost of LRT is three times BRT, such cost savings means that under the same budget, far more BRT services can be provided than rail, delivered in a shorter period. Therefore, it is possible to build BRT system for the whole Phase II (40 km). The life of a project depends on the initial cost (capital cost) and it is also the main criteria for selection and such significant great reduction in cost has to be utilized.

6.2 Operation and Maintenance Cost

The operation and maintenance costs of the LRT at the opening year is ETB 146 million while the BRT is ETB 88 million for the same period. Here also the operation cost of LRT is not better than the BRT. The BRT operation and maintenance costs are lower than the LRT costs. This is due to LRT staff requirements being very skilled such as: track crew; structures crew; switch maintainers; overhead lines crew; signals and communications crew and substation maintainers. This increases the staff requirements for LRT thereby contributing to higher operating costs. The high rates of LRT staff wages contribute to the higher operating cost. Figure 6.2 below shows Operation costs at opening year and per vehicle-km.

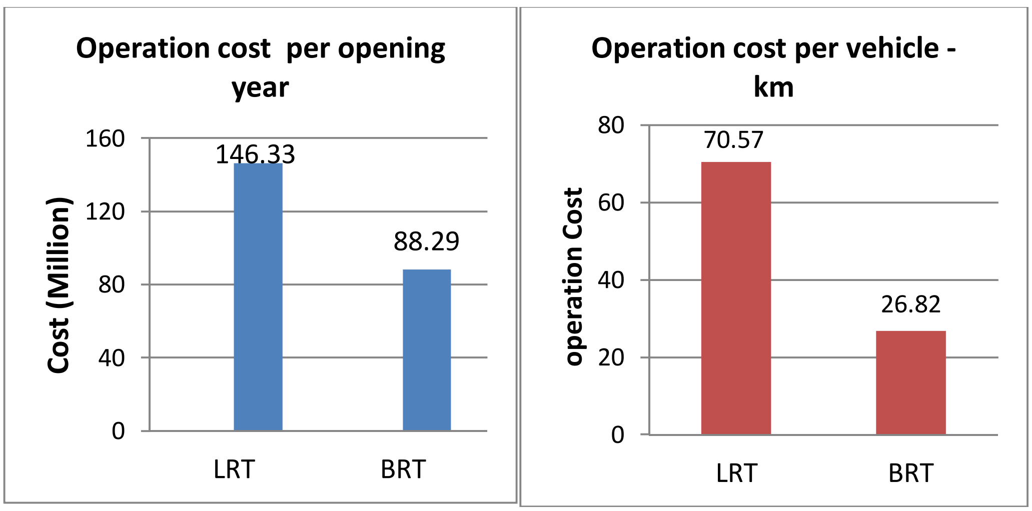


Figure 6.2: Operation Costs at Opening Year and Per Vehicle-Km

6.3 Capacities

With bus capacity of 160 passengers and thirty second headway between buses, the BRT system has a capacity of 19,200 PPHPD. If we make the bus to stop at alternate station the system capacity can be increased twice since it is relatively easy for two buses to use a single off-line station at the same time, thereby doubling capacity.

The design capacity of Phase I LRT is 15,000 PPHPD with coupled train of two minutes head way but from experience around the world we can hardly find LRT which has attended 15,000 passenger per direction per hour; but, the BRT can attain this design capacity and can be practically attended as experienced even with higher capacities around the world.

6.4 Trip Speeds

The design average speed of the LRT is taken as 18 km/hr to calculate cycle time and number of bus. This design speed is also taken for BRT system but both systems can attend average speed greater than 18 km/hr if passing lane is provided at station and vehicle stop at alternative station as required.

It is easier to introduce express- and limited-stop services into BRT systems, since an express bus simply needs a passing lane at stations; whereas, rail-based transit systems essentially require double-tracking for express services. Thus, the BRT can have comparable speed to LRT. The time taken for AA - LRT from Piassa to Kality (17 km) is about one hour that with 17km/hr average speed by stopping at every station but if the LRT is scheduled to stop at alternate station it can attained higher average speed. The Tunis LRT average speed is 20km/hr while the South Africa (Johannesburg) BRT and the Nigeria (Lagos) BRT average speed 30 and 25 km/hr respectively.

6.5 Attracting Ridership

The image of the LRT can attract more ridership than BRT due to bad image of normal bus. The rapid buses could also operate more frequently than light-rail trains as observed in Table 5.4. The other main factor is the travel fee since the overall cost of the BRT is significantly different than the LRT. In this respect, it is possible to make fee of the trips cheaper than the LRT trip to attract passengers to the BRT system. But whichever system is implemented, due to shortage of transport problem in the city both systems can attract enough passengers and run at full load at peak hour for the design capacity.

6.6 Financial Viability

At present, the Anbesa city bus and minibus fares are ETB 0.25 per km and 0.55 per km respectively and the average between is ETB two 0.4 per km was considered for initial analysis. If the system to compute with minibus the fee of the trip must be less than ETB 0.5 per km and from the normal bus it can attract passengers with its quality. As shown in the financial analysis the BRT is viable for trip cost of ETB 0.32 per km as observed in Table 5.12. Since public transport demand is relatively sensitive to fare changes, fare reduction can play a substantial role in encouraging the use of public transport, thus reducing the use of private cars. To be financially viable, the LRT system has to be heavily subsidized as in the case of Phase I which have travel costs of ETB 0.43 per km on the average.

6.7 Implementation Time and Phasing

For comparative purpose, it is assumed that the construction time of BRT is the same as to the LRT that is 3 years. From experience on the city road project, the BRT can be completed within two years. Due to high capital costs of the LRT project, it is difficult to start Phase II construction in the near future; but, at the two ends currently, mass transport is required. Due to its low cost, the BRT can be implemented within one year especially up to Ayertena and can be extended further as budgets are available, regarding the construction period, BRT is favorable since it can be designed and implemented within a short time frame. As a very good project in the world, like Guangzhou BRT, went from a firm political commitment to implementation within eighteen months. Even in Istanbul turkey a portion of a BRT was completed within less than six months. This kind of short time construction duration is extremely important in public transports in Addis Ababa before the situation goes from bad to worst. It can also be asserted means that the mass transit and land use benefits will be felt much more quickly with BRT than with rail-based modes.

