Performance Assessment of Addis Ababa's Light Rail Transit (LRT) Based on Sustainability Variables

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DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

Abdlemalik Mohammed

ABSTRACT

This paper examines how Addis Ababa's public transport conditions compare in terms of sustainability before and after the introduction of a proposed LRT system. The system was proposed in order to improve the infrastructure for commuters in the city and alleviate Economic, Social and Environmental problems within the existing system. The project has started operation since September 2015 with 70% of its finances coming from the China Exim bank and the rest from the government of Ethiopia.

The study tried to describe the real sustainability benefits of the urban mass transport system, especially in terms of how to quantify the determining indicators in specific and empirical terms to measure the extent of these benefits. Sustainability evaluation and enhancement can be accomplished in a scientific, reasonable and logical manner within the general planning as the beginning of improving progress toward sustainability development. Indicators such as travel time (timesaving), affordability, accessibility, employment, safety, modal shift, urban regeneration, air pollutant emissions, are used for the analysis.

LRT system has numerous evident gains in terms of alleviating the urban mobility challenges in the city. Nevertheless, it also has shortcomings on low average speed due to close gap between the stations, short radius curves and low operating speed of the trams.

Keywords: Light Rail Transit (LRT), Public Transport, Sustainable Transport, Sustainability indicators, Travel time, Emissions

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List of Abbreviations

LRT Light rail transit

CBD central business district

ERC Ethiopian Railway Corporation

ECMT European Council of Ministers of Transport

GIS Geographic Information System

VOC Volatile Organic Compounds

NOx Nitrous Oxide

CO Carbon Monoxide

CO2 Carbon dioxide

UNCED United Nations Conference on Environment and Development

EU European Union

EEA European Environmental Agency

MCA Multi Criterion Assessment

CBA Cost Benefit Analysis

WHO World Health organization

AOI Area of interest

GCP Geographic Control Points

GPS Geographic positioning systems

RII Relative Importance Index

VTTS Value of Travel Time Savings

AARTA Addis Ababa Road Transport Authority

AAIT Addis Ababa Institute of Technology

Acknowledgment

First of all, I thank Allah for making it all possible.

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CHAPTER ONE: INTRODUCTION

1.0 Background

Addis Ababa, capital city of Ethiopia, is currently facing rapid urbanization and high population growth. Overall population is expected to grow from 3.2 million to 5.5 million inhabitants by 2020 and reach double figures within the next two decades. Car ownership is still significantly low in Addis Ababa, though rapidly increasing mainly due to economic growth and the introduction of low cost private vehicles into the local market. Public transportation and Non-motorized transport, and particularly walking, still dominates the modal split for daily trips in Addis Ababa with most of total trips, whereas public transport service is not adequate to accommodate the respective demand.

Since most people in the city are relatively poor and cannot afford a private car, public transport is one of the most common transportation modes that can be accessed by the urban population where most of trips in Addis Ababa are made by walking and public transport. Like any other rapid growing city in the developing world, Addis Ababa has not escaped from the impacts of poor public transport services; improvements in Addis Ababa's public transit network will improve mobility for residents who currently rely on inefficient and unpredictable minibus and midi-bus bus services. It is in this respect the government has decided to implement a Light Rail Transit (LRT) System. The System is defined by a combination of these components together: main truck, Depot, stations and operational characteristics. A LRT system is described as public transport's response with an attempt to provide a tram competitive quality service

In many cities, urban rail transportation projects, i.e. the light rail, metro and tram systems over the years demonstrated itself as the optimal solution in providing sustainability mobility for the increasing urban population. This light rail also provides other benefits such as better comfort, medium-high carrying capacity, faster, more regular and safer. The light rail system is a large project that requires very high amount of investments, especially for the construction of infrastructure and maintenance costs. Apart from the economic benefits, the social and environmental improvement benefits are also derived from the rail system projects (Cascajo, 2004). Investing in transportation infrastructure does have continuing effects on both the transportation system and the sustainability system, i.e. economic, social and environmental, which interacts with transportation (Barrella, 2012).

The light rail is expected to provide the city with social, economic and environmental benefits which also needs to be assessed or measured using specified indicators that is related to ascertain its level of benefit to sustainability development.

The scope and contents of local indicators differ from one large infrastructural investment to another. Nevertheless, the main intention of a sustainability assessment is to include the most important local indicators in the assessment model. An assessment model with a comprehensive inclusion of key issues provides findings that will be very beneficial to an inclusive decision making ground to support development of policies and effective measures for a more sustainability urban future. Sustainability model is characterized with three main aspects, i.e., environmental, economic and social. It is not completely adequate just to gain the knowledge about the importance of indicators to achieve a sustainability transportation system. A framework in form of instruments is needed to determine if the transportation system is progressing towards sustainability. Therefore, a set of indicators is required to assess the progress in development of a sustainability urban transportation system, which may also serve many other purposes, such as benchmarking, evaluating effectiveness of policies and measures, comparing between two cities and monitoring the trend of progress towards sustainability development.

However there exist other not economic benefits, social benefits and environmental improvements-induced by such rail projects.

Therefore, it is required to develop an ex-post evaluation considering economic, social and environmental effects in order to find the real benefit provided by these projects and to justify these large investments.

The methodology is based on a multicriteria analysis which considers a number of criteria to achieve the global objective of sustainability

1.1 Statement of the Problem

The common perception about the real and quantifiable sustainability benefits of the urban public transport system is still poorly understood, especially in terms of how to quantify and assess these benefits. Over the years, the sustainability of infrastructures in Ethiopia has suffered a serious obstacle due to inadequate measures to assess its sustainability benefits for better decision making in the long term. The conventional methods of measuring the sustainability benefits of the light rail transit system are deeply rooted in the economic theory, depicting inadequacies in the perception of understanding by the local communities on the sustainability value of public transport.

This necessitates the development of a methodology to measure the social, economic and environmental effects and impacts generated by the urban transport investment projects.

Various aspects of the ways indicators are selected and applied in practice by local authorities including their ability to reflect objectives, their use in developing targets and to form a comfortable ground with which they are understood in the monitoring process.

Therefore, it is very important to identify specific indicators that are measurable in quantifying the sustainability benefits of the Addis Ababa light rail and use them to assess the extent of its benefits. This provides an informed situation where decision makers understands the trade-offs and comparison between different scenarios of the economic, environmental and social benefits and how each of them has more weight of importance than the other, thereby providing empirical and provable reasons for crucial decisions to be implemented. Especially this will help in the decision making of the next LRT phase two project.

1.2 Objectives of the Study

The main research objective is to show the impact of Addis Ababa's Light Rail Transit based on most significant sustainability development variables. Therefore, the specific objectives are:

- Identify the most significant indicators which are used in assessing the sustainability benefits of the urban light rail system
- Determining the weight of each indicator based on importance for global sustainability.
- Perform an analysis on empirical assessment of the most ranked indicators

1.3 Research Questions

- The main research question is:
- How do Addis Ababa's public transport conditions improved in terms of sustainability after LRT?

- Specific questions are:
- How much spatial coverage of Addis Ababa's LRT system?
- What are economic benefit indicators and variables of light rail transit?
- What are social benefit indicators and variables of light rail transit?
- What are environmental benefit indicators and variables of light rail transit?
- How do the weight of each indicator and the empirical assessment of the most ranked indicators can be shown based on importance for global sustainability.

CHAPTER TWO: LITRATURE REVIEW

2.1 Light Rail Transit

Light rail transit (LRT) system is a mass transport system that uses rail-based technology and typically operates in urban. Vehicles are usually relatively lightweight, run on steel rails and are driven by overhead electrical wires (Marko, Soskolne, et al., 2004),

The LRT has the potential to open up a new market for public transport travel in our cities, which has largely remained untapped by bus. Where demand can justify the volumes of patrons, a natural progression from a bus based system to LRT (modal shift) may occur on defined line haul routes. Moreover, LRT are meant for solving existing public transport system problems, if significant modal shifts towards urban public transport are to be achieved.

The success of light rail along defined corridors is attributed to its modern, reliability and effectiveness in moving commuters especially during peak periods to the central business district (CBD). Most commuters in the study area lives in the suburbs due to high cost of living in the CBD, but needs to transport to the CBD daily to work. The LRT system encourages people to plan their lives around the system with confidence, which ensures them with transport choices based on its availability. It also encourages businesses to develop along the routes, which in turn concentrates development, so that it can be more effectively served by public transport (ERC, 2009).

2.2 Sustainability development

Sustainable transport planning refers to transport policy analysis and planning practices that support sustainable development. Sustainable development constitutes environmental, social and economic objectives. Transport policy and planning decisions can have diverse, long-term impacts. A critical component of sustainable transport planning is the development of a comprehensive evaluation program that evaluates transport system performance based on an appropriate set of environmental, social and economic indicators. (Daniel and Litman, 2011)

The European Union's Sustainability Development Strategy defines transport sustainability as ''the ability to meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values today or in the future'' (Bojković, Macura, et al., 2011).

2.3 Transport Sustainability Benefits

It has been proposed many definitions for sustainable transportation. Of them, the common definition selected by the European Council of Ministers of Transport (ECMT, 2004) because it has a broad scope and recognizes specific transportation issues. According to this definition, a sustainable transport system:

- Allows the basic access and development needs of individuals, companies and society to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations.
- Is affordable, operates fairly and efficiently, offers a choice of transport mode and supports a competitive economy, as well as balanced regional development
- Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes, while minimizing the impact on the use of land and the generation of noise.

In achieving a reasonable level of sustainability, it depends on the integrated pattern of human actions, which therefore necessitates the coordination of deliberations between different actors and sectors. This consequently tries to achieve consistency between the local short-term and global long-term targets. (Litman, 2007).

Therefore, achieving benefits in a sustainability manner in the transport sector requires a very critical dimension of integrating the necessary elements capable of consistent management of the developed process.

2.3.1 Social Benefit Sustainability Assessment in Transportation

Developing indicators need the innovative use of data, as many variables can be put together into a quality life index, which helps to identify trade-offs amongst them. The experience in the United Kingdom (UK) shows how the use of conventional statistics, using socioeconomic or geographic statistics can provide a useful strategy for assessing social equity. This type of study would require census data, i.e, geopolitical boundaries, demographics, and available transportation statistics, which a Geographic Information System (GIS) could also support such analysis. The use of environmental justice and contextual sensitive solutions policies are some of the most common ways that the United States (US) agencies use to address social equity through consideration of the local context and a comprehensive public involvement process (Steg and Gifford, 2005). The Health Impact Assessment is an example of such method, which has started been put to use for transportation planning strategies both in the US and other countries. The Geographic Information System is one of the analytical tools used to assess sustainability in transportation plans (Macharis and Pekin, 2009), such as criteria selection, scenario building, healthy practices, and climate support initiatives (Barrella, 2012).

Generally the selected indicators should raise the following issues: (Tara Ramani, 2009)

- People must be able to interact with one another and with nature.
- A safe and secure environment must be provided.
- There must be equity between societies, groups, and generations.
- There must be adequate access to employment and other opportunities.
- It includes issues such as equity, safety, security, human health, education, and quality of life.

2.3.2 Environmental Benefit Sustainability Assessment in Transportation

Sustainability Transport is connected to travel framework that can meet up with the transport requirements more efficiently, while also reducing the undesirable impacts and its related costs over the long term at different geographic locations.

The environmental impacts of transport sustainability deal towards attaining a reduction in local atmospheric pollution, global warming, negative impact on plants and animals, impact of waste disposal on environment, e.t.c. This over the years has given rise to developments such as technology for more efficient waste disposal methods to reduce the waste disposal effects and its use for alternative fuel to decrease dependence on non-renewable resources, also reduce pollution from the energy use of fossils. (Whiteing and Stantchev, 2008).

Trains and buses provide a reasonable solution In order to reduce carbon dioxide (CO2) emissions from road transport by providing of a significant modal shift onto public transport. This initiative also facilitates state policies like greenhouse gas budget (Barrella, 2012).

The de-carbonisation of our transport networks will play a considerable part in meeting the challenging targets for carbon reduction. Climate change is the defining challenge of the 21st century. The Government is leading the charge internationally for global action on this key issue. It is also firmly committed to further action within the United Kingdom to reduce carbon emissions. The United Kingdom's Climate Change Act 2008 is the world's first national long-term legally binding framework. It commits the Government to cut emissions by at least 80% by 2050. To ensure the United Kingdom is on a cost-effective path to meet this target, the Act provides for a system of rolling, five-year carbon budgets for the United Kingdom. However, the delivery of carbon budgets will require action by businesses and individuals as well as Government, and local authorities will have an important role to play (Chapman, 2007). Investing in public transport, including light rail, can play a key part in meeting this challenge. This is why offering sustainability transport choices, at the local level is important, as short-distance, local trips are where the biggest opportunities for people to change the way they travel can be found given that two out of three journeys are under five miles. Light rail schemes in operation have contributed to the removal of car trips from overcrowded roads which have led to the reduction in the amount of pollution caused by car exhausts (Barrella, 2012).

The anthropogenic signal has now become increasingly evident in the climate record where the rate and magnitude of warming due to greenhouse gases is directly comparable to actual observed increases of temperature.

This is caused by the build-up of key greenhouse gases in the atmosphere accumulated from combustion of fossil fuels and land use changes over the 20th century. (Chapman, 2007).

2.3.3 Economic Benefit Sustainability Assessment in Transportation

The economic aspect of sustainability assessment in transportation is very important because it provides the enabling environment for investments to meet its profit margin and maintain the system. The concept of cost benefit analysis and multi criteria analysis is very useful in this dimension, which also consequently determines the extent of funding instruments such as user-cost financing, public-private partnerships and tax (Barrella, 2012).

There has been an underlying concept that transport infrastructure has the effect of promoting economic growth, especially among the politicians. However, according to Vickerman (2001) the correlation between transport infrastructure and economic growth is not so stable. It is difficult to assume a single causal direction of these two factors, regarding the high possibility of mutual interaction. According to Banister and Berechman (2001), it is widely agreed that the economic growth happens mainly due to capital, labour, etc. and only partly relying on the infrastructure improvement. Transport acts as a necessary condition for the growth to occur. Although there is no doubt about the direct effect that the transport infrastructure improvement contributes to cost savings of productive sectors, such as time saving.

Economic sustainability maintains a distinction between growth (increased quantity) and development (increased quality), which focuses on social welfare outcomes rather than simply measuring material wealth, and questions common economic indicators such as gross domestic product, which measure the quantity but not the quality of market activities (Litman and Burwell, 2006). Sustainability tends to show a conservation ethic, which means that production and consumption patterns are structured to minimize resource consumption and waste. This requires changing current economic policies that encourage inefficient production and consumption. Example, many countries minimize energy prices in order to keep utilities and driving affordable, and to encourage manufacturing. That reflects a consumption ethic.

A conservation ethic might increase energy prices, may be through a carbon tax while implementing programmes to protect buildings, increase vehicle fuel efficiency, improve alternative modes, and increase industrial efficiency so that manufacturers and consumers can meet their needs with less resource consumption (Litman and Burwell, 2006).

2.4 The Role of Indicators in Assessing Sustainability Transport

The overall planning process starts by using indicators, which includes consulting stakeholders, defining problems, establishing goals and objectives; identifying and evaluating options, developing policies and plans, implementing programs, establishing performance targets and measuring impacts (Litman, 2007). Indicators can reflect various levels, For example, indicators may reflect the decision-making process (the quality of planning), responses (travel patterns), physical impacts (emission and accident rates), effects this has on people and the environment (injuries and deaths, and ecological damages), and their economic impacts (costs to society due to crashes and environmental degradation).

