ADDIS ABABA UNIVERSITY

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AFRICAN RAILWAY CENTER OF EXCELLENCE

Feasibility Study of At-grade versus Highway Overpass Rail-Road Crossing.

Case Study of Addis Ababa Light Rail Transit: East-West line

A Thesis in MSc. Railway Engineering (Civil Infrastructure)

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Approval

The undersigned have examined the thesis entitled '**Feasibility Study of At-grade versus Highway Overpass Rail-Road Crossings. Case Study of Addis Ababa Light Rail Transit: East-West line**' presented by **JOSEPINE AGUTI,** a candidate for the degree of Master of Science, and hereby certify that it is worthy of acceptance.

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I certify that research work titled "Feasibility Study of At-grade versus Highway Overpass Rail-Road Crossings. Case Study of Addis Ababa Light Rail Transit: East-West line" is my own work; and it has not been presented elsewhere for assessment or academic award. All the material obtained and used from other sources has been properly acknowledged/referenced.

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Abstract

The Addis Ababa Light Rail Transit, East-West line in particular, has a number of at-grade rail-road crossings with an increasing road traffic volumes and train frequencies which affect the smooth operation of the Light Rail Vehicles.

Therefore, a study on feasibility of at-grade versus highway overpass rail-road crossings was sought of, by considering the economic aspects involved with each; with the objective of determining which of the two crossings would be feasible for investment. Different techniques used to achieve the objectives included: manual traffic counts technique, document review, field observations, queuing model, and NPV, IRR, BCR analysis methods, sensitivity analysis technique, etc.

Based on the methodology, different economic and transport impact cost and benefit values were obtained, with the highway overpass crossing generating a net benefit of $6,758,782.17, unlike the at-grade rail-road crossing that gave a net loss of -$7,753,428.07. The aggregated at-grade and highway overpass rail-road crossing cost values of $2,613,280 and $1,880,786, respectively; and benefit values of $307,866 and $763,011.38, respectively, were obtained.

The feasibility of highway overpass crossing over the at-grade rail-road crossing was determined based on the NPV, BCR, IRR analysis results. Where, $119,875.45 NPV, 15.87% IRR and 3.3704 BCR value for highway overpass crossing; and -$3,427,488.39 NPV, 0.2576 BCR and a negative IRR for at-grade rail-road crossing. These results show that the highway overpass crossing is feasible than the at-grade crossing.

Therefore, this thesis is relevant in identification and quantification of the transport and economic impacts; supports decision-making when choosing a rail-road crossing alternative.

Key words: Feasibility study; at-grade rail-road crossing; highway overpass crossing; economic and transport impacts; monetary form; and AALRT.

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Last but not least, I acknowledge my friends and family for their emotional support/encouragement, prayers, and love that kept me strong and motivated throughout the research period, especially my mother - Mrs. Christine Asao Okale and Daughter – Abbiah Karen.

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List of Acronyms

Term	Meaning
AA-LRT	Addis Ababa Light Rail Transit
AVO	Average Vehicle Occupancy
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BRT	Bus Rapid Transit
CV	Current Value
ERA	Ethiopian Roads Authority
ERC	Ethiopian Railway Corporation
E-W	East-West
FV	Future Value
GHG	Greenhouse Gases
HC	Human Capital
hrs	Hours
IRR	Internal Rate of Returns
km	Kilometre
LRV	Light Rail Vehicle
NPV	Net Present Value
N-S	North-South
OCS	Overhead Contact System
RTC	Road Traffic Cost
RVs	Random Variables
USD	United States Dollars
VKT	Vehicle Kilometres Travelled
WTP	Willingness to Pay

CHAPTER 1: INTRODUCTION

1.1 Introduction/Background

The at-grade rail-road crossings being the most commonly used in many countries and on the Addis Ababa Light Rail Transit lines (AALRT). In the United States, there are around 250,000 at-grade rail-road crossings, or one for every 0.6 km of rail line [1]. Australia has more than 23,000 at-grade rail-road crossings, or one for every 1.8 km of rail line, while New Zealand has more than 3,000 at-grade crossings equivalent to one for every 1.3 km of rail line [2]. Meaning, as the volume of vehicular traffic and train frequencies increase, traffic delays and road accidents at such crossings become a problem [3]. Over a period of time, other crossing alternatives like grade separation, may be explored to facilitate safe, cost-effective and financially feasible rail-road crossing railway and road vehicles, as well non-motorized users [3].

Notably, the AALRT covers a total length of 31.6 Km; comprising two lines, i.e. the East-West (E-W)/Green line that stretches for 17.4 km from Ayat (East) to Tor-Hailoch (West), and the North- South (N-S)/Blue line which is 16.9 Km and stretches from Menelik II (North) to Kaliti (South). It currently operates a fleet of 40 low-floor trams manufactured by CNR Changchun. This Light Rail Vehicles (LRV) operate for only 16 hours, during the day and have a full right of way at the LRT railway track and road level crossings [4]. However, in order to achieve adequate transportation within the city, road vehicles are as well being utilized e.g. Public road vehicles like buses, taxis and privately-owned cars. This create congestion and traffic jam along controlled AA-LRT rail-road at-grade crossings during peak hours of the day [5].