BRT provides much greater flexibility in terms of phasing. A city can build high-quality BRT along just a segment of an existing route where the BRT infrastructure is most needed, then extend this BRT when budget and the need for these measures increases. Furthermore, BRT generally has the advantage of having more flexibility than LRT, being able to phase in service rather than having to wait for an entire system to be built.

In terms of right-of-way the BRT running way can be constructed with 8-10m as shown in Figure 6.3 whereas the LRT required 11m on normal section which exceeded the BRT by 1-3m as shown in Figure 6.4.

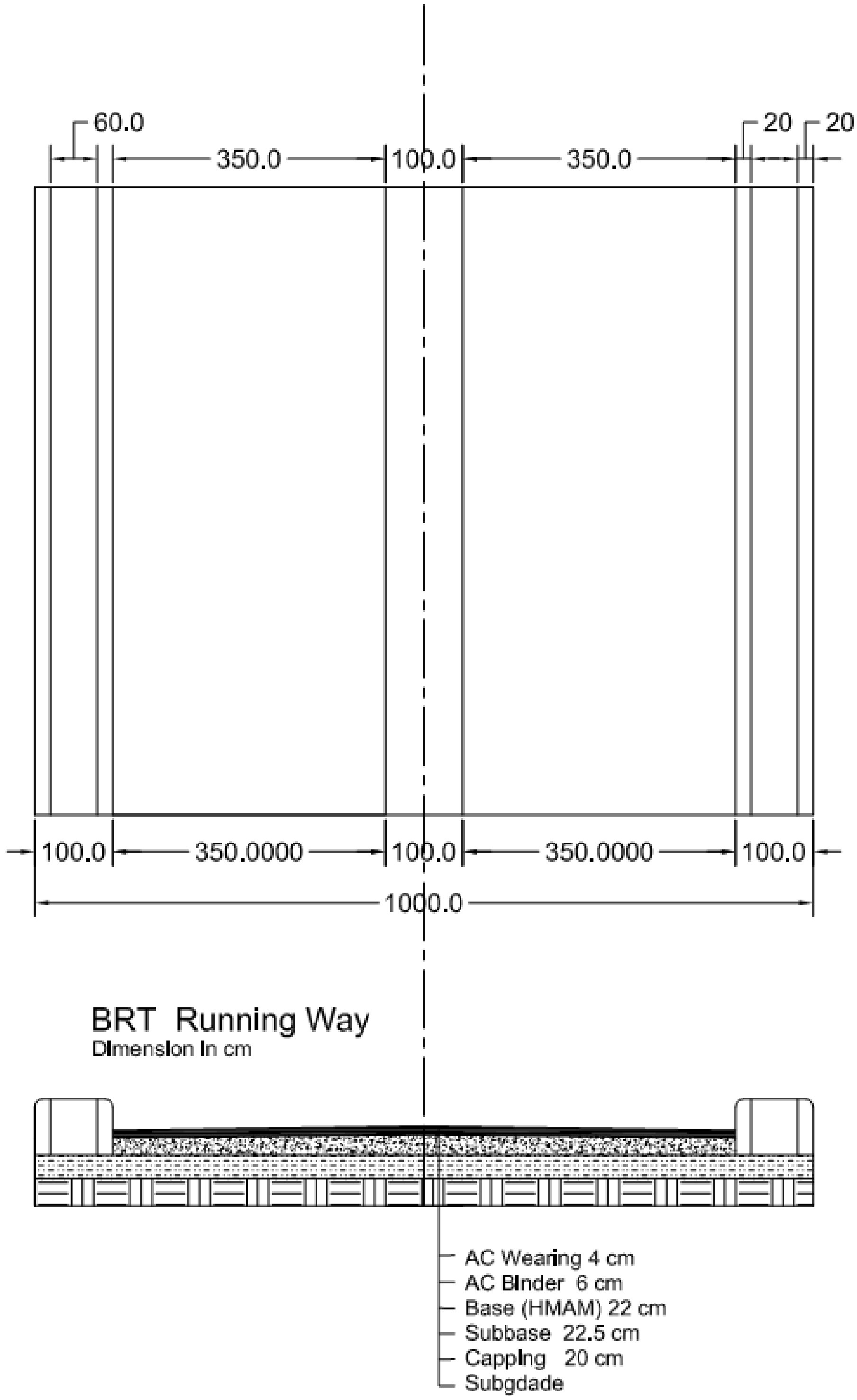


Figure. 6.3 Cross-Section of BRT

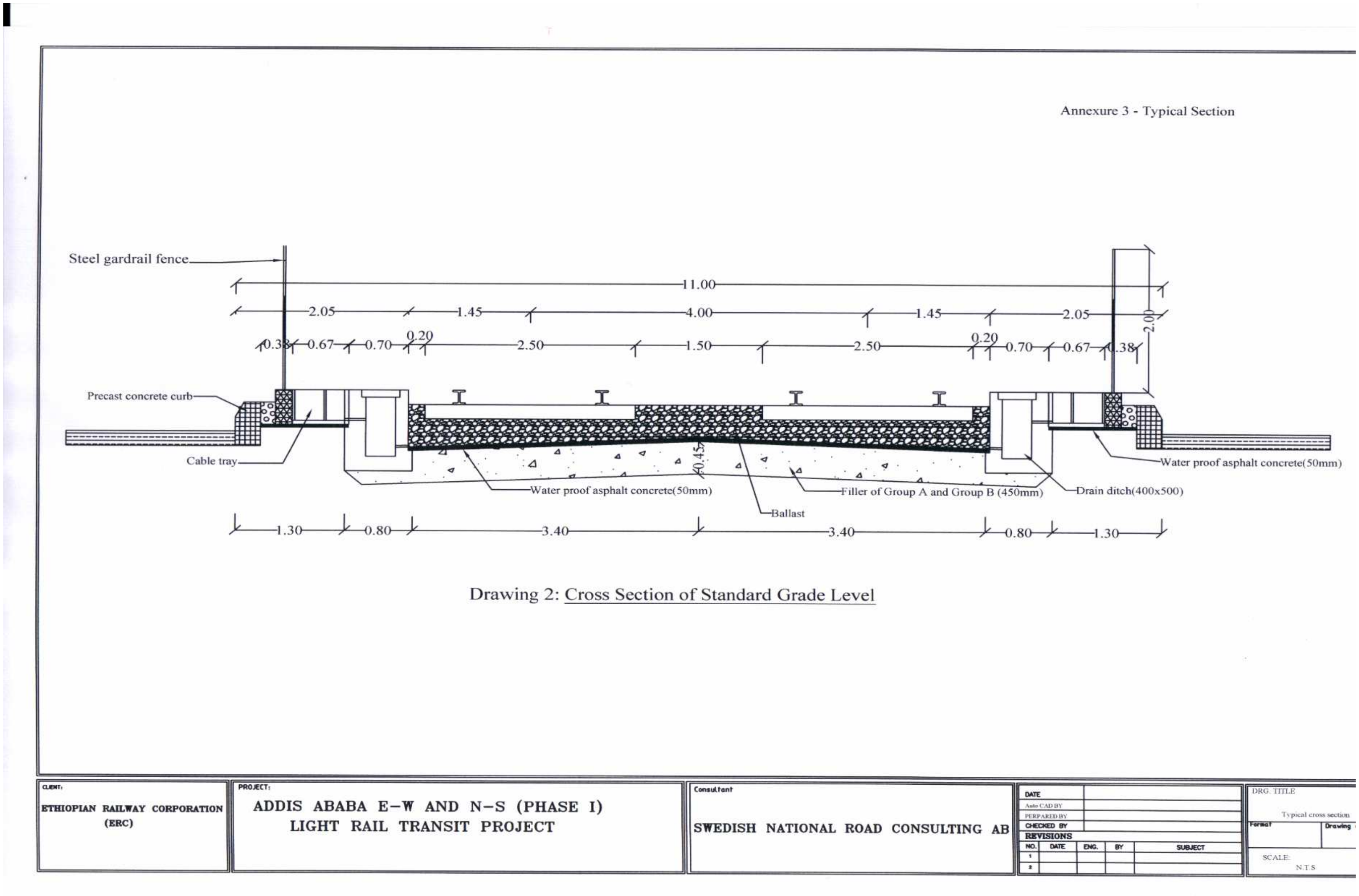


Figure. 6.4 Cross-Section of LRT

6.8 Environmental Impacts

In transit system, more passengers mean greater environmental benefit. To know the actual environmental impact of a mass transit project, one has to look at a number of factors: the impact the project has on modal shift, the vehicle kilometers traveled by the transit fleet before and after project implementation, % of deduction of the emissions as compared to the overall transport emissions, and the vehicle-specific emissions from the transit vehicles. The values are shown in Appendices F, G & H. Figure 6.5 shows the volume of greenhouse removed as a result of operation of LRT and BRT during projects lives.