Indicators arise from values and, in turn, they create values; therefore, the biggest advantage of an indicator-based urban sustainability assessment model is the quantifiability of the sustainability levels. Another instrumental purpose of using sustainability indicators is that, by visualising phenomena and highlighting trends, indicators simplify, quantify, analyse and communicate otherwise complex and complicated information. Depending on these qualities, indicators have attracted a wide range of interest, and this has led to generation of a large number of relatively successful urban sustainability assessment practices. The main difficulty faced while using indicators is to find a common unit and method of measurement leading to comparison of performance of a setting or policy package. Over the last decade, there has been an increasing effort to structure an indicator system and monitoring process to accurately formulate an integrated urban sustainability monitoring and assessment strategy (Tan Yigitcanlar, 2011).

An indicator can be expressed as a variable chosen within a scope to measure the development towards a planned objective. A very important approach to measure and evaluate transport sustainability is the use of indicators.

Definitions and characterization of sustainability transport systems help to define the scope of measurement using indicators. In the argument for using valid and reliable indicators for monitoring and evaluating transport,

In transportation, no single indicator is adequate to provide useful information for effective decision-making, therefore a set of indicators should be developed, reflecting various goals and objectives.

Indicators are mostly defined as quantitative measures that can be used "to illustrate and communicate complex phenomena simply, including trends and progress over time" (EEA, 2005). During the last two decades measurement of sustainability issues by indicators has been widely used by the scientific community and policy-makers. Development of sustainability development indicators was first brought up as a political agenda issue at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The UNCED policy declaration Agenda 21 requested countries at the national level and international governmental and non-governmental organizations at the international level to develop indicators in the context of improving information for decision-making (United Nations, 1992, Chapter 40). Since then, indicators are considered to be important tools for measurement of different aspects of Sustainability development, including transport related issues (Litman, 2007).

2.4.1 Criteria for selecting an Indicator

In most situations, no single indicator is adequate, so a set should be selected. An indicator set should reflect various goals and objectives. Indicators should be carefully selected to provide useful information.

There is internationally established and commonly used quality criteria that are used as a base in the selection of indicators. This part of the research briefly outlines basic indicator quality criteria used by various European and other international organizations. Afterwards, quality criteria specific for transport indicators are defined.

Quantitative policy targets for sustainability transport are presented as additional useful criteria for the selection of transport indicators.

In general, indicator quality criteria reflected in the policy documents of the international organizations commonly state that indicators must be clear and understandable, policy relevant, accessible, and reliable and the indicator data must be accurate. Most of the organizations in the European Union and World Health organization (WHO) agree that indicators should be the representatives of selected geographical or political area (Litman and Brenman, 2012). Timeliness is an important indicator quality criterion for the EU, Eurostat, European Environmental Agency (EEA) and OECD. The EEA and the UN take into account the number of indicators as an important quality aspect. Cost efficiency of indicators plays an important role for the OECD and UN indicator selections (Litman, 2007).

The following principles should be applied when selecting transportation performance (Todd Litman, 2007)

- Comprehensive – Indicators should reflect various economic, social and environmental impacts, and various transport activities (such as both personal and freight transport).
- Data quality – Data collection practices should reflect high standards to insure that information is accurate and consistent.
- Comparable – Data collection should be standardized so the results are suitable for comparison between various jurisdictions, times and groups. Indicators should be clearly defined. For example, "Number of people with good access to food shopping" should specify 'good accesses and 'food shopping.'
- Easy to understand – Indicators must useful to decision-makers and understandable to the general public.
- Accessible and Transparent – Indicators (and the data they are based on) and analysis details should be available to all stakeholders.
- Cost effective – The suite of indicators should be cost effective to collect. The decision- making worth of the indicators must outweigh the cost of collecting them.

- Net Effects – Indicators should differentiate between net (total) impacts and shifts of impacts to different locations and times.
- Performance targets – select indicators that are suitable for establishing usable performance targets..

In the area of transport, as in many other fields, indicators play a useful role in highlighting problems, identifying trends, contributing to priority setting, policy formulation and evaluation and monitoring of process, in this way informing the public and decision-makers.

On the basis of Vancouver principles (Organisation for Economic Co-operation and Development, 1996) Sustainability transport can be defined by the following criteria: Access, equity, health and safety, individual responsibility, integrated planning, Pollution prevention, land and resource use, education and public participation. In summary, comprehensive criteria defining sustainability transport system may help to define the scope of indicators for measurement of transport sustainability performance and may provide with the more complete overview of various aspects of transport sector (Barrella, 2012).

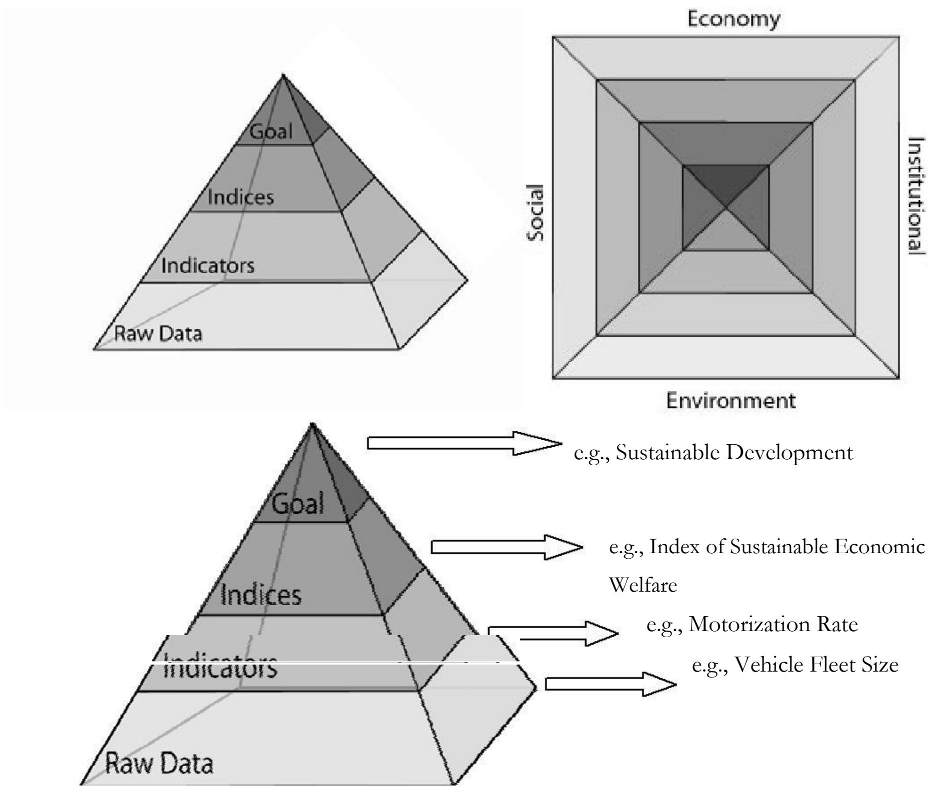
2.5 Evaluating the Real Sustainability Benefits of Urban Transportation

In many cities, urban rail transportation projects, i.e. the light rail, metro and tram systems over the years demonstrated itself as the optimal solution in providing mobility for the increasing urban population, considering sustainability as a core issue of relevance. This light rail also provides other benefits such as better comfort, medium-high carrying capacity, faster, more regular and safer. The light rail system is a large project that requires very high amount of investments, especially for the construction of infrastructure and maintenance costs. Investing in such a large project is far more expensive than the alternative transport mode of a new bus line, which indicates that the low financial profitability of the rail transport. Apart from the economic benefits, the social and environmental improvement benefits also derived from the rail system projects.
Zegras (2006) presented the sustainability indicator prism that innovatively represents the hierarchy of goals, indexes, indicators, and raw data as well as the structure of multidimensional performance measures.

As shown in Fig.1, the top of the pyramid represents the community goals and vision, the second layer represents a number of composite indexes around the selected themes, third layer represents indicators or performance measures building from raw data at the bottom of the pyramid. This concept can also be considered as the combination of Hart's category or issue lists (environmental, economic, and social aspects) with the goal-indicator matrix, which organizes indicators/indexes around a set of community goals or various sustainability issues. This framework is especially helpful when decision makers first set the community goals for sustainability around the essential dimensions of sustainability (environmental, economic, and social dimensions, etc.) and indicators and composite indexes are constructed based on the categorized goals and objectives.

The critical points that emerge from these constructs are that performance measures must be developed to capture a community's broader vision.

The Information Hierarchy through the Sustainable Indicator Prism



Source: Zegras, 2004..

Figure 1: Zegras's sustainability indicator prism (adapted from Hart, 1998).

2.5.1 Existing Assessment Techniques for Sustainability Benefits of Urban Rail Transport

Current practices in sustainability assessment

Jeon, 2010 used Multiple Criteria Decision Making (MCDM) approach for evaluating selected transportation and land use plans in the Atlanta US region using multiple sustainability parameters. A composite sustainability index was introduced as a decision support tool for transportation policymaking, where the sustainability index considers multidimensional conflicting criteria in the transportation planning process. They conducted a literature review on sustainability indicators from sixteen different initiatives around the world, including North America, Europe, Australia, and New Zealand (Jeon and Amekudzi, 2005).

Jeon and Amekudzi, (2005) addressed sustainability in transportation planning and provision seems to indicate a higher focus on the effectiveness of transportation systems as well as the resulting environmental impacts (mainly air quality impacts), and less of a focus on economic and social impacts.

The measurement using the monetary value shows more objectivity than the MCA, but does not factor in the non-monetized effects, such as the social and environmental which are more difficult to monetize, making the CBA approach non-useful in the transport assessment that includes the social and environmental objectives. While the MCA assesses collectively, the objective achievement through impact quantification, which is qualitative and quantitative, these have to be in monetary values. The MCA approach for measuring the criteria has its level of subjectivity but accommodates the use of both the quantitative and qualitative indicators. Another important method is the multi-criterion decision-making method, Elimination Et Choix Traduisant la Realite (ELECTRE), developed by Bernard Roy in 1991 in an effort to solve the inadequacies of the existing decision making techniques. The ELECTRE comprises of two main concepts, namely the threshold of indifference/preference and outranking relations that seeks to develop an outranking relation using thresholds. Considering these three methods, the MCA is still a more suitable technique to assess transport investment for the benefit of sustainability development, which takes into consideration the socio-economic and environmental factors (Cascajo, 2004).

2.5.2 Multicriteria Assessment Methodology

This approach is demonstrated also with the three aspects of sustainability development, namely environmental, social and economic benefits to be assessed. The evaluation carried out for transport investment is dependent in their comparison in different scenarios. In this method, the benefits will be evaluated by the difference between the reference scenario, i.e. scenario without the plan and the real scenario with the plan which both scenarios are referred to as the evaluation year, as shown in figure 2 below (Cascajo, 2004).

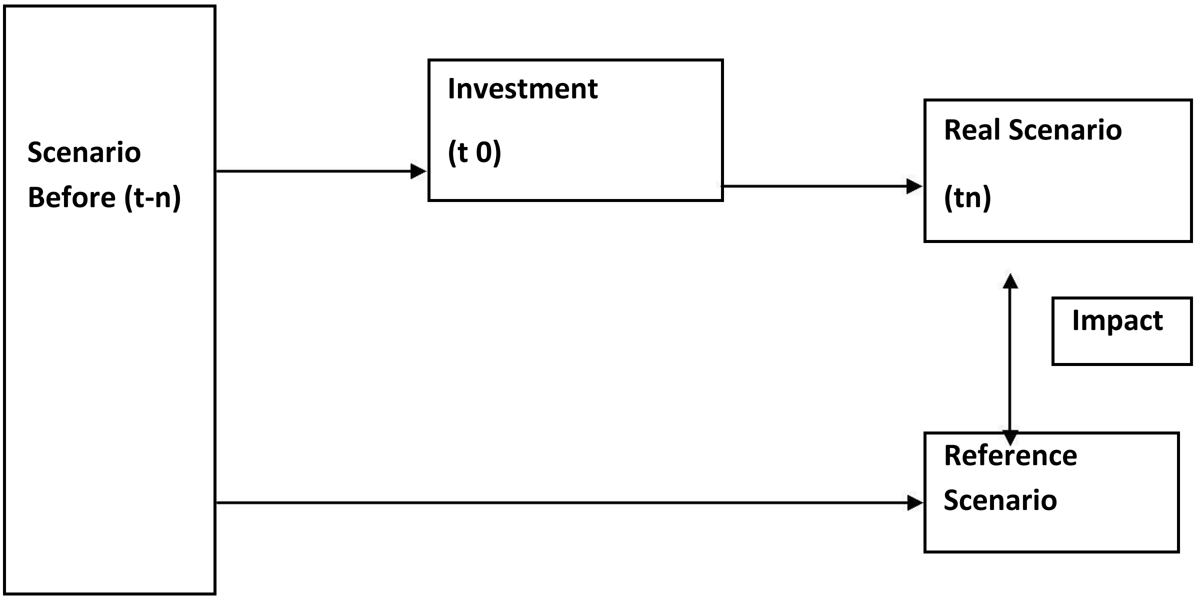


Figure 2: Evaluation Scenarios

(Cascajo, 2004)

In figure 2 above, considering the fact and taken into awareness that a specific number of objectives are to be evaluated, each objective will be evaluated in the two scenarios by one or even more criteria, which earns a value through one related indicator. This criterion is either qualitative or quantitative, measured with a proper indicator in numeric figures to ascertain its level of impact. These defined indicators quantify the criteria and are calculated in the reference and real scenario situation, to depict the final impact of a ratio of difference between reference and real scenarios. The second level in this approach is to allocate the homogenised indicators to every criterion to represent its relative importance to the overall objective of sustainability (Cascajo, 2004).

Thus, the final impact will be calculated as the weighted sum of all indicators multiplied with the weight allocated to its related criterion.

The level of achievement of each objective has to be expressed as a numeric value in order to quantify the final value of impact. Therefore, it is required from each topic under evaluation to define a procedure to convert the qualitative results into a numeric score.
The indicators defined for quantifying the criteria are calculated in the reference scenario and the real scenario, and the final impact will be the percentage of variation between reference and real scenarios (Cascajo, 2004).

When the individual effects have been measured, they have to be aggregated in a final single value: first of all, it is necessary to convert the range of every indicator's variation in a homogeneous one, from 0 to 1. This conversion will be done through value functions, one for each indicator. The value function will convert the indicator variation among scenarios in a homogeneous value scaled from 0 (no impact) to 1 (maximum impact). These normalized values will be the individual social utility for each criterion (Vicky Mabin and Michael Beattie, 2006).

The second step in the aggregation procedure is to assign the homogenised indicators to each criterion to represent its relative importance to the overall objective of sustainability. The final impact will be the weighted sum of all indicators multiplied by the weight assigned to their corresponding criterion (Vicky Mabin and Michael Beattie, 2006). The final formulation of the process will be the following:

$$\text{Socio + Economic + Environment Utility} = \sum W_i \alpha_i \qquad \textbf{(2.1)}$$

Where W_i are the weights and α_i the individual social utilities of each of the n indicators. Further assessment is prepared with respect to the objective of the three aspects of sustainability development, i.e. social, economic and environmental. This will produce an overview of its contribution to global sustainability in transport developments. To do this, a set of criteria is developed and its relevant indicators to measure it as well.