Moreover, at-grade crossings create serious potential conflict points for collisions between road vehicle and LRV. Also Taylor and Crawford [6], explained that each crossing represents a conflict point between trains and road traffic including cars, buses, trams, cyclists and pedestrians. With average crossing closure times well in excess of one minute, these conflicts represent a constraint to road capacity and hence contributing to traffic congestion at the crossing locations. Which in turn result to high operating cost, loss of user's productive time, and extra fuel consumption (which is relatively different from vehicle to vehicle due to their efficiency) [7]. Therefore, provision of a systematic approach that is essential for decision makers to consider grade separation alternative based on the benefits and costs associated with it, are of interest in this thesis [8].

The AALRT E-W line has a number of rail-road at-grade crossings that are observed to be concentrated within a length of about 6 kilometres from Ayat to Gurdshola I; especially at CMC round about and management institute roundabout – which have two at-grade crossings each. These impact the operating speed of LRV, and disrupted road vehicle movements and such conflict points are observed to experience problems such as: vehicle congestion; compromised operational safety, increased operation and maintenance cost of the crossing facility, and sustainability of the railway track components at the level crossing area. Such problems may be possibly caused by the increasing road vehicle traffic, rough at-grade surface that causes vehicle delays at the crossing, poor traffic control system installed at the crossing, to mention but a few. However, such problems can be mitigated through the installation of grade separated crossing that will give a lasting solution [8].

Therefore, better understanding of the economic costs and benefits associated with rail-road grade separation over and at-grade crossing can help the railway industry of Ethiopia and its stakeholders to better evaluate the benefits of having a particular type of rail-road crossing in a particular location, over another [9]. Hence, a feasibility study of at-grade crossing versus highway overpass grade separated crossing for the AALRT rail-road crossings, at selected locations of the line; for effective and efficient performance of the AALRT (E-W line).

1.2 Statement of the Problem

The AALRT East-West line is characterized with a number of at-grade crossings with majority of them concentrated towards the East end (Ayat) of the line. The 6 rail-road at-grade crossings within the length of about 5.5 Km starting from Ayat. These at-grade crossing sections are observed to experience serious road traffic congestion problems and safety problems; which are currently affecting the effective and efficient operation of the LRVs, especially during peak hours of the day where the LRVS are forced to suddenly stop/brake at such crossing sections, although they have a complete right of way. Hence, causing delays and discomfort to the LRV passengers, as well as incidents between the road vehicles and LRVs.

The congestion problem is noted to be due to increasing population growth that influences transportation demands like car ownership [10]. Also, the at-grade crossing surface roughness may cause the slowing down of road traffic at the crossing, hence contributing to congestion problems, that affect the maintenance costs incurred and excessive settlement that affects the geometric features of the rail line - increasing the likelihood of derailments for railway vehicles [11].

Despite drastic industry-wide safety improvements over the past years, at-grade crossings remain hazardous [11]; no study has been done on feasibility of at-grade versus highway overpass crossings for the AALRT line. Although, Mohammed et al [10] carried-out research to quantify sustainability variables of the AALRT before and after its establishment; and Mitiku et al. [13], from Arba, Minch, Ethiopia quantified congestion impacts at road level crossings, quantification of other impacts like accidents and benefits was not considered. Their research was not related to the performance of the at-grade versus highway overpass crossings for the AALRT East-West line. Therefore, Feasibility study of at-grade versus highway overpass rail-road crossing alternatives was sought of in this case, by considering the economic aspects involved with both crossing alternatives.

1.3 Study` Objectives

General objective:

To carry out a feasibility study of at-grade versus highway overpass railroad crossings for AALRT E-W line selected sections.

Specific objectives:

- To identify the existing at-grade rail-road crossing physical conditions that influence its performance, and selection of the at-grade and highway overpass crossings for evaluation.
- To identify and quantify into monetary form, at-grade and highway overpass rail-road crossing economic and transport impacts that influence their performance.
- To determine the feasibility of at-grade versus highway overpass rail-road crossings.

1.4 Study Questions

General question:

What are the ways to achieve a feasibility study of at-grade rail-road crossing versus highway overpass railroad crossings for AALRT E-W line selected sections.

Specific questions:

- How can the existing at-grade crossing physical conditions be identified, and how can the selection of the at-grade and highway overpass crossings for evaluation be done?
- What are the ways for identifying and quantifying at-grade and highway overpass rail-road crossing economic and transport impacts?

- How can the feasibility of at-grade versus highway overpass rail-road crossings be determined?