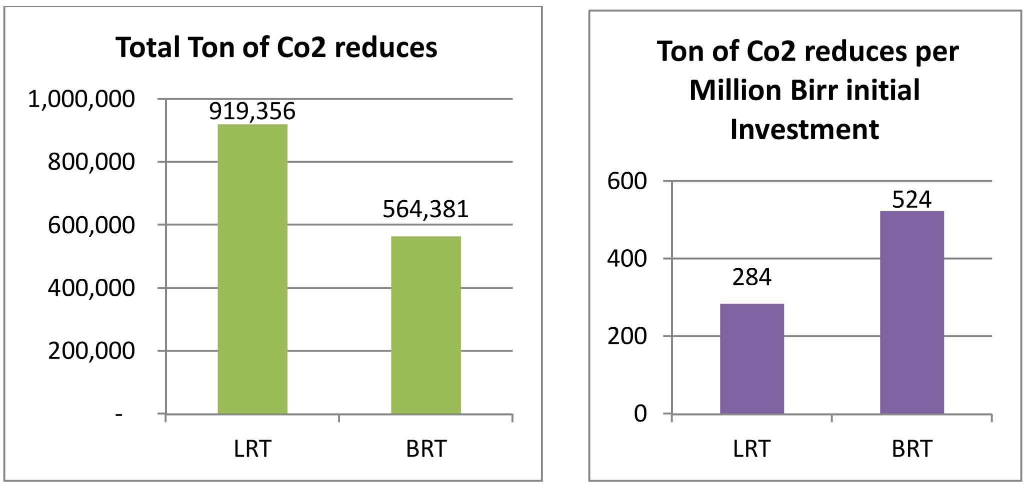


Figure 6.5: Greenhouse Gases Removed.

If we compare the LRT cars with the bus only, there is no question the LRT have great advantage since it uses electrical energy. But if we considered the overall effect, for instance with the ETB 3 billion around 12 km of LRT can be constructed but 40 km (the whole phase II) of BRT can be constructed with the same costs as observed in Table 5.8. That means more area can be serviced thereby reducing the number of small cars three times compared to LRT. The other main thing to be considered is the amount of emission reduction as compared to the other cars in the city. If the LRT reduces emissions by 5% or less, it is not justifiable to say the LRT was implemented for environmental reason. Even the number of BRT buses at opening year is less than 150 for both phases as compared to the number of cars in the city. This number of buses will have practically negligible effect, with less than 1% share of emission (for instance the GHG emission share of the Anbssa Bus Enterprise in the city for more than 600 buses is less than 1% of the total missions). In the future, as the number of buses increase, it is possible to purchase less pollutant and high fuel efficient buses or we can use biofuel and CNG (compressed Natural Gas).