Table 1 shows some criteria and their indicators defined which are selected from different literatures. The table depicts eleven criteria, nine of them measured by quantitative indicators, while qualitative indicators measured two, haven gone through a consultation process with some principal actors of various cities participating like Stuttgart, Lyon, Madrid, Vienna, Manchester, Valencia and Abuja (Cascajo, 2004)

Table 1: Objectives, Criteria and Indicators for the overall assessment

Sub-Objectives	**Criteria**	**Indicators**	**Quantitative/ Qualitative Assessment**
Economic Benefits	Reduction of travel time	Total travel time saved by the project in both, public and private transport, between the scenarios	Quantitative
	Economic Efficiency	Difference between 'Fare revenues' and 'Operation costs'	Quantitative
	Employment Generation	Additional Regional Employment	Quantitative
	Economic Growth	Economic Development Effect	Quantitative
Social Benefits	Social Equity	Quantified questionnaire responses	Qualitative
	Increase in the use of PT	Increase in public transport (PT) trips per day	Quantitative
	Urban regeneration	Urban regeneration in the vicinity of PT	Qualitative
Environmental Improvements	Air Pollution	Reduction of pollutant Emissions (Tons/year of CO, SO_2, NO_x, lead, PM)	Quantitative
	Greenhouse effect	Reduction of emission of CO_2 (tons/year)	Quantitative
	Safety improvements	Reduction of accident costs per year	Quantitative

Source: (Cascajo, 2004)

In the table above the sub-objectives, which are in form of economic, social and environmental benefits are measured using measurable indicators with specific units to attain categories of criteria, using the qualitative and quantitative approaches. As seen above, the social equity and urban regeneration as a social benefit, has a qualitative approach, while all others have the quantitative approach.

2.6 Transport System of Addis Ababa

2.6.1 Transport before LRT

According Addis Ababa transport authority report on 2009, mobility was normal at 1.07 per capita trip rate; walking is the predominant mode (60.5%). Vehicular ownership is low. Vehicular trip rate is also low at 0.47 per capita. The main transport facilities in Addis Ababa is on the road network, which is used by Anbassa Bus Service, mini-bus taxi services, and number of rapidly increasing private motor vehicles.

Anbassa Bus Service and Mini-bus Taxi Service are the backbone of Addis Ababa's transport system. They provide limited mobility for the population but suffer from many constraints. Access to finance; an ageing bus fleet; inadequate infrastructure; an adverse external operating environment particularly due to severe traffic congestion; extensive competition, etc. have restrained the growth and efficiency of the various systems. They require rejuvenation and their route structure and service pattern improved. Future public transport capacity must be supplemented by medium and large capacity vehicles preferably incorporating some modern technology.

2.6.1.1 Hourly Distribution of the Demand in the LRT Corridor

Table 2 shows the recorded average hourly distribution in the corridor. While there are confirmed peak points from 07:20 to 10:20 and between 16:20 and 19:20, there is good midday demand.

Table 2: Hourly Distribution of the Demand Based on the LRT Corridor Data

From (hour)	To (hour)	Approximate Percent of Trips in the Corridor
0:00	4:00	0.00%
4:00	6:00	2.00%
6:00	9:00	30.00%
9:00	12:00	10.00%
12:00	13:30	10.00%
13:30	15:30	10.00%
15:30	21:00	32.00%
21:00	22:00	4.00%
22:00	24:00	2.00%
Total per 24 hours		100.00%

*Source: ERC, Feasibility study report, 2009

The major part of the LRT alignment route is located along existing streets which are serviced by buses, and taxis.

2.6.1.2 Transit Demand and its Characteristics before LRT

On an average day, Addis Ababa public transport system in the East-West and North-South corridors (Table 3) carried more than 1.2 million passengers on the Anbessa bus, Medi bus, mini bus and taxi network before construction of LRT. As most of the trips require transfers, the number of journeys per day is estimated to be approaching 2 million. The mini bus/taxi system carries over 0.5 million passengers.

Table 3: Daily public transit passenger volumes by modes

	Reported, passengers (2009)
MinibusTaxi	516,560
Midi Bus	326,118
Anbessa Bus	97,306
Other Support Buses	331,344
Total	1,271,328

*Source: Addis Ababa Transport Authority, 2009

2.7 LRT system

2.7.1East-West and North-South Corridors Overview

The Addis Ababa LRT covers the East-West and North-South transport corridors. The East-West corridor passes through the city centre from the eastern peripheries of the city to the west. In its final phase, the East-West corridor will connect suburban towns from the Oromia region such as Legetafo in the East and Sebeta in the West.

Major residential and real estate development locations at Ayat, CMC, Gurdshola and the area west of Torhailoch are accessed through this route. Meskel Square is the major public gathering location in Addis Ababa and Meganagna Square is an important transit hub and commercial centre. The East-West corridor crosses the ring road at Megenagna

In its final phase, it is proposed that the LRT route will connect to the future national railway hubs at Legetafo and Sebeta (ERC, 2009).

The North-South corridor is a heavily-used route; it is utilized to access Africa's largest open market at Merkato. The initial phase of the project starts from Giorgis (Piazza) in the north and heads a little distance to the west to access Merkato and Autobus Tera (the Intercity Bus Terminal).

Afterwards, the route heads south until it joins the East-West route at Lideta. From Lideta to Meskel Square both services have a common route until the North-South route divides to the south heading to the new Gotera interchange, Saris and Kaliti.

In its final phase the route will cross the ring road at Kaliti interchange and extend to a new railway hub at Akaki. The northern end of the route will be extended from Giorgis to Shiromeda (ERC, 2009).

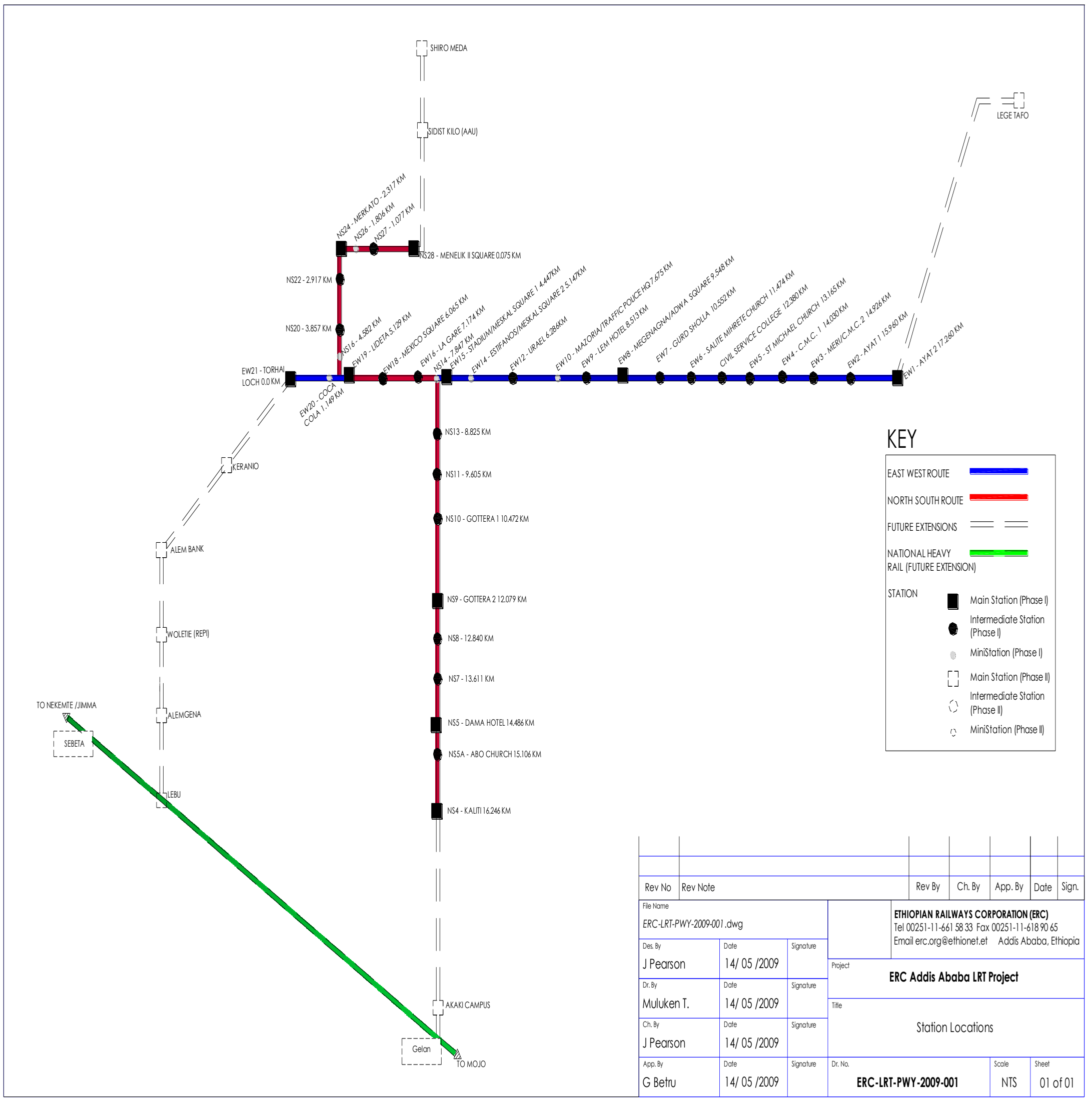


Figure 3: Schematic Diagram of Station locations (ERC, Design report of LRT, 2009).

2.7.3 Horizontal and Vertical Alignment Design Parameters

The design criteria were developed considering passenger comfort, safety, and accepted engineering practices used in currently operating rail transit systems of a maximum commercial speed of 60 km/h for primary track and 40 km/h for depot tracks. The alignment design parameters are presented in the Table 4.

Table 4: Alignment Design Parameters

Nominal Track Gauge	1435mm
Maximum Service Speed	60 km/h
Maximum Grade, typical	5%
Maximum Grade reduced distance	6%
Minimum Horizontal Curve Radius (MSF)	30m
Minimum Horizontal Curve Radius (main line)	50m
Crest	250m
Sag	350m

*Source: (ERC, Design report of LRT, 2009).

CHAPTER THREE: METHODOLOGY

3.1 Research Methods

The research methods used in this research are the questionnaire survey, and the experimental analysis. The questionnaire survey and interview will present a set of ten indicators for prioritization by the light rail experts, allocating a score to each indicator. These selected ten indicators will be scored based on the most significant approach, by the participatory selection of experts. Each indicator is given score separately under its sub division of economic, social and environmental which were selected from the already existing indicators in literature based on highest common factor, especially as it relates to its applicability in a developing country like Ethiopia. Thus, the first with the highest ranked score amongst the indicators are used for the experimental analysis for quantitative assessment to empirically determine its level of contribution to sustainability. While the second and third ranked indicators are discussed to understand the viability of its assessment.

3.2 Study Population and Sample Size

3.2.1 Study Population

The experts on the light rail development are the target group for the questionnaire administration. The private experts involved in the project are consultants employed for contract by the government to supervise the activities of the rail construction. While the other experts are related to federal government bureaus such as the Addis Ababa Transport Authority and Ethiopian Railway Corporation (ERC), Addis Ababa Urban Planning Institute.

These experts were selected for the participatory indicator scoring because of their relationship with this light rail infrastructural development as one of the major working group. Their knowledge and experience during the planning and implementation is useful in administering the questionnaire, scoring the indicators, thereby giving them score.

Respondents to be used in the thesis:

- The urban planners that involved in the planning of the light rail with regards to the city.
- Railway administrators who are in top railway administrative positions as decision makers, such as directors and head of departments.
- Engineers, Sociologists, Economists and Environmentalist that works related to the project.
- Each expert and Engineers within these stakeholders have a very high level of understanding concerning the recent developments on the urban light rail.
- Transportation Engineers, who work in Transport Bureau and have knowledge in LRT project.

3.2.2 Sample Size and Selection

The selected sample size for the experts is 50 with 95% confidence interval and the true mean to be within margin of error of 0.46 and check for the sample size is shown annex 2. The type of sampling used is the stratified random sampling. 41 respondents ended up filling the questionnaire out of the 60 copies distributed due to the fear of limited return rate. The percentage of respondents selected for all institutes is based on the number of professionals who are related to planning, decision making and construction of Addis Ababa light rail project.

Total 50 questionnaires are administered, 25 of respondents are professionals from (civil, mechanical and electrical/electronic engineers, sociologists, Economists and Environmentalists) who were working at the railway planning, construction, consulting or operation. The urban planner Institute (engineers, sociologists, Economists and Environmentalists) are 5 respondents which involved in the planning of the light rail with regards to the city. City administration (engineers, sociologists, Economists and Environmentalists) are 5 respondents, who are in top positions as decision makers, such as directors and head of departments and 10 respondents from transports Bureau (engineers). And the rest 5 respondents are from Universities (Railway Engineering students).

Each expert within these stakeholders has a very high level of understanding concerning the recent developments on the Addis Ababa light rail project.

These chosen 50 respondents within these different but interlinked experts were selected because each of the questionnaires administered is done under organizations that have a common goal and objective, i.e. mandate as a purpose to achieve that, which is directly related to their important roles in the light rail transit project. This selection is also because it is mainly the technical and top ranking officials of the related organizations in Addis Ababa that are involved in such technical oriented infrastructural projects. These technical staff from each organization directly or indirectly involved in planning, decision making, design and construction of this project. Due to this, they have technical information on the existing infrastructure; therefore it necessitates the selection method to give weight to the criteria and their respective indicators according to its importance.

It is recommended in the literature that selecting the most appropriate individuals can also be achieved through nomination process within each stakeholder organization (Sandford, 2007). The top ranking technical officers also nominated some of their technical staff known to them, working on the light rail project to respond to the questionnaires.

Users of LRT weren't selected for sample this is due to fear of biased (not sound) result on Environmental sustainability criterias and indicators, especially on Air pollution and greenhouse effect as most people relate sustainability concept only to social and economic aspect.

3.3 Variables and Indicators to be used in the Analysis

Ten variables and their indicators are selected for scoring from different literature. While three out of these ten indicators with the highest score will be operationalized and measured in order to quantify their sustainability benefits. The first with the highest ranked score amongst the indicators are used for the experimental analysis for quantitative assessment to empirically determine its level of contribution to sustainability. While the second and third ranked indicators are discussed to understand the viability of its assessment.

3.3.1 Criteria for selection of Indicators

It is necessary to determine a set of criteria in order to measure the three main objectives for the socio, economic and environmental evaluation of the transport projects related in terms of sustainable development.

For each group of sub-objectives, a set of criteria has been chosen in order to measure the benefits achieved due to the new infrastructure.

A. Economic Indicators

Reduction of travel time: This will be measured by the reduction of travel time, because the more savings in travel time the more operating costs are saved, and also the time saved has a value and could be used in other productive activities.

Transport fare Affordability: Transport user benefits in relation with the decreased transport fare due to the project under evaluation.

Employment Generation: The economic benefits for society are evaluated through the employment generation, since this infrastructure creates job opportunity.

B. Social Indicators

Proximity settlements of station: The improvement in accessibility is one of the greater social issues. Not all society has equal access to transport, and provision has to be made for those without access to a car or public transport system.