7. Conclusion and Recommendation

7.1 Conclusion

A BRT system with dedicated right of way which has station length enough to accommodate two articulated buses at a time per direction (i.e. 40m or more) and passing lane at station can have a capacity of more than 30,000 pphpd using articulated bus of capacity 160 passenger.

The commercial speed of a trip mainly depend on distances between stops, the dwell time at station and intersection treatment. Since the maximum speed of both LRT and BRT cars are about 80 km/hr and the above factors are the same for both systems, the average trip speed of BRT is comparable to LRT.

The environmental effect of the LRT cars has great advantage to that of BRT buses with one - to - one comparison. The main thing to be considered here is the overall effect of the transit system emission reduction compared to other cars in the city, especially emission from small cars. The BRT system, due to their lower infrastructure cost, more network can be constructed for the same initial investment than the LRT system. Thus they cover more area and reduce or control growth rate of small cars thereby reduce emission as a whole. The BRT system has also comparable advantage over the LRT system in terms of environmental effect.

Due to bad image of normal bus, the BRT bus may be considered inferior quality to LRT cars. The cost of LRT car is up to 10 times BRT vehicle, therefore, it is possible to purchase more buses which have comparable interior quality even to aeroplane for half cost of a single LRT car.

The infrastructure construction costs of LRT is more than three times of BRT and the operation and maintenance cost of LRT is also higher than BRT. Due to this, the BRT have attractive benefit and short payback period that is advantages to work without subsidy and for sustainability of the system.

Comparative analysis of LRT and BRT system was conducted using economic parameters of NPV, IRR and BCR and it was found that the BRT system is a superior option to the LRT system

7.2 Recommendations

Operation flexibility and shortage of implementation time is extremely important in a growing city like Addis Ababa. Currently in Addis Ababa, passenger transport is getting worse by the day. Therefore, before the problems goes from bad to worse the choice of a transit system type must consider effective means to solve the problem within the shortest time possible, otherwise, the transport problem will continue for a very long time to come.

BRT is a better alternative to the LRT system without reducing the capacity and the quality of the service. The BRT options can be the best choice from the perspectives of cost efficiency, level of service offered to users and overall cost-effectiveness.

The choice of BRT as an effective option relates mostly to its relatively low infrastructure costs and ability to operate without or minimum subsidies. BRT's ability to be implemented within a short period also has proven to be a significant advantage. The flexible and scalable nature of BRT infrastructure also means that the systems can be cost-effectively adapted to a range of city conditions.

BRT can be implemented much quicker than rail modes and can be done in phases as the passenger demand dictates. This provides the greatest flexibility in meeting transit demand and the existing infrastructure can be utilized if BRT is implemented.
For the city which needs shorter term solution to urban transport problem and ease of operation, construction, design, with limited amount of budget BRT is a better solution.

There is still big room to develop BRT in the City of Addis Ababa and most of the newly constructed roads on major corridors have three lanes per direction and so. It is possible to designate one lane per direction for BRT without major reworks Thus, to solve transportation related problem in the city such as shortage of transport, congestion and accidents, BRT has to be implemented.

LRT is recommended on utilize the existing structure under Phase I which is already constructed and has to be fully utilized to get the desired benefits. The capacity of Phase I at opening year on 90% of the route is less than 3,000 pphpd but currently the demand for public transport on the routes is more than three times that and to accommodate the demand, normal bus and minibus must be there since the LRT alone cannot fulfill the existing demand with 41 trains. Besides solving the urban public transportation shortage, the main advantage of mass transit is reduction of congestion, accidents and emissions on general traffic due to removal of normal bus and minibuses from the road along the LRT routes especially on Stadium - Kality and Stadium - Megnagna - Ayat routes. Unless the LRT accommodates all the public transport demand on the routes and removes the normal buses and minibuses from the road, it is impossible to reduce congestion on general traffic, accidents and air pollution. Therefore, to get these benefits the capacity of the LRT has to be increase up to more than three times opening year capacity by increasing the number of trains up to 120 LRT single cars; otherwise, it is impossible to reduce traffic congestion, accidents from the general traffic which is the city's main transport related challenges.

7.3 Proposed Future Research Area

1. Identifying of Potential Mass Transit corridor in the City which can be easily implemented.
2. Evaluation of Phase I LRT Performance as compared to expected benefit or designed parameters.
3. The Effect of small taxi on the City Transport.

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Appendix

Appendix A: Equivalent Standard Axel Load (ESAL)

Mode Type	Design passenger flow /Direction/hr	Service (working) time (hr)			Number of bus pass (frequency)									Remark
		week day	Saturday	Sunday & Holiday	week day	Sunday	Sunday & Holiday							
Peak Hour														
BRT	5000	8			250.0									Weight of bus including 160 passenger = 28,000kg = 5.91 ESAL
LRT	5000	8								Axel load of bus kg				
70% of Peak hour										Front	Middle	Rear		
BRT	3500	6	12		131.3	262.5			Load (L)	8,000.0	10,000.0	10,000.0		
LRT	3500	6	12											Equivalent Axel load = (L/8160)^4.5
50% of Peak hour									L/8160	0.98	1.23	1.23		
BRT	2500	2	4	16	31.3	62.5	250.0						Sum	
LRT	2500	2	4	16					(L/8162)^4.5	0.91	2.50	2.50	5.91	Damaging Power
				Total	412.5	325.0	250.0							
					# pass/week		2,637.5							
					# pass/year		137,150.0		ESAL for the first Year				810,345.89	
									ESAL for the first seven Year r=9%				8,936,878.37	
									ESAL for the next 12 Year r=4%				23,148,721.95	
									ESAL for the last 10 year at design capacity				23,716,794.41	
									For design period ESAL				55,802,394.74	