Increase in the use of mass transit: Public transport benefits everybody in a society, so the increase in the use of public transport will measure the social benefits achieved to all the citizens in relation to reducing congestion and better land use utilization.

Urban regeneration: The construction of a modern public transport infrastructure in deteriorated areas can produce an urban regeneration of the zone in which it has been built; there are also other benefits related to this regeneration, as the reduction of the level of crime, the attraction of new enterprises, the increase in quality of life, etc.

Safety improvements: Reduction of accidents associated to the project under evaluation.

C. Environmental Indicators

Air Pollution affecting air quality: pollutant emission from vehicle such as Carbon monoxide (CO), sulphur dioxide (SO2), nitrous gases (NOx), lead, particulate matter (PM) that have impact on Health by affecting lung, respiratory system, haemoglobin in the blood, nervous system, digestive problems, and in some cases cause cancer. The improvement of public health due reduction of air pollution is selected as one of environmental quality of life indicator.

Greenhouse effect: is the rise in temperature that the Earth experiences because of the presence of greenhouse gases (e.g. water vapour and carbon dioxide (CO2)), in the atmosphere that trap energy from the sun. This environmental indicator helps to measure how the selected infrastructure keep the study area liveable and at a temperature for life to flourish on Earth

Noise: Noise pollution levels (reduction of noise from road traffic due to introduction of LRT).

Table 5 below shows criteria, variable, indicators and methodology used for sustainability assessment of transport facility.

Table 5: Sustainability indicators selected from different literature and experts for the assessment

SN	Variables	Indicators	Instrument of Measurement for Anaysis
Economic Sustainability			
1	Reduction of travel(both peak and off peak hour)	Total travel time saved in between scenarios by the project in both the public and private transport	Geographical Information System (GIS) and simple Calculation
2	Employment Generation	Additional city employment	Scenario modelling and simple calculation using with and without situations of the light rail
3	Transport fare Affordability	Difference between the LRT fare and vehicle transport fare	Scenario modelling and simple calculation using the rail transit access fee as compared to the vehicle road transport
Social Sustainability			
4	Increase in the use of mass transport (public transport)	Increase in public transport trips per day, based on reduction of congestion and periods of availability	Scenario modelling and simple calculation using with and without situations of the light rail
5	Proximity settlements of station	Accessibility without extra cost	GIS for Spatial Analysis
6	Urban regeneration	Urban regeneration in the vicinity of light rail transit	GIS for Spatial Analysis for land use changes
7	Safety improvements	Reduction of accidents per year and death rate from vehicle accidents	Scenario modelling and simple calculation using with and without situations of the light rail
Environmental Sustainability			
8	Air Pollution affecting air quality	Pollutant emissions reduction in CO, SO2, NOx, lead, PM per tons/year of reduced vehicles compared to the light rail.	Scenario modelling for level of diesel fuel consumption per cycle, per day to be used and Pollutant emissions.
9	Greenhouse effect	Emissions reduction in CO_2 per tons/year of reduced.	Scenario modelling for level of diesel fuel consumption per cycle, per day to be used and Pollutant emissions.
10	Noise	Percentage of persons that are less affected by noise.	Scenario modelling.

3.4 Data Collection Methods

The data collection process involved four stages. The first stage is reviewing of relevant literature related to urban rail transport assessment using sustainability indicators which made to identify the key indicators and analysis methods.

The second stage involved the development of questionnaire incorporating score of indicators given by experts. The questionnaires comprised of open-ended and closed-ended questions. A hand delivered questionnaire method was used in order to minimize a low response rate.

The third stage focused Vector data extraction of road and rail line features by digitizing from the high resolution quick-bird image line data for the LRT and roads used by different modes of transport.

Finally Average speed of different modes of transport was determined by using all type of modes for consecutive 21 days both on peak and offpeak periods.

In summary the following are the primary and secondary data used for the study.

3.4.1 Primary Data

1. Questionnaire response from experts.
2. Addis Ababa Sat-X satellite imagery covering the Federal Capital Territory (FCT) and Quick-bird satellite imagery covering the whole area of Federal Capital City. This shows all the spatial coverage of the rail corridor using Arc gis 10.1.
3. Line data for roads in Addis Ababa using Arc gis 10.1.
4. Geographic positioning systems (GPS) location of rail stations and ground control points (GCP).
5. Waiting and access time recording on public transport station.
6. Average speed data for the road transport modes and LRT.

3.4.2 Secondary Data

1. Most significant sustainability indicators from literature review.

2. Feasibility study and design report of conceptual design of corridor 1and 2 of the Addis Ababa Light Rail Transit System.

3.6 Data Analysis Methods

3.6.1 Descriptive Statistics Analysis from Questionnaire Results

The data that is collected from the questionnaire is analysed first of all by using excel descriptive statistics software to generate the bar chart, representing the differences in the scores of the indicators according to the most significant.

Excel descriptive statistics is also used to generate a pie chart representing the percentage participation of the experts who administered the questionnaire. The information gathered from the questionnaire is based on figures to scores regarding the economic, social and environmental sustainability as listed in table 5.

3.6.1.1 Mean score and Weight of Each Indicator

This was used in determining the weight of each sustainability variables in terms of degree of importance. The respondents were asked to give score or quantify the indicators (out of 10) in order of importance in measuring the benefits of the light rail transit economically, socially and environmentally as a reason for investing and constructing the rail transport. The criteria were scored from 1 to 10, where 10 was the maximum importance with respect to sustainable development

Mean score value $(MS)_i = \sum F_i * S_i / N$ (3.1)

Where,

F_i = frequency of score given to indicator (i)

S_i = Score given by respondents for indicator (i) by respondents, ranging from 1 to 10,

N= the total number of respondents (sample).

Within this methodology it has been considered that the relative contribution of each sub-objective to sustainable development must be equal, and all the weights should sum 100 (∑weight=100). So, economic benefits must weight 100/3, social benefits 100/3 and environmental improvements also 100/3. This requirement makes normalisation of the Mean score (shown on Table 6). Thus, the final weights to be applied in the MCA procedure are those which appear in the "mean normalized" column.

3.6.2 Geospatial Analysis from Satellite Imagery and Light Rail Master Plan

The satellite imagery showing the spatial coverage of the rail corridor settlements and the whole study area acquired and used to extract relevant features such as roads, corridor 1 and 2 of the rail line corridors, rail station points and settlements with over lay analysis before further analysis will be carried out.

During field work four station corners selected as Ground Control Points (GCP's) and determined their coordinates using GPS for geo-referencing. The Area of Interest (AOI) is spatially geo-referenced to the projected coordinate system. The Ground Control Points (GCP's) is accurately referenced to its proper position with respect to the world. Hence, the satellite imagery is geo-referenced using the acquired Ground Control Points (GCP's) of already geo-referenced image of the same study area and confirmed with the four GCP's acquired with the GPS during fieldwork. The data are spatially created to its specific referenced location and their attributes are generated as a database that can be spatially analysed and saved in the GIS environment (ArcGIS10.1) software.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

In order to achieve the purpose of study, a methodology consisting of a review of literature and a survey were held with the planners of the systems as well as the officials working closely with the public transport sector of the city and the main stake holders which are related LRT construction to assess the sustainability of Addis Ababa's LRT projects, was depicted. This chapter therefore presents the survey results and findings of the desk study.

4.2 Score Result for Each Indicators Given By Respondents

4.2.1 Percentage of Respondents per Profession and Institution

The sampling technique used for the study is stratified sampling The percentage of each profession of expert is based on their involvement on the planning, decision making, design and construction stage of Addis Ababa light rail project. As seen in chart 1, From the total respondents completed their questionnaire, 13 % were Environmentalists, Economists and Sociologists each, 12 % were Railway Administrator and Urban Planners each as there decision is important in planning stage of the project. And 15 % were Transportation Engineers as they involve both on the planning and design stage of the project, and the rest 22 % were from Civil/Railway Engineers from the selected institutes for the study as they involve on planning, design and construction stage of the project.

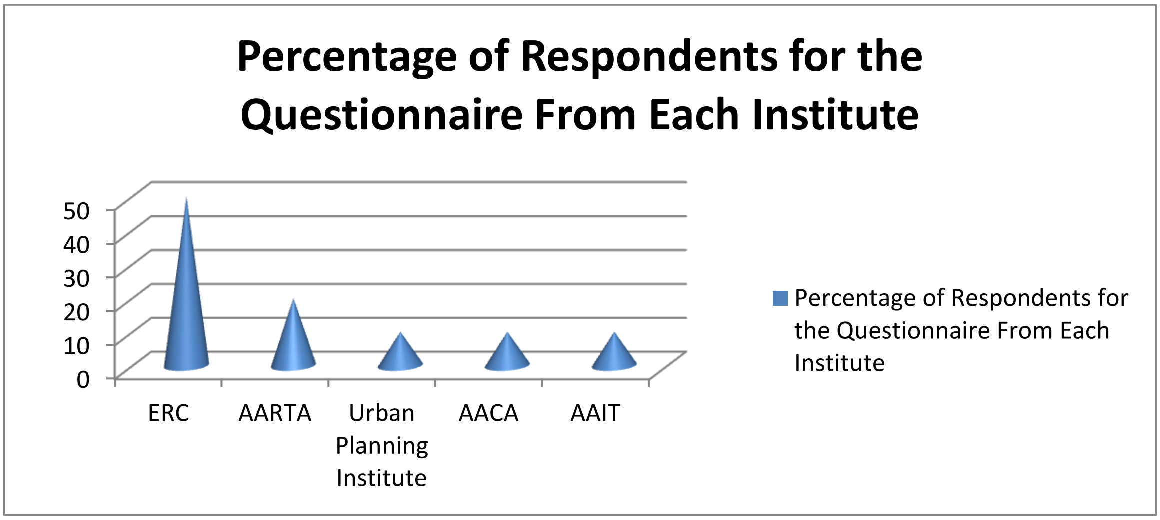


Chart 1: Percentage of Respondents from Different Institute

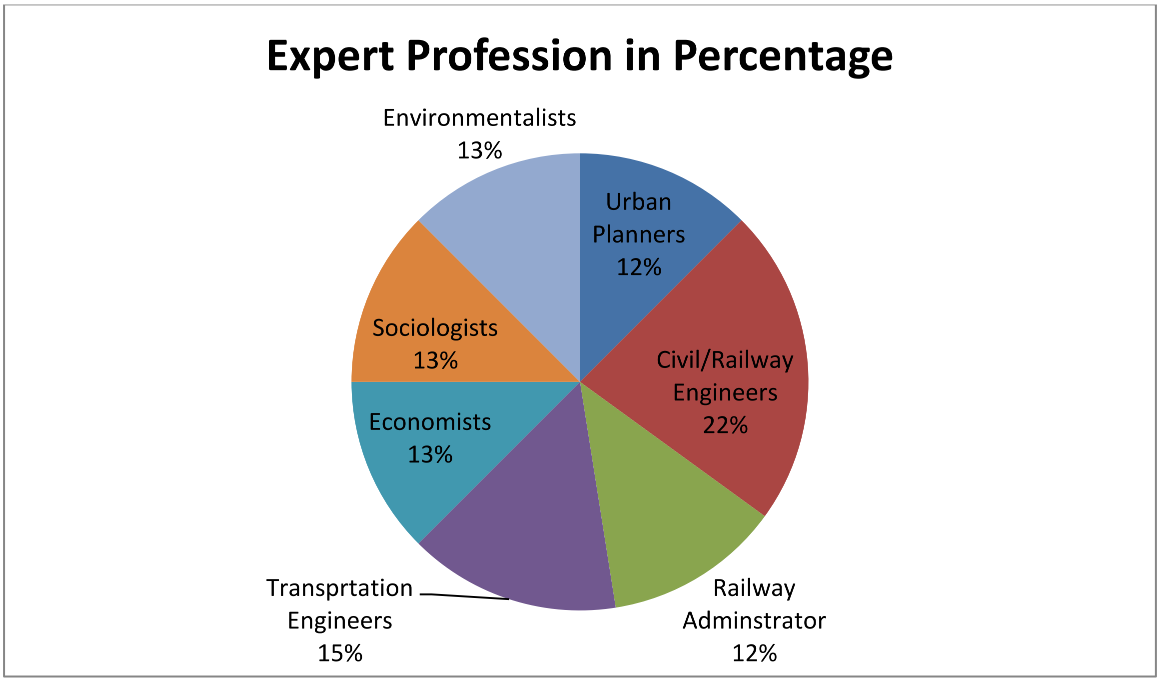


Chart 2: Expert profession in percentage

4.2.2 Score Result for Each Indicator

The summation and, mean score, weight and rank of each indicator are shown on the table 6 and chart 3 below. Accordingly, travel time as an economic sustainability indicator and reduction of air pollution and reduction of greenhouse effect as environmental sustainability indicator are the first to third most ranked score. Therefore based on the ranking of travel time and reduction of air pollution as the most ranked indicator respectively, this research will be based on the experimental approach assessment of the travel time and discussion on the viability of assessing the reduction of air pollution indicator and reduction of greenhouse effect for sustainability benefits of the urban light rail.

Table 6: Summary of the ten indicators, the total sum of the scores and their weight

SN	Variables	Summation of the score($\sum F_i * S_i$)	Mean score	Normalized Weight	Summation of Each Criteria Weight
Economic Sustainability					
1	Reduction of travel(both peak and off peak hour)	348.50	8.71	12.16	33.33
2	Employment Generation	296.00	7.40	10.33	
3	Transport fare Affordability	310.50	7.76	10.84	
Social Sustainability					
4	Increase in the use of mass transport (public transport)	308.50	7.71	8.69	33.33
5	Proximity settlements of station	273.50	6.84	7.71	
6	Urban regeneration	285.00	7.13	8.03	
7	Safety improvements	316.00	7.90	8.90	
Environmental Sustainability					
8	Air Pollution affecting air quality	338.00	8.45	12.15	33.33
9	Greenhouse effect	322.00	8.05	11.58	
10	Noise	267.00	6.68	9.60	
Total			76.63	100.00	100

As it is shown on the table 6 above, the summation of mean score value of the selected indicators is less than 100% hence the mean score value of each indicator is normalised based on clustered weighting given to each criteria (Economic, Social, and Environmental) to determine the weight of each indicator.

i.e

∑weight of social indicators = ∑weight of Economic indicators= ∑weight of Environmental indicators=33.33%

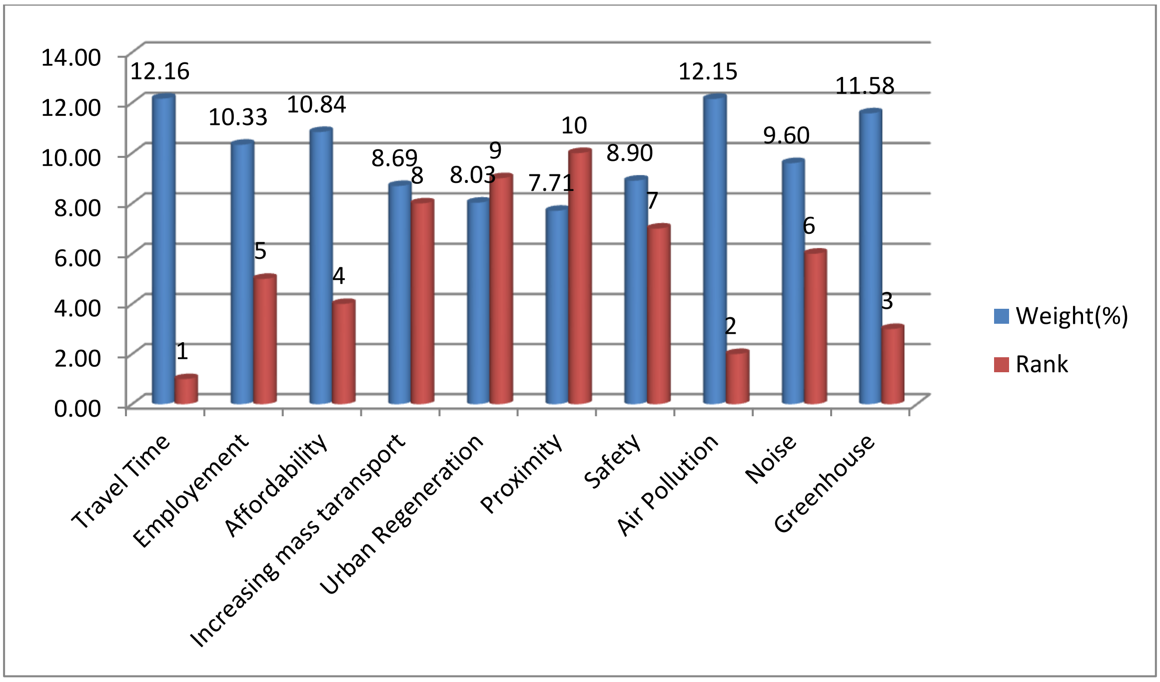


Chart 3: Weight and rank of each indicator based on importance for global sustainability.

On chart 3 above, travel time (timesaving) took the 1st rank position as the indicator with the most ranked figures of the maximum weight and reduction of air pollution is the 2nd rank position with 12.15% weight .Reduction of greenhouse effect indicator is 3rd position with 11.58% weight, affordability is 4th position with 10.84% weight, Employment generation is 5th position with 10.33 % weight, noise is 6th with 9.6 % weight, Safety is 7th position with 8.9% weight, Increasing mass transport is 8th position with 8.69% weight and urban regeneration as the 9th position with 8.09% weight, and proximity take last position with 7.71% weight.

Therefore, it implies that most of the respondents give higher weight for travel timesaving as their first choice by scoring it as highest value in the questionnaires and reduction in air pollution as their second ranked choice to sustainability benefit of the Addis Ababa light rail. These rankings as first to third for the travel timesaving, reduction of air pollution and reduction of greenhouse effect are the three indicators that will form the basis for the rest of the research.

Table 7: The first three indicators with the highest rank score were selected for analysis

SN	Variables	Indicators	Instrument of Measurement for Anaysis
Economic Sustainability			
1	Reduction of travel(both peak and off peak hour)	Total travel time saved in between scenarios by the project in both the public and private transport	Geographical Information System (GIS) and simple Calculation
8	Air Pollution affecting air quality	Pollutant emissions reduction in CO, SO2, NOx, lead, PM per tons/year of reduced vehicles compared to the light rail.	Scenario modelling for level of diesel fuel consumption per cycle, per day to be used and Pollutant emissions.
9	Greenhouse effect	Emissions reduction in CO_2 per tons/year of reduced.	Scenario modelling for level of diesel fuel consumption per cycle, per day to be used and Pollutant emissions.

The first most ranked indicator therefore qualifies for assessment and the second and third for discussion on viability of assessment.

4.3 Assessing the Sustainability benefit of total travel time saved by the light rail as compared to road vehicle transport scenarios

The average speed of the light rail varies with time due variation of stoppage time on stations on peak and offpeak periods, therefore the travel time of the light rail is compared with the travel time of the road vehicle, at peak and off-peak periods for lots 1, and 2 and the road along the same routes.

Table 8: key operating assumptions

SN	Assumptions	Default Level
1	Peak Hours per Day	8:30
2	Non-Peak Hours per Day	15:30
3	AM Peak Hours	3
4	PM Peak Hours	5:30
5	Service Days per Year	365

Source: Feasibility Study and Conceptual Design of Addis Ababa Light Rail Transit (LRT)

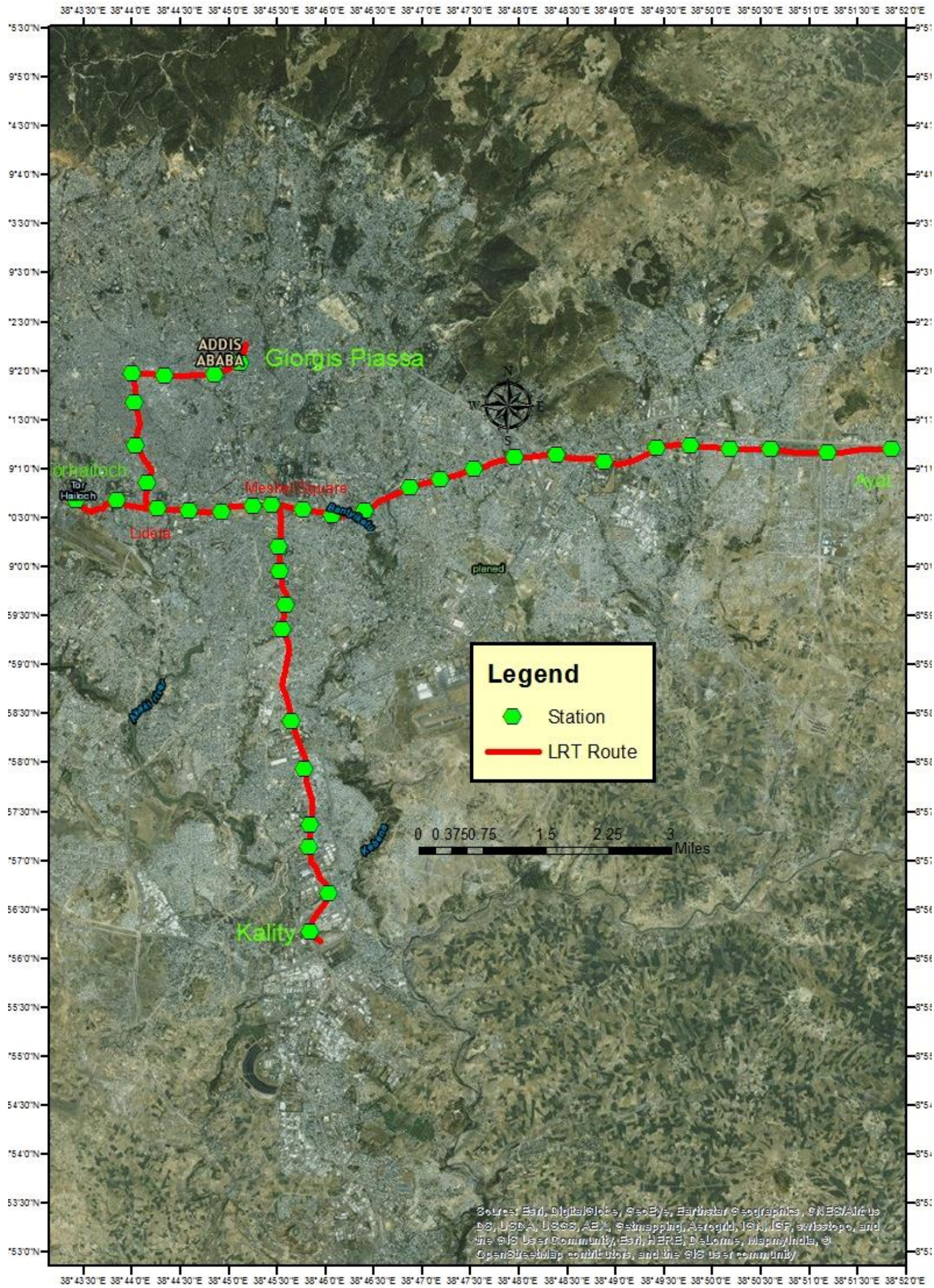


Figure 4: N-S, E-W Rail tracks and their Rail Stations

Figure 4 above shows E-W and N-S rail track lines colour red, to depict all the rail stations in green colours with a common change over rail station at Lideta, Tegbared, Mexico, Legar, and Stadium. This is carried out by digitizing the rail tracks line by line, with critical attention to end and start points to avoid the under shoot (digitizing below expected line length) or over shoot (digitizing beyond the expected line length) errors.

Table 10 and 12 show the distances as measured with the route measurement tool of the ArcGIS 10.1 software for the rail lot N-S and E-W. The average speed of each type of vehicle (Anbessa bus, Midi-bus, and Mini-bus) is studied by using each type of mode of transport mode under study and confirmed by interviewing many drivers as they have experience in using that road.

Thus, a total of 39 rail stations are available for the two lots (E-W and N-S), all having a major interchange at Lideta, Tegbared, Mexico, Legar, and Stadium station. According Addis Ababa light rail transit daily recorded data there is a (15-20) minutes headway time and addition of one minute stoppage time at each rail station during offpeak hours and one and half minute during peak hour, appreciating to its total minutes of stoppage time at each rail lot (ERC, 2016). The more the rail stations ahead at each rail lot, the more the stoppage time of one minute each at the rail stops. Hence there is more than twenty two minutes stoppage time on each the E-W and N-S lot.

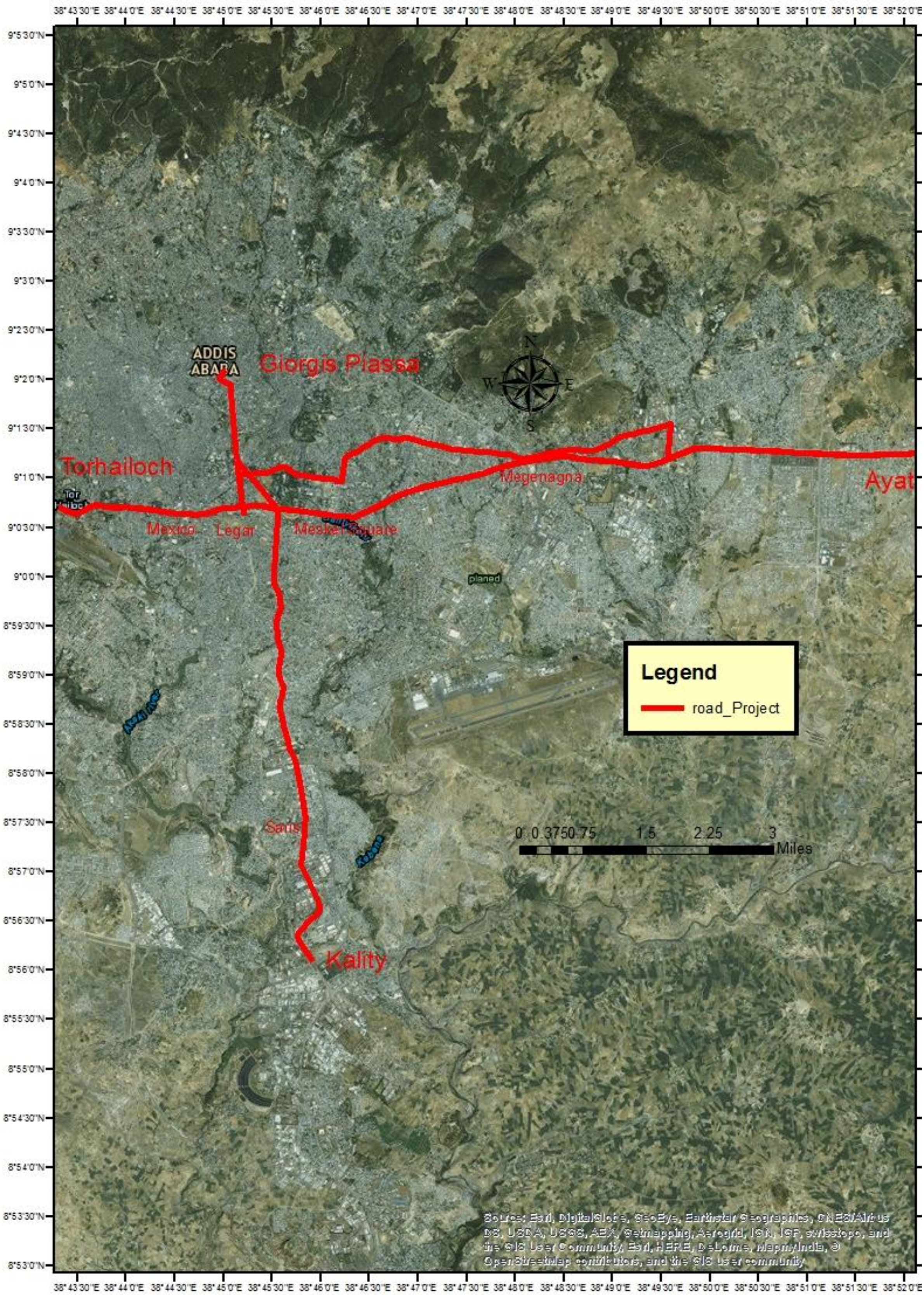


Figure 5: Road map showing the alignment from Piassa Giorgis to Kality, and Torhailoch to Ayat which are used by different mode of transport

Figure 5 shows the road measurements of the available road routes the commuters use. And it is measured using the ArcGIS 10.1 measurement tool. The results of the measurements from Piassa Giorgis to Kality and Torhailoch to Ayat by different kind of transport modes are described below in the tables.

Table 9: Shows routes taken by different kind of mode of transport in the two Lot.

Lot/Mode	Anbessa	Midi-bus	Mini-bus
N-S	Giorgis, Churchil, Ambassador, Meskel Square, Gotera, Saris, Kality	Giorgis, Churchil, Ambassador, Meskel Square, Gotera, Saris, Kality	Giorgis, Churchil, Legar, Meskel Square, Gotera, Saris, Kality
E-W	Torhailoch, Lideta, Mexico, Legar, Filwiha, Kasanchis, Megenagna, Ayat	Torhailoch, Lideta, Mexico, Legar,Meskel Square, Bambis, Urael, Megenagna, CMC, Ayat	Torhailoch, Lideta, Mexico, Legar,Meskel Square, Bambis, Urael, Megenagna, CMC, Ayat

The methodology used on the analysis is based on origin to destination of the light rail transit corridor and the analysis on travel time saved by LRT is based on data of key factors (inputs) that affect travel time. These are:

- Distance travelled by the vehicle
- Average Speed of vehicle
- Waiting time
- Access time

This method can clearly shows the pros and cons of LRT on each factors (inputs) compared to the road transport modes. In this regard, it shows which factors affected the travel time and how to improve it on next phase of LRT project.

The following four tables shows, the distance covered by each mode on both road and rail routes using Arc gis software. And the average speed of the vehicles was determined based on the continuous observation and recording of average speed of vehicles for consecutive 21 days.

Total of 182 vehicles were used for the study (98 vehicles from E-W lot and 84 vehicles from N-S lot) both at peak and offpeak hours with 95% confidence interval and error of estimation (<2minute) shown on annex 3. Access time was determined by recording the time spent by walking to transfer from one vehicle to the next. Besides, the waiting time spent by Midi-bus and Mini-bus transport users on each station was determined by recording and interviewing public transport user on both corridors and at peak and offpeak periods. The headway schedule time was used for waiting time of Anbessa bus both on peak and offpeak periods incorporating early and late arrives. On the other hand all data on LRT was taken from Addis Ababa light rail transit office (kality).