Number of bus pass (frequency) = [(Design passenger flow /Direction)*Service (working) time(hr)]/ Capacity of Bus

# of bus pass/week = 5*weekday + Saturday + Sunday=5*412.5+325+250=2637.5

# of bus pass/year = # pass/week*52=2637.5*52=137,150.0

ESAL of bus /year= # bus pass/year*ESAL of a bus = 137,150.0*5.91=810,345.89 ESAL

Bus Travelled km/year = (# of bus pass/year) * Route cycle length(=24km) = 137,150*24 = 3,290,744.73 km

Appendix B: Operation Revenue of LRT

Year	passenger /year	Revenue (Million Birr)					Remark
		Fare	advertisement on bus	advertisement & rent on station	Carbon Credit	Total	
1							
2							# of day 330/year
3							
4	37.0	177.41	0.54	0.72*	3.59	182.26	
5	40.3	193.37	0.58	0.72	3.92	198.60	
6	43.9	210.78	0.64	0.72	4.27	216.41	
7	47.9	229.75	0.69	0.72	4.66	235.82	Fare revenue 0.4 birr/km
8	52.2	250.43	0.76	0.72	5.07	256.98	
9	56.9	272.96	0.83	0.72	5.53	280.04	
10	62.0	297.53	0.90	0.72	6.03	305.18	
11	64.5	309.43	0.94	0.72	6.27	317.36	
12	67.0	321.81	0.97	0.72	6.52	330.02	
13	69.7	334.68	1.01	0.72	6.78	343.20	
14	72.5	348.07	1.05	0.72	7.05	356.89	revenue from station 4000 birr/ month/ station
15	75.4	361.99	1.09	0.72	7.33	371.14	
16	78.4	376.47	1.14	0.72	7.63	385.96	
17	81.6	391.53	1.18	0.72	7.93	401.37	
18	84.8	407.19	1.23	0.72	8.25	417.39	
19	88.2	423.48	1.28	0.72	8.58	434.06	
20	91.8	440.42	1.33	0.72	8.92	451.39	
21	95.4	458.04	1.38	0.72	9.28	469.42	
22	99.2	476.36	1.44	0.72	9.65	488.17	
23	103.2	495.41	1.50	0.72	10.04	507.67	
24	110.9	532.2	1.61	0.72	10.78	545.34	112,000p/day
25	110.9	532.22	1.61	0.72	10.78	545.34	P=passenger
26	110.9	532.22	1.61	0.72	10.78	545.34	
27	110.9	532.22	1.61	0.72	10.78	545.34	
28	110.9	532.22	1.61	0.72	10.78	545.34	
29	110.9	532.22	1.61	0.72	10.78	545.34	
30	110.9	532.22	1.61	0.72	10.78	545.34	
31	110.9	532.22	1.61	0.72	10.78	545.34	
32	110.9	532.22	1.61	0.72	10.78	545.34	
33	110.9	532.22	1.61	0.72	10.78	545.34	
Total	2,521	12,099	36.6	21.6	245.2**	12402.7	

* For 15 station, 4000birr/month/station = 0.72 million/year
** 919,357 ton of carbon (15 USD/ton or 266.67 birr/ton)

Appendix C: Operation Revenue of BRT

Year	passenger /year	Revenue (Million Birr)					Remark
		Fare	advertisement on tramcar	advertisement & rent on station	Carbon Credit	Total	
1							
2							# of day 330/year
3							
4	37.0	177.41	0.54	0.72	2.21	180.87	
5	40.3	193.37	0.58	0.72	2.41	197.08	
6	43.9	210.78	0.64	0.72	2.62	214.76	
7	47.9	229.75	0.69	0.72	2.86	234.02	Fare revenue 0.4 birr/km
8	52.2	250.43	0.76	0.72	3.12	255.02	
9	56.9	272.96	0.83	0.72	3.40	277.90	
10	62.0	297.53	0.90	0.72	3.70	302.85	
11	64.5	309.43	0.94	0.72	3.85	314.94	
12	67.0	321.81	0.97	0.72	4.00	327.51	
13	69.7	334.68	1.01	0.72	4.16	340.58	
14	72.5	348.07	1.05	0.72	4.33	354.17	revenue from station 4000 birr/ month/ station
15	75.4	361.99	1.09	0.72	4.50	368.31	
16	78.4	376.47	1.14	0.72	4.68	383.01	
17	81.6	391.53	1.18	0.72	4.87	398.30	
18	84.8	407.19	1.23	0.72	5.07	414.21	
19	88.2	423.48	1.28	0.72	5.27	430.75	
20	91.8	440.42	1.33	0.72	5.48	447.95	
21	95.4	458.04	1.38	0.72	5.70	465.84	
22	99.2	476.36	1.44	0.72	5.93	484.44	
23	103.2	495.41	1.50	0.72	6.16	503.79	
24	110.9	532.22	1.61	0.72	6.62	541.17	112,000p/day
25	110.9	532.22	1.61	0.72	6.62	541.17	P=passenger
26	110.9	532.22	1.61	0.72	6.62	541.17	
27	110.9	532.22	1.61	0.72	6.62	541.17	
28	110.9	532.22	1.61	0.72	6.62	541.17	
29	110.9	532.22	1.61	0.72	6.62	541.17	
30	110.9	532.22	1.61	0.72	6.62	541.17	
31	110.9	532.22	1.61	0.72	6.62	541.17	
32	110.9	532.22	1.61	0.72	6.62	541.17	
33	110.9	532.22	1.61	0.72	6.62	541.17	
Total	2,521	12,099	36.6	21.6	150.5**	12308.0	