Hence, Total travel time = In vehicle travel time + Waiting time + Access time

In vehicle time = Distance travelled/Average speed (4.1)

Table 10: Shows the total travel time taken by E-W LRT, and other mode of transport on peak hour

Peak hour	LRT	Anbessa P.T		Midi-bus		Mini bus taxi		
	Tor hailoch - Ayat	Tor hailoch-Legar	Legar-Ayat	Tor hailoch - Mexico	Mexico-Ayat	Tor hailoch-Mexico	Mexico-Megenagna	Megenagna - Ayat
Distance measured by GIS(meters)	17350	3650	15010	2641	14359	2641	7025	7334
Average Speed(km/hr)	15.8	6.6	10.6	6.3	11.2	7.9	15.7	13.8
In vehicle Time(min)	66	33	85	25	77	20	27	32
Access Time(min)			5		10		5	5
Waiting Time(min)	15	10	15	10	20	10	20	15
Total Time(min)	81	148		142		134		

Table 11: Shows the total travel time taken by E-W LRT, and other mode of transport on offpeak hour

Offpeak hour	LRT	Anbessa P.T		Midi-bus		Mini bus taxi		
	Tor hailoch - Ayat	Tor hailoch - Legar	Legar-Ayat	Tor hailoch - Mexico	Mexico - Ayat	Tor hailoch - Mexico	Mexico-Megenagna	Megenagna-Ayat
Distance measured by GIS(meters)	17350	3650	15010	2641	14359	2641	7025	7334
Average Speed(km/hr)	20.0	8.8	13.9	10.6	14.1	15.8	21.1	20.0
In vehicle Travel Time(min)	52	25	65	16	61	11	20	21
Access Time(min)			5		10		5	5
Waiting Time(min)	18	10	15	10	20	5	5	5
Total Time(min)	70	120		117		82		

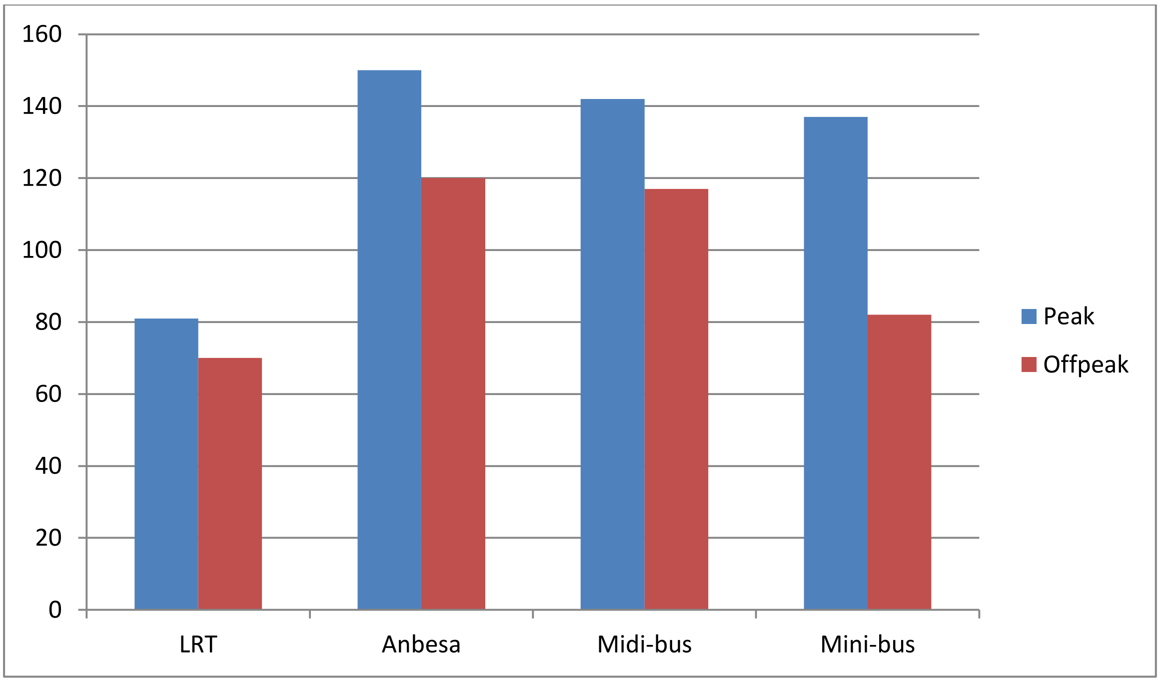


Chart 4: Shows total travel time taken by E-W LRT, and other mode of transport both in peak and off peak hours

Table 10 and 11, and chart 4 show time spent by different kinds of transport modes including Addis Ababa LRT from Torhailoch to Ayat both on peak and offpeak hours. Hence taking trip by Anbessa bus would take longest time compared to LRT, Midi-bus and Mini-bus both on peak hour and off peak hour. And taking trip by LRT would take smallest time compared to Anbessa, Midi-bus and Mini-bus both on peak and offpeak hour. This is due to Anbessa, Midi-bus and Mini-bus take longer stoppage, access and waiting time during offpeak hours and also road congestion would cause another additional time during peak hours. Besides Anbessa bus take the longest route compared to the others.

Table 12: Shows the total travel time taken by N-S LRT, and other mode of transport on peak hour

	LRT	Anbessa P.T		Midi-bus		Mini bus taxi	
Peak hour	Giorgis - Kality	Giorgis-Saris	Saris abo-Kality	Giorgis - Saris Abo	Saris Abo-Kality	Giorgis - Saris	Saris-Kality
Distance measured by GIS(meters)	16900	9094	2723	9294	2525	12400	2723
Average Speed(km/hr)	16.5	6.8	16.3	7.4	15.2	14.9	16.3
In vehicle Travel Time(min)	63	79	11	75	10	50	11
Access Time(min)			3		5		2
Waiting Time(min)	15	15	15	20	10	10	5
Total Time(min)	78	123		120		79	

Table 13: Shows the total travel time taken by N-S LRT, and other mode of transport on offpeak hour

OffPeak hour	LRT	Anbessa P.T		Midi-bus		Mini bus taxi	
	Giorgis - Kality	Giorgis-Saris	Saris-Kality	Giorgis - Saris Abo	Saris Abo-Kality	Giorgis - Saris	Saris-Kality
Distance measured by GIS(meters)	16900	9094	2723	9294	2525	12400	2723
Average Speed(km/hr)	20.3	9.9	32.7	11.2	30.3	24.8	20.4
Travel Time(min)	50	55	5	51	5	33	8
Access Time(min)			3		5		2
Waiting Time(min)	18	15	15	20	10	10	5
Total Time(min)	68	95		91		58	

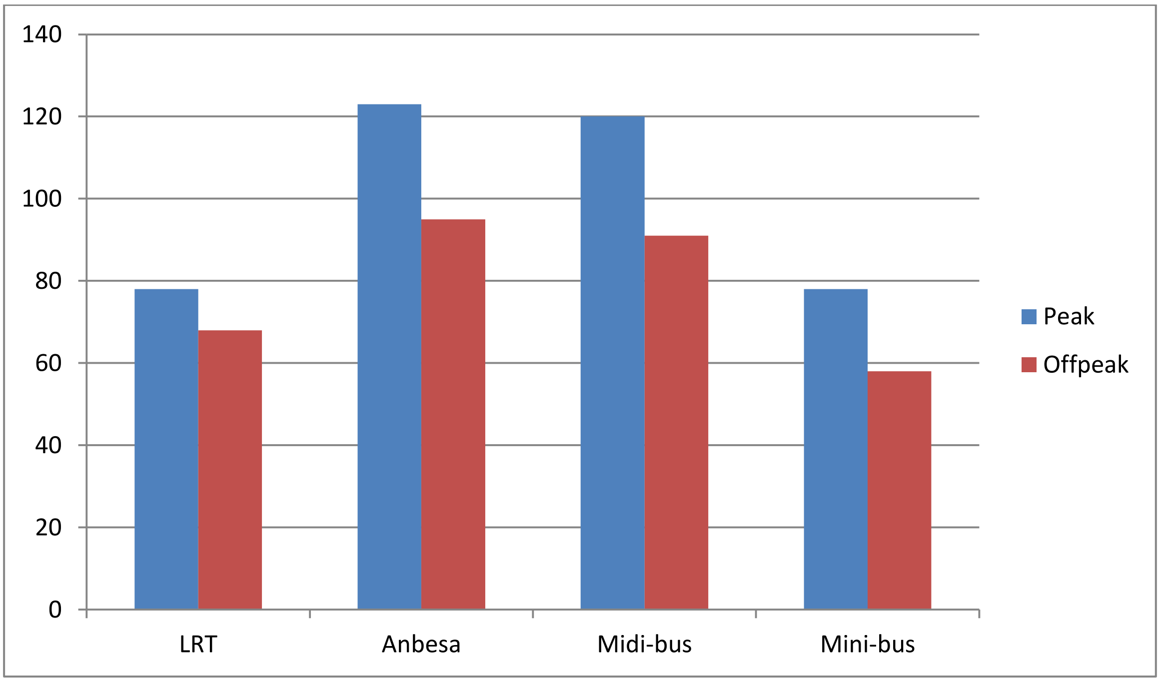


Chart 5: Shows total travel time taken by N-S LRT, and other mode both in peak and off peak hours

Table 12 and 13, and Chart 5 show time spent by different kinds of transport modes including Addis Ababa LRT from Piassa Giorgis to Kality both on peak and offpeak hours. Hence taking trip by Anbessa bus and Midi-bus would take longer time compared to LRT and Mini-bus both on peak hour and off peak hour.

And taking trip by LRT would take smallest time compared to Anbessa, Midi-bus and Mini-bus both on peak hours but during offpeak hours Mini-bus take smallest time. This is due to Anbessa, Midi-bus and Mini-bus take longer stoppage, access, waiting time and additional time spent due to road congestion during peak hours. But during offpeak hours Mini-bus has higher average speed than the other modes hence it has a better timing.

Table 14: Summary of Timesaving by E-W LRT compared to other modes

E-W route	Anbessa	Midi-bus	Mini-Bus
Off Peak Hour	50	47	12
Peak Hour	67	61	53

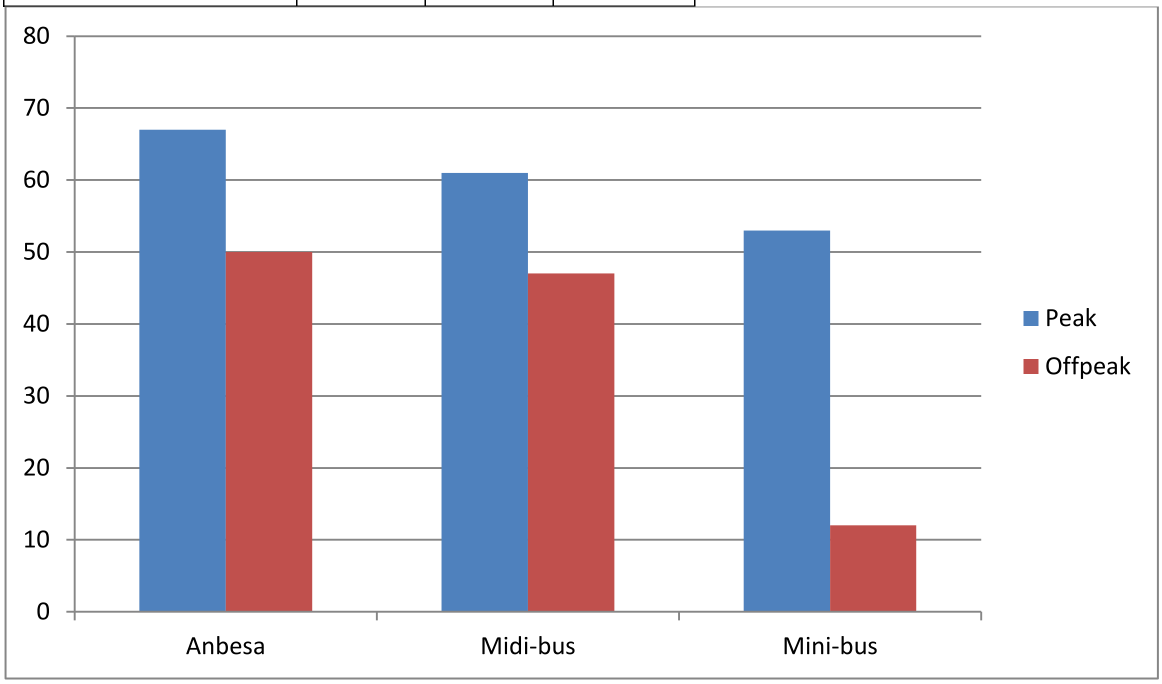


Chart 6: Summary of Timesaving by E-W LRT compared to other modes

Table 14 and Chart 6 show timesaving benefit by E-W LRT compared to the other modes which shows the minutes spent by rail and the minutes spent by road. The time saved by both scenarios is also calculated. LRT saves 50 minutes compared to Anbessa bus, 47 minutes compared Midi-bus and 12 minutes compared to Mini-bus during offpeak hours. And during peak hours LRT saves 67 minutes compared Anbessa bus, 61 minutes compared Midi-bus and 53 minutes compared to Mini-bus

Table 15: Summary of Timesaving by N-S LRT compared to other mode

N-S route	Anbessa	Midi-bus	Mini-Bus
Off Peak Hour	27	23	-10
Peak Hour	45	42	1

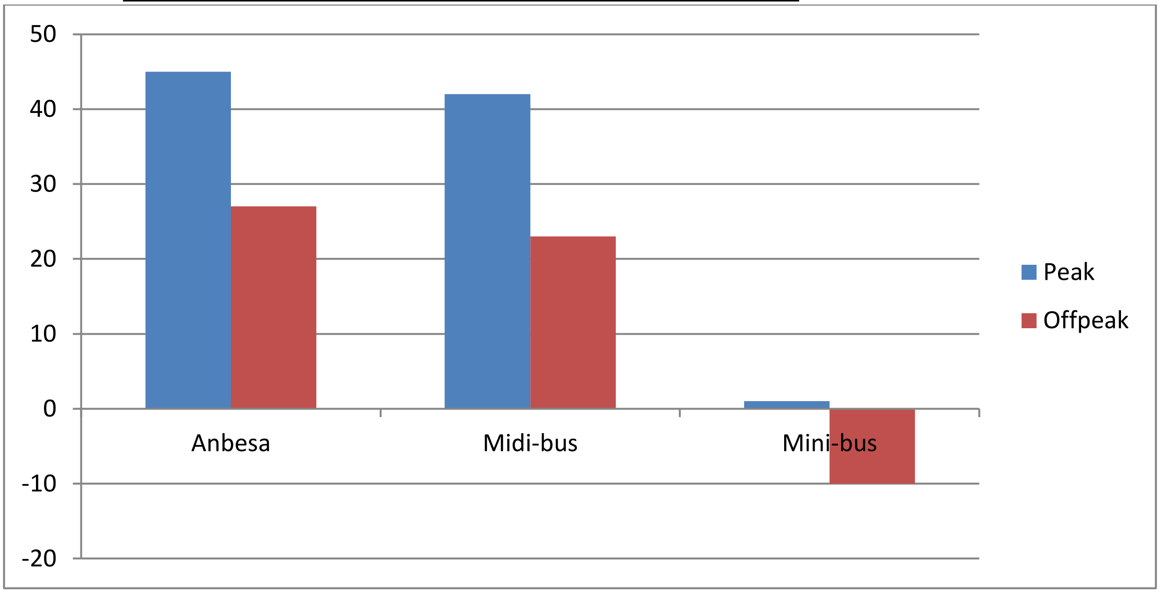


Chart 7: Summary of Timesaving by N-S LRT compared to other modes

Table 15 and Chart 7 show timesaving benefit by E-W LRT compared to the other modes which shows the minutes spent by rail and the minutes spent by road. The time saved by both scenarios is also calculated. LRT saves 27 minutes compared to Anbessa bus and 23 minutes compared to Midi-bus during offpeak hours. And during peak hours LRT saves 45 minutes compared Anbessa bus, 42 minutes compared Midi-bus and 1 minute compared to Mini-bus. But during offpeak hours Mini-bus saves 10 minutes compared to LRT. As it is shown in the result the N-S LRT route doesn't save much time as compared to E-W LRT route, this is due of N-S route is longer than the respective road route.

As it is shown on table 14 and 15, it is clear that, road transport modes took longer travel time than LRT. This is due to long access, stoppage and waiting time both at peak and offpeak periods. LRT doesn't show much improvement in vehicle time due to low average speed.

This could give a lesson for the next phase LRT project which extends to Shiromeda, Legetafo, Lebu and Akaki. Hence it is better to give higher weight to the time saving than the other sustainability indicators and optimise its benefits on key factors or inputs. Here are some proposed ways to improve the travel time on LRT:

- Increasing the distance between the stations which minimize the stoppage time
- Increasing the speed of the trams like other countries
- Choosing a best alignment which allows higher radius and speed.

This developed logical and spatial reasoning provides more insights to the level of trade-offs some routes can provide in the form of better travel demand and traffic modelling for optimum benefit as income to be generated from the users. Furthermore, considering that there are still four more light rail lots to be built, loosing time during the peak and off peak periods as compared to the road routes, can be avoided through alternative route designs. This is capable of delivering cost effective large capital expenditures on the rail, minimum time of movement between locations and better travel demand for higher income to the government. Promoting better timesaving benefit as useful information for the transport user will go a long way in facilitating a high modal shift from the roads to the rail usage, thus fulfilling the provision of a common good, as a mass transport system in a fast growing population and city like Addis Ababa.

4.4 Value of Travel Time in Monetary term

The Value of Travel Time (VTT) refers to the cost of time spent on transport, including waiting as well as actual travel. It includes costs to consumers of personal unpaid time spent on travel, and costs to businesses of paid employee time spent in travel. The Value of Travel Time Savings (VTTS) refers to the benefits from reduced travel time costs (Victoria Transport Policy Institute, 2013).

Total travel time costs are the product of time spent traveling measured as minutes or hours multiplied by unit costs measured as cents per minute or dollars per hour. Travel time unit costs vary depending on type of trip, travel conditions, and traveller preferences.

For example, ten minutes spent relaxing on a comfortable seat imposes less cost than the same amount of time spent driving in congestion or standing on a crowded bus. Travel time costs often vary for different parts of a trip. For example, walking to a bus stop, waiting for a bus, riding an uncrowded bus, and riding a crowded bus may each have different unit costs. Travel time costs also vary depending on traveller needs and preferences. For example, a person might one day enjoying a relaxed recreational walk or drive, but another may pay generously for faster travel when rushing to an important event. Travel time unreliability (uncertainty how long a trip will take, and unexpected delays) imposes additional costs.

Due to inadequacy of data to estimate accurate time unit cost, the prevailing wage rate ($0.52/hour) was used for the study. This time unit cost was used by International Council on Clean Transportation (ICCT) for travel time value of Addis Ababa bus rapid transit (BRT) on the report of Cost and benefits of clean technologies for Addis Ababa's bus rapid transit (International Council on Clean Transportation (ICCT), 2013).

According to transport Authority data report on passenger data in 2009, the modal share of each mode before construction of LRT for the two lots were 40.6% mini-bus, 25.7% midi-bus, 7.7% Anbessa bus and 26.1% were other support buses. Assuming that 40.6% of LRT users were mini-bus users, 25.7% of LRT users were midi-bus users, and 7.7% of LRT users were Anbessa bus users and 26.1% of LRT users were other support buses users (Transport Authority, Addis Ababa Branch office).

Lot1, (Torhailoch-Ayat)

Value of time saved by LRT users who were other mode users before start of LRT

$$VTTS = \sum P_i * N * Ti * C \qquad (4.2)$$

Where,

Pi is percentage of LRT users who were mode i users

N is number of LRT users per day on one corridor = 60,000 E-S, and 55,000 for N-S (ERC, 2016)

Ti is time saved by LRT users who were i mode users in hours per day.

Time unit cost (C) = $0.52/hour

According to table 2, hourly Distribution of the passengers on the LRT Corridor 62% passengers were on peak hour and 38% on offpeak hour (ERC, Feasibility study report, 2009)

VTTS = ∑Pi*N*Ti*C = 0.62(7.7%*1.11+25.7%*1.01+40.6%*0.88)*60,000*0.52+ 0.38(7.7%*0.88+25.7%*0.78+40.6%*0.20)*60,000*0.52= $ 17,728.4/day

Lot2, (Piassa Giorgis-Kality)

Value of time saved by LRT users who were other mode users before start of LRT

VTTS = $\sum P_i$****N*Ti*C***

VTTS = ∑Pi*N*Ti*C = 0.62(7.7%*0.75+25.7%*0.70+40.6%*0.02)*55,000*0.52+

0.38(7.7%*0.45+25.7%*0.38+40.6%*-0.17)*55,000*0.52= $ 5,045.8/day

The value time saved by LRT on the two lots is the sum of the value of time saved by each lot.

Hence, VTTS = $ 17,728.4+$ 5,045.8 = $22,774.23/day

4.5 Assessing the Sustainability benefit of reduction of Air pollution Greenhouse Effect by the light rail as compared to road vehicle transport scenarios

4.5.1 Impact of LRT on Air pollution and Greenhouse Emission Reduction

The transport sector is a major consumer of energy. It is also a major emitter of the carbon dioxide that is contributing to global warming. Most of this comes from road transport. In contrast, LRT emission much less compared to road transport and strong justification for a modal shift from road to rail. More than 400,000 passengers will use LRT per day when all of 40 LRT trams start service. That means LRT covers 26% traffic volume (out of 1.52 million). Hence Fuel consumption reduction is assumed 26% from the total fuel consumption, as LRT started operation assuming the emission rate constant. Tables 17 and 18 show the estimated total pollutant emission with and without LRT introduction.

The impact of the integrated solution, based on the decrease of road kilometres through the shift of car and bus users towards the light rail, is a reduction of 26 % in 2024 on traffic CO2 emissions, corresponding to a level of emissions of 81,701.98 tons. CO emissions decrease further by 26 % to reach approximately 1,016.38 tons in 2024. Similarly Particulate matter (PM) and total hydrocarbon (THC) exhaust emissions will also decrease further by a 26 % in 2024.

Table 16: Estimate of Total Emission from Addis Ababa Road Network without construction of LRT

S.No	Source of Pollutant	Carbon emissions (M Tones/Year)					
		1999	2004	2009	2014	2019	2024
1	CO	1,244.00	1,268.88	1,294.26	1,320.14	1,346.55	1,373.48
2	THC	110.70	112.91	115.17	117.48	119.83	122.22
3	PM10	40.57	41.38	42.20	43.05	43.91	44.79
4	CO2	100,000.00	102,000.00	104,040.00	106,120.80	108,243.22	110,408.08
TOTAL		101,395.27	103,423.17	105,491.63	107,601.47	109,753.50	111,948.57

Source: Estimated from Federal Transport Master Plan Study, Appendix 1.9, Environmental Studies, November 2008, Carbon Dioxide Emissions in Ethiopia, Transportation

Table 17: Estimate of Pollutant Emission from Addis Ababa Road Network after construction of LRT

S.No	Source of Pollutant	Carbon emissions (M Tones/Year)					
		1999	2004	2009	2014	2019	2024
1	CO	1,244.00	1,268.88	1,294.26	1,320.14	996.45	1,016.38
2	THC	110.7	112.91	115.17	117.48	88.67	90.44
3	PM10	40.57	41.38	42.2	43.05	32.49	33.14
4	CO2	100,000.00	102,000.00	104,040.00	106,120.80	80,099.98	81,701.98
TOTAL		101,395.27	103,423.17	105,491.63	107,601.47	81,217.59	82,841.94

Table 18: Estimated Emission reduced due to LRT project

Year	Source of Pollutant(M Tones/year)				
	CO	THC	PM10	CO_2	Total
2019	350.10	31.16	11.42	28,143.24	28,535.92
2024	357.10	31.78	11.65	28,706.10	29,106.63

4.5.2 Award from Clean Development Mechanism (CDM)

The Clean Development Mechanism is one of the key components of the Paris Protocol. United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol is a legally binding global agreement to combat climate change through a reduction of greenhouse gas (GHG) emissions.

The scheme appears simple: private companies fund projects in developing countries that reduce greenhouse gas emissions. This means CDM awards these projects certified emission reductions (CERs), each equivalent to one ton of carbon dioxide. Certified emission reductions (CERs) are then sold to developed countries, which use them to meet a part of their reduction commitments under the Kyoto.

Accordingly,

Total CO_2 reduction (MT) after LRT operations for 10 years between the period (2015-2024) GC

= 281,432.4 MT

Total Carbon Reduction Cost (€) = CER * Total CO_2 emission reduced (4.3)

Certified emission reductions (CERs) = €8.23/MT of CO2, Source: (Investing.com, 11/9/ 2015)

Total Carbon dioxide reduction cost = €2,316,188.652

In Paris on December 12, 2015, countries adopted new international agreement to address climate change that requires deeper emissions reduction commitments from developed and developing countries (NRDC, 2015). Countries responsible for 97 percent of global emissions submitted their climate commitments prior to the conference. Developed countries are being obliged to create a Green Climate Fund of about $100 billion to help developing countries to achieve their goals. This protocol will be put in to action in 2020 replacing Kyoto protocol (UNFCCC, 2016).

4.5.3 Limitation of the Estimated Pollutant Emission

The study considered vehicle emission rate constant for all vehicle type. But vehicle emission affected by the following factors:

- Vehicle type: larger vehicles tend to produce more emissions.
- Vehicle age and condition: Older vehicles have less effective emission control systems. Vehicles with faulty emission control systems have high emissions.
- Driving cycle: Emission rates tend to be relatively high when engines are cold.
- Driving style: Faster accelerations tend to increase emission rates.
- Driving conditions: Emissions per mile increase under hilly and stop-and-go conditions, and at low and high speeds,
- Slope of road

4.6 List of other benefits as stated by respondents

The respondents stated some other vital social, economic and environmental indicators to be considered in assessing urban light rail transport. These are:

- Moving large numbers of people more efficiently and effectively to key centres and employment nodes.
- Reducing car use and congestion, which can reduce business costs.
- Making trams and buses work together to provide efficient and cost effective access to more destinations.
- Making the transport system more efficient by getting more people to catch public transport to major destinations rather than drive
- Encouraging more people to catch public transport because it can move more people, in fewer vehicles and less space
- Providing quality infrastructure and services to encourage land use decisions that support good public transport outcomes.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research multicriteria assessment is used in addition to Geographical Information System (GIS) to show the spatial coverage of light rail transit, stations and road networks that used by different mode transport. This kind of analysis helps to compare transport routes alternatives of the rail and their corresponding road routes, measuring the timesaving as an economic sustainability benefit. Thus, revealing how the economic measurement indicator, i.e. timesaving, reduction of air pollution and reduction of greenhouse, which are selected as the most ranked indicator that results into different empirical rate or level of contribution to sustainability benefit, thus answering the question how are the sustainability benefits of the urban light rail system assessed.

This thesis explains the necessity and weight of different indicators in measuring the sustainability assessment of rail project which make transport planners to give priority for the indicators based on their weight for upcoming projects. Hence to measure the contribution of LRT project and monitor the level of its benefit, most ranked indicators are selected which are used to analyse the project. In the case of this thesis, the timesaving, Air pollution and Greenhouse effect indicators were able to show the extent at which each lot rail track was able to contribute to sustainability benefit. During this process it is clear to note that N-S lot does not save time as compared to minibus, by losing 10 minutes during off peak period, but gained a minute during peak period despite it showed advance in saving time as compared to other road transport mode. On the other hand the E-W lot save time during the peak and off-peak periods as compared to all road transport modes.

The multicriteria assessment concept further illustrates the relative impacts of alternative plans on system performance, i.e. the economic, environmental and social quality of life that helps decision-makers categorize the main choice.

In the case of this research, the relative impact of the travel timesaving indicator can be used to determine different parameters that could be used by decision makers to reduce or increase certain planned inputs, such as head way time, stoppage time, and number of rail stations on each lot, in order to improve the economic, social and environment benefits. This is such that the headway time can be increased or reduced, for example in the case of N-S lot, to improve its travel time-savings benefit. This can also help to determine the addition of more or less rail station stops that will guarantee more revenue income at a national scale to the government as an economic benefit.

The use of Geo-Information System (GIS) to quantitatively evaluate the empirical level of benefit and simple calculus to quantify also in empirical terms that is practically provable, which provides quality in terms of reliability and validity of result over time. Ethiopian Railway Corporation planned to construct LRT phase 2 project in near future hence timesaving, reduction Air pollution and reduction Greenhouse effect to be core sustainability benefit indicators in assessing the sustainability benefits of an infrastructure especially before it is implemented, in order to achieve a more time and economic efficient transport system that will provide valid base information in delivering quality service to the people. This provides adequate chance to observe different scenarios that will be of optimum benefit, limiting cost and encouraging in-depth understanding of assessing sustainability benefits before its operation.

In summary, indicator based multi criteria assessment on large infrastructural projects like Addis Ababa light rail project assessment, is reliable because it can prove in a scientific, provable and non-subjective manner, delivering accurate empirical values that are used to measure the rate or level of a sustainability benefit or negative impact, promoting a more informed and reliable implementation.

5.2 Recommendations

1. As shown on the result, Addis Ababa Light Rail Transit brought benefit for public transport user in saving travel time. This is due to road transport modes affected by waiting time, access time, stoppage time, congestion and shortage of road network in the city. And it is clear that LRT doesn't show much improvement in operating speed compared to road transport modes. Hence it is better decision makers to consider the following inputs in planning the next phase project:

- Increasing the distance between the stations which minimize the stoppage time
- Increasing the speed of the trams like other countries
- Choosing a best alignment which allows higher radius and speed.

2. To make informed and reliable planning and decision making for infrastructure, the study of how indicators affect our decisions and use of indicator assessment tools should be encouraged. This will promote the development of required data and the use of it. This can be done through funding of research years ahead, before the implementation of any form of assessment.

3. All sectors especially in the transports and urban management sectors should be empowered to acquire adequate data for easier and researchable models to be analysed. This will promote easy modelling of scenarios over time that will assist indicator-based assessments.

5.3 Recommendations for Future Research

Two new research questions for this further research are:

1. What inputs and factors affect the indicators that are used for the assessment of Light rail transit?
2. How is indicators based assessment data generated in Ethiopia to assess the sustainability benefits of the light rail transit?
3. How can scenario modeling or forecasts for indicator based assessment be validated?