* For 15 station, 4000birr/month/station = 0.72 million/year
** 564,381 ton of carbon

Appendix D: Commercial Viability LRT

No	Cost (Million Birr)			Benefit Categories (Million birr)			Total Benefit	NPV*	Remark
	Capital	Operations and Maintenance	Total	Fare revenue	Carbon Credit	Advertisement & rent			
1	972**		971.81				0	-971.81	
2	1,296		1295.75				0	-1295.75	
3	972		971.81				0	-971.81	
4	-	146.33	146.33	177.41	3.59	1.26	182.26	35.93	
5	-	161.51	161.51	193.37	3.92	1.30	198.60	37.08	
6	-	176.05	176.05	210.78	4.27	1.36	216.41	40.36	
7	-	191.89	191.89	229.75	4.66	1.41	235.82	43.92	
8	-	209.17	209.17	250.43	5.07	1.48	256.98	47.81	
9	-	227.99	227.99	272.96	5.53	1.55	280.04	52.05	
10	-	248.51	248.51	297.53	6.03	1.62	305.18	56.67	
11	-	256.73	256.73	309.43	6.27	1.66	317.36	60.63	
12	-	267.00	267.00	321.81	6.52	1.69	330.02	63.02	
13	-	277.68	277.68	334.68	6.78	1.73	343.20	65.52	
14	1,300*	288.79	1588.95	348.07	7.05	1.77	356.89	-1232.05	
15	-	300.34	300.34	361.99	7.33	1.81	371.14	70.80	
16	-	312.35	312.35	376.47	7.63	1.86	385.96	73.61	
17	-	324.85	324.85	391.53	7.93	1.90	401.37	76.52	
18	-	337.84	337.84	407.19	8.25	1.95	417.39	79.55	
19	-	351.35	351.35	423.48	8.58	2.00	434.06	82.71	
20	-	365.41	365.41	440.42	8.92	2.05	451.39	85.99	
21	-	380.02	380.02	458.04	9.28	2.10	469.42	89.40	
22	-	395.22	395.22	476.36	9.65	2.16	488.17	92.94	
23	-	411.03	411.03	495.41	10.04	2.22	507.67	96.63	
24	1,300*	439.00	1739.16	532.22	10.78	2.33	545.34	-1193.82	
25	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
26	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
27	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
28	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
29	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
30	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
31	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
32	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
33	-	439.00	439.00	532.22	10.78	2.33	545.34	106.34	
Σ	5840	10020	15860	12099	245	58	12403	-3457	
					B/C	0.78			

*As the system capacity increases additional train will be purchased.

** based on project progress 30% of cost on 1st year, 40% on 2nd year & the rest 30 % on 3rd year

Appendix E: Commercial Viability of BRT

No	Costs (million Birr)			Benefit (Million birr)			Total Benefit	NPV	Remark
	Capital Costs	Operations and Maintenance	Total	Fare revenue	Carbon Credit	Advertisement & rent			
1	324.4		324.4				0.0	-324.4	
2	432.5		432.5				0.0	-432.5	
3	324.4		324.4				0.0	-324.4	
4		88.3	88.3	177.4	2.21	1.26	180.9	92.6	
5		98.2	98.2	193.4	2.41	1.30	197.1	98.8	
6		107.1	107.1	210.8	2.62	1.36	214.8	107.7	
7		116.7	116.7	229.7	2.86	1.41	234.0	117.3	
8		127.2	127.2	250.4	3.12	1.48	255.0	127.8	
9		138.7	138.7	273.0	3.40	1.55	277.9	139.2	
10		151.2	151.2	297.5	3.70	1.62	302.9	151.7	
11		155.5	155.5	309.4	3.85	1.66	314.9	159.4	
12		161.7	161.7	321.8	4.00	1.69	327.5	165.8	
13		168.2	168.2	334.7	4.16	1.73	340.6	172.4	
14	446.9	174.9	621.8	348.1	4.33	1.77	354.2	-267.6	
15		181.9	181.9	362.0	4.50	1.81	368.3	186.4	
16		189.2	189.2	376.5	4.68	1.86	383.0	193.8	
17		196.7	196.7	391.5	4.87	1.90	398.3	201.6	
18		204.6	204.6	407.2	5.07	1.95	414.2	209.6	
19	53.0	212.8	265.8	423.5	5.27	2.00	430.7	164.9	
20		221.3	221.3	440.4	5.48	2.05	447.9	226.6	
21		230.2	230.2	458.0	5.70	2.10	465.8	235.7	
22		239.4	239.4	476.4	5.93	2.16	484.4	245.1	
23		248.9	248.9	495.4	6.16	2.22	503.8	254.8	
24	670.3	264.9	935.2	532.2	6.62	2.33	541.2	-394.0	
25		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
26		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
27		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
28		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
29		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
30		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
31		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
32		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
33		264.9	264.9	532.2	6.62	2.33	541.2	276.3	
Σ	2252	6061	8313	12099	151	58	12308	3995	
					B/C	**1.48**			