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ANNEX 1: QUESTIONNAIRE

Dear Sir/Madam,

I'm a graduate student in Addis Ababa Institute of Technology, School of Civil and Environmental Engineering. This questionnaire is prepared to collect data for a Master's Thesis work in the Road and Transport Engineering program under the title "**Assessment of Addis Ababa's Light Rail Transit Based on Sustainability Variables**."

The purpose of the questionnaire is to determine the weight of assigned indicators to represent its relative importance to the overall objective of sustainability by rating the level of contribution to sustainability benefit. This further explains the necessity to measure the specific rate of contribution of different indicators to measure and monitor the level of benefit in either an increase or a decrease in a specific indicator.

Three thematic areas are adopted as indicators of Sustainability in transport, which also reflect a standard definition of Sustainable transport. These indicators, described below, are the three 'Sustainable Development Pillars', and, they have been applied here to study the sustainability of light rail transit in Addis Ababa.

A. ECONOMIC - Creating Sustainable economic growth and prosperity

B. ENVIRONMENTAL - Protecting and enhancing the environment

C. SOCIAL - Ensuring social equity (fairness) or well being

As an expert in the area, your participation is very crucial to the success of this study. Therefore, your cooperation is highly appreciated. All the collected information will be used for academic purpose only and will not be disclosed to any third party, including any personal identifiers, if any.

SECTION A: Personal Information

1. Profession of respondent

2. Job Experience

3. Mode(s) of transport used presently by you. Please tick below your corresponding answer.

Public transport	Private transport	Both public and private Transport

4. Number of times in a week you use the mode of transport in question 3 above?

5. Do you use the light rail transit?

Yes	No

6. If yes, how many days a week do you use the light rail?

7. How many minutes does it take you to get to your place of work, using the light rail from the nearest rail stop?

8. How many minutes does it take you to get to your home, using the light rail from the nearest rail stop?

B. Giving score to Indicators to represent its relative importance to the overall objective of sustainability by rating the level of contribution to sustainability benefit.

In your own opinion, how would you give score or quantify the following indicators in order of importance in measuring the benefits of the light rail transit economically, socially and environmentally as a reason for investing and constructing the rail transport?

The score is from 1 – 10, where 1 = Lowest importance and 10 =Highest importance,
INSTRUCTION: Please write the score number (1 - 10) by the side of your corresponding indicator

SN	Indicator	Score
	ECONOMIC SUSTAINABILITY	
1	Reduction of travel time as compared to the use of vehicles on the roads (Total travel time saved by the use of the light rail as compared to the public road transport, such as public bus mass transit.	
2	Employment generation (Additional employment to be generated by the new light rail transit).	
3	Transport Affordability by people as compared to public road transportation (i.e. as compared to mass transit buses and taxis within the same route)	
	SOCIAL SUSTAINABILITY	
4	Increase in the use of the light rail public mass transport, i.e. Increase in public transport trips per day, based on better timing and periods of availability (modal shift)	
5	Urban Regeneration (Urban regeneration in the vicinity of light rail transport, i.e. urban development for improved environment along the areas of the light rail corridor)	
6	Proximity of Settlements to Rail stations (Accessibility to the rail station without extra cost of using a public or private road vehicle to get to the rail station or rail stop, i.e., are the rail stops within 5-20 minutes walking distance to the settlements?	
	ENVIRONMENTAL SUSTAINABILITY	
7	Reduction in Air Pollution (Reduction of pollutant emissions of carbon-monoxide (CO), Sulphur Oxide (SO2), Nitrogen Oxide (NOx), lead, particulate matter (PM) in tons/year of road vehicles to be reduced from roads, such as trailers, buses, cars and as compared to pollution emitted by the light rail.	
8	Percentage of persons that are less affected by noise	
9	Greenhouse effect Emissions reduction in CO2 per tons/year of vehicles to be reduced from roads, such as trailers, buses, cars and as compared to pollution emitted by the light rail.	
10	Safety Improvements (reduction of accidents and death rate from road accidents per year)	

Are there other indicators you think can also be useful in assessing the benefits of the light rail? Please feel free to use extra sheets if needed. If yes, please list and weigh them on a scale of (1-10), just as the ten indicators where listed and given score above).

S/N	Indicator	Score
1		
2		
3		

ANNEX 2: Sample size and error estimation for questionnaire

To calculate the required sample size in this study, the following inputs were considered:

1. The level of confidence required for the true value of a mean. This is closely connected with the level of significance for statistical tests, such as a t-test. Hence 95% confidence was selected for the study. I.e., the true mean value lies somewhere within a valid 95% confidence interval, and this corresponds to significance testing at the 5% level ($P < 0.05$) of significance and .

2. The degree of precision is required (margin of error). In this study margin of error 0.46 is selected.

3. Standard deviation, May be guided by past research or pilot survey. The collected data was used.

Table 19: Number of respondents that give weight for each indicator

weight given by respondents	Travel Time	Employement	Affordability	Modal shift	Urban regeneration	proximity	Air pllution	Noise	Green House	Safety
10	14	2	5	4	1		12		10	4
9	10	5	6	9	5	4	4	3	6	11
8	11	14	16	6	11	7	14	5	10	10
7	1	9	4	17	8	13	6	6	6	9
6	4	6	6	3	10	11	4	12	7	4
5		4	3	1	2	5		14	1	2

Mean, standard deviation of the sample and Number of respondents required

$N = (Z_{\alpha/2} * \sigma/e)^2$

$Z_{\alpha/2}$ =1.96 for 95% confidence interval

σ = is calculated for each indicators based on the sample

e= 0.46 (margin of error selected for the sample)

Table 20: Mean, standard deviation of the sample and Number of respondents required

	Travel Time	Employem	Affordabil	Modal shif	Urban regeneration	proximity	Air pollution	Noise	Green House	Safety
Mean	8.713	7.400	7.763	7.713	7.050	6.838	8.350	6.263	8.063	7.900
standard daviation(σ)	1.254	1.300	1.405	1.332	1.284	1.131	1.314	1.250	1.476	1.319
respondents required(N)	28.5686094	30.68197	35.85331	32.19961	29.91037807	23.23558	31.36278	28.36437	39.5297	34.52678

Hence the sample size is 41 > 39.5 (maximum no. respondents required for indicators with 95% CI and 0.46 margin of error) , so its ok

Table 21: Error of estimation (±) for mean value of sustainability indicators weight with (95% CI &,N= 41)

	Travel Time	Employem	Affordabil	Modal shif	Urban regeneration	proximity	Air pollution	Noise	Green House	Safety
Mean	8.713	7.400	7.763	7.713	7.050	6.838	8.350	6.263	8.063	7.900
standard daviation(σ)	1.254	1.300	1.405	1.332	1.284	1.131	1.314	1.250	1.476	1.319
Error of estimation(e)	0.385	0.399	0.431	0.409	0.394	0.347	0.403	0.383	0.453	0.405

ANNEX 3: Error estimation for mean value of Passenger's in vehicle time, (min)

Mean, standard deviation of passenger's **in vehicle time** and Number of vehicles surveyed

e = ($Z_{\alpha/2}$ * σ/√N)

$Z_{\alpha/2}$ =1.96 for 95% confidence interval

σ = standard deviation

N = Number vehicle surveyed 49 for Torhailoch- Ayat lot both on peak off peak hour and 42 for Giorgis- Kality both on peak and offpeak hour

e= error of estimation (min)

Table 22: Error of estimation (±) for mean value of passengers in vehicle time on peak hour at Torhailoch-Ayat lot

Torhailoch-Ayat(peak)							
Mode	Anbessa bus		Midi- bus		Mini-bus		
Route	Torhailoch - Legar	Legar- Ayat	Torhailoch - Mexico	Mexico- Ayat	Torhailoch - Mexico	Mexico- Megenagna	Megenagna- Ayat
Mean	32.571	85.286	24.714	77.571	20.143	27.286	32.286
σ	2.441	4.978	2.763	5.039	2.799	2.603	3.493
e	0.731	1.490	0.827	1.508	0.838	0.779	1.046

Table 23: Error of estimation (±) for mean value of passengers in vehicle time on offpeak hour at Torhailoch-Ayat lot

Torhailoch-Ayat(offpeak)							
Mode	Anbessa bus		Midi- bus		Mini-bus		
Route	Torhailoch - Legar	Legar- Ayat	Torhailoch - Mexico	Mexico- Ayat	Torhailoch - Mexico	Mexico- Megenagna	Megenagna- Ayat
Mean	25.714	64.571	15.714	61.286	11.429	20.286	21.143
σ	2.537	4.795	1.320	3.576	1.742	2.345	2.641
e	0.760	1.435	0.395	1.070	0.522	0.702	0.791

Table 24: Error of estimation (±) for mean value of passengers in vehicle time on offpeak hour at Gorgis- kaliti lot

Giorgis- kality(off peak)						
Mode	Anbessa bus		Midi- bus		Mini-bus	
Route	Giorgis -saris abo	Saris abo- kality	Giorgis -saris abo	saris abo- kality	Giorgis -saris	saris - kality
Mean	55.429	4.857	50.857	4.857	32.571	8.429
σ	3.458	1.125	3.870	1.125	2.499	1.400
e	1.035	0.337	1.159	0.337	0.748	0.419

Table 25: Error of estimation (±) for mean value of passengers in vehicle time on peak hour at Gorgis- kaliti lot

Giorgis- kality(peak)						
Mode	Anbessa bus		Midi- bus		Mini-bus	
Route	Giorgis -saris abo	Saris abo- kality	Giorgis -saris abo	saris abo- kality	Giorgis -saris	saris abo- kality
Mean	80.143	10.857	75.286	10.857	49.857	10.857
σ	4.060	1.244	3.781	1.512	2.755	1.211
e	1.215	0.372	1.132	0.453	0.825	0.363

ANNEX 4: Sensitivity Analysis on Each Sample Selected from Each Profession

I. Null hypothesis (H_0), $\mu_0 = \mu$

II. Alternative hypothesis (H_a), $\mu \neq \mu_0$ either $Z \geq Z_{\alpha/2}$ or $Z \leq -Z_{\alpha/2}$

Test statistics value $Z = \frac{X-\mu_0}{\sigma/\sqrt{N}}$

Where, $\alpha=0.05$, $Z_{\alpha/2}=Z_{0.025} = 1.96$

Table 26: Z – Test for sample taken from Economists

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	8.6	7	8.4	7	7	6.4	9.2	7.2	8.6	8.4
SD	0.8	0.894427	0.489897949	1.095445	1.26491106	1.0198039	1.16619	1.469694	0.8	1.356466
μ-X	0.1125	0.4	-0.6375	0.7125	0.05	0.4375	-0.85	-0.9375	-0.5375	-0.5
SD/√N	0.357771	0.4	0.219089023	0.489898	0.56568542	0.4560702	0.521536	0.657267	0.35777088	0.60663
Z value	0.314447	1	-2.909776087	1.454385	0.08838835	0.9592822	-1.6298	-1.42636	-1.50235817	-0.82423
μo	NR	NR	R	NR	NR	NR	NR	NR	NR	NR

Table 27: Z – Test for sample taken from Sociologists

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	8.3	7.4	7.5	7.3	7	7.3	9.6	7.1	9.5	8
SD	1.077033	0.8	0.774596669	1.777639	1.67332005	1.2489996	0.8	1.428286	0.4472136	1.095445
μ-X	0.4125	0	0.2625	0.4125	0.05	-0.4625	-1.25	-0.8375	-1.4375	-0.1
SD/√N	0.481664	0.357771	0.346410162	0.794984	0.74833148	0.5585696	0.357771	0.638749	0.2	0.489898
Z value	0.856407	0	0.757772228	0.518878	0.06681531	-0.828008	-3.49386	-1.31116	-7.1875	-0.20412
μo	NR	NR	NR	NR	NR	NR	R	NR	NR	NR

Table 28: Z – Test for sample taken from Environmentalists

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	7.6	6.2	7.6	7.8	6.6	6	9	6.4	8	7.6
SD	1.496663	1.16619	1.854723699	0.979796	1.0198039	0.6324555	0.894427	1.2	1.26491106	0.8
μ-X	1.1125	1.2	0.1625	-0.0875	0.45	0.8375	-0.65	-0.1375	0.0625	0.3
SD/√N	0.669328	0.521536	0.829457654	0.438178	0.45607017	0.2828427	0.4	0.536656	0.56568542	0.357771
Z value	1.662115	2.300895	0.195911147	-0.19969	0.98669027	2.9610096	-1.625	-0.25622	0.11048543	0.838525
μo	NR	R	NR	NR	NR	R	NR	NR	NR	NR

Table 29: Z – Test for sample taken from Railway Administrators

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	9	8.166667	7.5	8.333333	6.5	7.1666667	8.666667	6.5	8.5	8.5
SD	1.356466	1.496663	1.743559577	1.019804	0.89442719	0.7483315	0.979796	0.489898	1.78885438	1.32665
μ-X	-0.2875	-0.76667	0.2625	-0.62083	0.55	-0.329167	-0.31667	-0.2375	-0.4375	-0.6
SD/√N	0.60663	0.669328	0.779743548	0.45607	0.4	0.334664	0.438178	0.219089	0.8	0.593296
Z value	-0.47393	-1.14543	0.336649147	-1.36127	1.375	-0.983574	-0.72269	-1.08403	-0.546875	-1.0113
μo	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Where, NR= Null hypothesis is not rejected

R= Null hypothesis is rejected

Table 30: Z – Test for sample taken from Transport Engineers

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	8.85	6.4	7.4	7.6	7	6.2	8.2	5.4	8	6.8
SD	1.16619	1.573	1.854723699	0.4	0.89442719	0.4898979	0.894427	0.748331	1.72046505	1.414214
μ-X	-0.1375	1	0.3625	0.1125	0.05	0.6375	0.15	0.8625	0.0625	1.1
SD/√N	0.476095	0.642175	0.757187779	0.163299	0.36514837	0.2	0.365148	0.305505	0.70237692	0.57735
Z value	-0.28881	1.557209	0.47874518	0.688919	0.13693064	3.1875	0.410792	2.823194	0.08898356	1.905256
μo	NR	NR	NR	NR	NR	R	NR	R	NR	NR

Table 31: Z – Test for sample taken from Railway Engineers

Indicators	Travel time	Employment generation	Transport fare affordability	Modal shift	Urban regeneration	Proximity service	Air pollution	Noise	Greenhouse effect	Safety
Grand mean(μ)	8.7125	7.4	7.7625	7.7125	7.05	6.8375	8.35	6.2625	8.0625	7.9
sample mean(X)	9.588889	8.333333	8.222222222	8.444444	7.77777778	7.6666667	7.444444	5.777778	7.22222222	8.444444
SD	1.7258	1.936832	1.227262335	1.342561	1.749562	0.942809	1.69375	0.95628	2.387286	1.4733
μ-X	-0.87639	-0.93333	-0.459722222	-0.73194	-0.7277778	-0.829167	0.905556	0.484722	0.84027778	-0.54444
SD/√N	0.575267	0.645611	0.409087445	0.44752	0.58318733	0.3142697	0.564583	0.31876	0.795762	0.4911
Z value	-1.52345	-1.44566	-1.123774948	-1.63556	-1.2479314	-2.638392	1.603936	1.520649	1.05594107	-1.10862
μo	NR	NR	NR	NR	NR	R	NR	NR	NR	NR

Where, NR= Null hypothesis is not rejected

R= Null hypothesis is rejected