Appendix F: Cost - Benefit Analysis LRT

Year	Costs (Million Birr)			Benefit (Million birr)				NPV DF= 10%	Remark
	Capital	Operations and Maintenance	Total	Travel time saving	Carbon Credit	VOC saving	Total Benefit		
1	971.8		971.8					-883.5	
2	1295.7		1295.7					-1070.9	
3	971.8		971.8					-730.0	
4	0.0	146.3***	146.3	197.1	3.6	179.9	380.6	160.0	112,000p/day
5	0.0	161.5	161.5	214.9	3.9	196.1	414.8	157.2	P=passenger
6	0.0	176.1	176.1	234.2	4.3	213.7	452.2	155.8	
7	0.0	191.9	191.9	255.3	4.7	232.9	492.9	154.4	
8	0.0	209.2	209.2	278.3	5.1	253.9	537.2	153.0	
9	0.0	228.0	228.0	303.3	5.5	276.7	585.6	151.6	
10	0.0	248.5	248.5	330.6	6.0	301.7	638.3	150.2	
11	0.0	256.7	256.7	343.8	6.3	313.7	663.8	142.7	
12	0.0	267.0	267.0	357.6	6.5	326.3	690.4	134.9	
13	0.0	277.7	277.7	371.9	6.8	339.3	718.0	127.6	
14	1300.2*	288.8	1588.9	386.7	7.1	352.9	746.7	-221.7	Additional
15	0.0	300.3	300.3	402.2	7.3	367.0	776.6	114.1	Train
16	0.0	312.4	312.4	418.3	7.6	381.7	807.6	107.8	
17	0.0	324.8	324.8	435.0	7.9	397.0	839.9	101.9	
18	0.0	337.8	337.8	452.4	8.3	412.8	873.5	96.4	
19	0.0	351.4	351.4	470.5	8.6	429.3	908.5	91.1	
20	0.0	365.4	365.4	489.4	8.9	446.5	944.8	86.2	
21	0.0	380.0	380.0	508.9	9.3	464.4	982.6	81.4	
22	0.0	395.2	395.2	529.3	9.7	483.0	1021.9	77.0	
23	0.0	411.0	411.0	550.5	10.0	502.3	1062.8	72.8	
24	1300.2*	439.0	1739.2	591.4	10.8	539.6	1141.7	-60.6	Additional train
25	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	64.9	
26	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	59.0	
27	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	53.6	
28	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	48.7	NPV = -170
29	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	44.3	BCR = 0.965
30	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	40.3	IRR = 9.45%
31	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	36.6	
32	0.0	439.0	439.0	591.4	10.8	539.6	1141.7	33.3	salvage value
33	-1624.1**	439.0	-1185.1	591.4	10.8	539.6	1141.7	100.2	
33									
	4215.6	10020.1	14235.7	13443.7	245.2	12267.0	25955.8	-170.0	
						B/C	**0.965**		

*As the system capacity increases additional train will be purchased.

** Salvage value of Train and Infrastructure.

*** For operation and maintenance cost of 70.57birr/vehicle–km. (Page - 62)

Appendix G: Cost - Benefit Analysis BRT

Year	Costs (Million birr)			Benefit (Million birr)			Total Benefit	NPV DF= 10%	Remark
	Capital	Operations and Maintenance	Total	Travel time saving	Carbon Credit	VOC saving			
1	324.4		324.4				0.0	-294.9	
2	432.5		432.5				0.0	-357.4	
3	324.4		324.4				0.0	-243.7	
4		88.3	88.3	197.1	2.2	179.9	379.2	198.7	
5		98.2	98.2	214.9	2.41	196.1	413.3	195.7	
6		107.1	107.1	234.2	2.62	213.7	450.5	193.8	
7		116.7	116.7	255.3	2.86	232.9	491.1	192.1	
8		127.2	127.2	278.3	3.12	253.9	535.3	190.4	
9		138.7	138.7	303.3	3.40	276.7	583.4	188.6	
10		151.2	151.2	330.6	3.70	301.7	635.9	186.9	
11		155.5	155.5	343.8	3.85	313.7	661.4	177.3	
12		161.7	161.7	357.6	4.00	326.3	687.8	167.6	
13		168.2	168.2	371.9	4.16	339.3	715.3	158.5	
14	446.9	174.9	621.8	386.7	4.33	352.9	744.0	32.2	New bus
15		181.9	181.9	402.2	4.50	367.0	773.7	141.7	
16		189.2	189.2	418.3	4.68	381.7	804.7	134.0	
17		196.7	196.7	435.0	4.87	397.0	836.9	126.7	
18		204.6	204.6	452.4	5.07	412.8	870.3	119.7	
19	53.0	212.8	265.8	470.5	5.27	429.3	905.1	104.5	Overlay
20		221.3	221.3	489.4	5.48	446.5	941.4	107.0	
21		230.2	230.2	508.9	5.70	464.4	979.0	101.2	
22		239.4	239.4	529.3	5.93	483.0	1018.2	95.7	
23		248.9	248.9	550.5	6.16	502.3	1058.9	90.5	
24	670.3	264.9	935.2	591.4	6.62	539.6	1137.6	20.5	New bus
25		264.9	264.9	591.4	6.62	539.6	1137.6	80.5	
26		264.9	264.9	591.4	6.62	539.6	1137.6	73.2	
27		264.9	264.9	591.4	6.62	539.6	1137.6	66.6	
28		264.9	264.9	591.4	6.62	539.6	1137.6	60.5	
29		264.9	264.9	591.4	6.62	539.6	1137.6	55.0	NPV = 2537.4
30		264.9	264.9	591.4	6.62	539.6	1137.6	50.0	BCR = 2.15
31		264.9	264.9	591.4	6.62	539.6	1137.6	45.5	IRR = 27.4%
32		264.9	264.9	591.4	6.62	539.6	1137.6	41.3	
33		264.9	264.9	591.4	6.62	539.6	1137.6	37.6	
	2251.6	6061.5	8313.3	13443.7	150.5	12267.0	25861.2	2537.4	
						B/C	**2.15**		

Appendix H: Carbon Credit and Fuel Saving

Variable	Maxibus	Midibus	Minibus	Unit	Source
Mode share	25%	25%	50%		CRGE
Vehicle load	90	25	9.2	Passenger-km per vehicle-km	Based on assumptions from CRGE calculations
Fuel Economy	45	25	15	Liters per 100 vkm	Average fuel economy based on national vehicle data and assumptions for the shares of mini, midi and large bus types from the CRGE calculations.
Fuel Economy	0.50	1.00	1.63	Liters per 100 passenger km	
Average Fuel Economy	1.1902			Liters per 100 passenger km	
Design passenger km	455,400,000.00			per year	112,000 passenger per day, trip distance 12km , 330 day per year
Fuel required	5,420,250.00			Liter per year	16.592birr/litre of diesel
Average Vehicle load BRT	136			passenger-km / VKM	based on load factor of 0.85 from Traffic count
BRT bus average fuel	62.5			Liters/100 vkm	From Anbessa Bus
BRT bus average fuel	0.460			Liters/100 passenger km	
Fuel required for BRT bus	2,092,830.88			Liter per year	
Net Fuel saving due to BRT	3,327,419.12			Liter per year	
Fuel saving due to LRT	5,420,250.00			Liter per year	89,932,7883.00 Birr/year
Emissions Factor	0.002487			Tons CO_2 / liter	From CRGC
CO_2 reduction due to BRT*	8,275.29			Tons CO_2	15USD/ton of CO_2
CO_2 reduction due to LRT*	13,480.16			Tons CO_2	

Source: - ERC- Climate Finance Project, Climate Finance Investment Plan-2013

*Amount of emission reduction for the service opening year

Appendix I Modal Split

The modal share of the mass transit can be calculated from the equation from NCHRP report.

$$P(m) = \frac{e^{-utility\ of\ mode\ m}}{\sum_{k=1}^{n} e^{-utility\ of\ mode\ x}}$$

Where: P (m) = the probability of using mode m for a given trip
n = number of modes available for a given trip

$Utility_m$ = *b* (IVTT) + *c* (OVTT) + *d* (COST)

Where

$Utility_m$ = utility function for mode *m*
IVTT = in-vehicle travel time (min)
OVTT = out-of-vehicle travel time (min)
COST = out-of-pocket cost (cents)
The selection of a mode is governed by its in-vehicle travel time, out-of-vehicle travel time, and cost. Based on methods published in NCHRP Report 365 the calibrating the coefficients *b, c,* and d approached as follow.

- In-vehicle travel time (IVTT) has a coefficient of *b* = 0.025
- Out-of-vehicle travel time has a coefficient of *c* = 0.050 which reflects the observation that time waiting for a vehicle is perceived to be twice as great as time spent inside a moving vehicle
- Cost coefficient *d* is computed as follows:

Where $d = \frac{(b)\ (1248)}{TVP\ (AI)}$

TVP the ratio of (value of one hour travel time)/ (hourly employment rate).
In the absence of other data *TVP*= 0.30
AI the average annual regional household income, ($) (2400birr/month=1440 $/year)
1248 is the factor that converts $/yr to cents/min.

No	Description	Minibus	small bus	Large bus	Articulated bus	MRT
	T1 travel time (min)	50	60	72	72	40
	T2 waiting time (min)	15	20	30	30	5
	Cost (cents)	30	20	15	15	24
	Ui	-4.167	-3.944	-4.383	-4.383	-2.983
	e^Ui	0.016	0.019	0.012	0.012	0.051
					sum Ui	0.110
	modal share %	14.04	17.53	11.30	11.30	45.83

Modal share

		Minbus	Small bus	Large bus	Articulated bus	MRT
T1 travel time (min)		50	60	72	72	40
T2 waiting time (min)		15	20	30	30	5
Cost (cents)		30	20	15	15	24
	Ui	-4.167	-3.944	-4.383	-4.383	-2.983
	e^Ui	0.016	0.019	0.012	0.012	0.051
	modal share %	14.036	17.529	11.302	11.302	45.831
d=b1248/tvp(ai)=0.025*1248/0.3/1440 =0.0722						
		Minbus	small bus	Large bus	Articulated bus	LRT
		50	60	72	72	40
		15	20	30	30	3
		30	20	15	15	24
	Ui	-4.167	-3.944	-4.383	-4.383	-2.883
	e^Ui	0.016	0.019	0.012	0.012	0.056
	modal share %	13.39	16.72	10.78	10.78	48.32
		Minbus	Small bus	Large bus	Articulated bus	BRT
		50	60	72	72	40
		15	20	30	30	2
		30	20	15	15	24
	Ui	-4.167	-3.944	-4.383	-4.383	-2.833
	e^Ui	0.016	0.019	0.012	0.012	0.059
	modal share %	13.07	16.32	10.52	10.52	49.57

Appendix - J Traffic Count

uni direction passenger traffic on Torhailoch -Jimma Jct from 6am-10pm (Monday)

No	Mode	Time (hr)																
		12	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	Minibus	206	215	272	240	193	189	140	146	150	162	204	249	243	228	172	123		3132
2	small bus	66	57	58	49	39	33	28	30	36	40	45	49	51	42	19	8		650
3	Large bus	9	10	13	12	10	8	6	5	7	11	12	13	12	8	5	2		143
4	Articulated bus	12	10	8	8	7	6	4	6	6	8	10	12	8	8				113

uni direction passenger traffic on Torhailoch -Jimma Jct from 6am-10pm (Saturday)

No		12	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	Minibus	148	165	170	175	160	165	154	145	141	146	151	160	168	165	147	91	0	2451
2	small bus	22	27	39	34	36	31	27	24	23	30	35	34	32	30	11	6	0	440
3	Large bus	6	8	8	7	7	5	4	3	5	8	8	8	8	5	4	1	0	96
4	Articulated bus	6	6	6	5	5	4	4	4	5	5	7	7	5	6	0	0	0	74

uni direction passenger traffic on Torhailoch -Jimma Jct from 6am-10pm (Sunday)

No		12	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	Minibus	113	114	125	125	120	110	95	102	100	104	108	12	119	117	81	63	0	1607
2	small bus	12	17	28	25	22	16	18	15	16	20	22	23	25	20	8	4	0	290
3	Large bus	4	6	6	5	4	4	2	2	5	6	5	7	5	4	2	1	0	67
4	Articulated bus	4	6	4	4	3	2	2	2	3	5	5	5	4	4	0	0	0	53