1.5 Study Scope and Limitations

This research was carried out on the AALRT E-W line, on the section spanning from Ayat train station to Management Institute area, see Figure 1-1. This section have a number of at-grade crossings, including the CMC roundabout that is crossed by the LRT E-W line at two points and located close to CM train station. This research was carried out within a period of 7 months, with a focus to carry out feasibility study of at-grade versus highway overpass rail-road crossing alternatives at the selected section, considering only the economic aspects of costs and benefits involved with each crossing type.

On the other hand, the limitations that may have consequently affected the outcome of the research findings include:

- Lack of organised, reliable and well detailed incident/accident records (particularly those registered at the CMC roundabout from the time the AALRT E-W line started operation) availed by the AALRT Safety and Security Department, could not help in detailed quantification of incident impacts on road and railway users.
- Also, some crossing impacts were challenging to quantify due to inadequate measures available for quantification. For example, at-grade rail-road crossing impacts, like accessibility and connectivity, LRV passenger discomfort, and noise/stress to the users and surrounding environment; and highway overpass crossing impacts like resiliency benefits, agglomerated economies and productivity, increased comfortability to the LRV users.
- The estimated construction cost used in this case, considered the highway overpass crossing direct costs consisting of: labour, material costs, subcontractor fees, equipment costs, and miscellaneous; but not the indirect costs (e.g. the value of time delay, vehicle operating costs, and accident costs and the indirect cost for local traffic below the bridge), since they require detailed separate studies to fully estimate them. Therefore, this construction cost value is expected to vary during implementation process and this may have flawed the analysis results obtained.

Figure 1-1: AALRT lines (Source: AALRT Feasibility Report)

1.6 Significance of this study

This research Contributes additional knowledge on quantification of transport and economic impacts that influence performance of railway and road transportation systems; since most impacts were quantified compared to other researches that have considered quantification of only a few impacts.

It also provides important economic analysis outcomes, essential in transportation planning, when taking decision on the feasible railroad crossing to consider for investment.

1.7 Structure of the study

This thesis has five major chapters; with the first chapter being the introduction, and it includes; the Problem statement, Research objectives, Research questions, and Research scope and limitations. The literature review and the research methodology are elaborated in the second and third chapters, respectively. While the results and discussion are presented under chapter four, the conclusion and recommendations taken are under chapter five.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The objective of the literature review was to identify recent studies and existing practices related to rail-road at-grade and highway overpass crossing impacts (transportation, economic, social, and environmental) that influence their performance. Also, the measures applicable for quantification and conversion of such impacts into monetary form, and identifying measures that could be used to perform economic analysis were as well explored. This intern, helps to establish the net benefits related to at-grade and overpass rail-road crossing alternatives, and guide decision makers when selecting rail-road crossing alternative for investment and use for the AALRT selected crossing locations.

2.2 Definition of Terms

Average Daily Traffic (ADT): This is also referred to as the mean daily traffic, and it is, the average number of vehicles that travel through a specific point of a road over a certain time period [14].

Passenger Car Units (PCU): This is a metric used in transportation engineering to assess traffic flow rate on a road; and it is the measure of the impact that a mode of transport has on traffic variables (such as speed, density, and headway) compared to a single standard passenger car [14].

Vehicle Occupancy: Refers to the number of people per vehicle and it is considered an important parameter in traffic engineering and transportation planning for calculation of congestion impact related costs, among others like calculating congestion impact parameters and space/sizing public facility e.g. roads, crossings, and parking [14].

Traffic Congestion: Is a condition where there are excess vehicles on the portion of the road way at a particular time of the day resulting to a slower speed from normal or free flow speed and mostly characterized by stop or stop-go traffic [14]. Also, Traffic Congestion is travel time or delay in excess of that normally incurred under light or free flow travel condition.

Overpass crossing: This is a type of grade separated crossing where two highways or highway and railway tracks meet at different levels/ elevations, created a bridge structure that spans over the railroad or road [15].

Benefits: Refer to the effects of the crossing alternative on its users or the society at large, including dis-benefits/negative benefits that are usually measurable and have economic value [8].

Net Present Value (NPV): this is the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present [18].

Feasibility study: is the study that examines current and future conditions of a rail-road with emphasis placed on effective delivery of emergency services, safety, and efficiency for all travel modes, business viability, and elimination of any real or perceived socio-economic division of the community created by the railroad tracks [19].

2.3 Rail-Road Crossing Alternatives

There are various rail-road crossing alternatives that are usually employed to ensure effective and efficient railway and road vehicle operations and performance and they include the following:

- At-grade rail-road crossing - Refers to "a location where a public or private roadway, footpath, or both, crosses one or more railway tracks at grade". It utilizes gates, signals, and automated barricades controlled or uncontrolled crossings [14].
- Grade separation - A grade separated crossing is where two highways or highway and railway tracks meet at different levels/ elevations, created by underpasses or overpasses crossing structure (bridge structure – spans over the railroad or road) [15]. Other grade separation alternatives include; Trumpet Interchange, Diamond Interchange, Cloverleaf Interchange, Directional Interchange, and Bridged Rotary [12].
- Rerouting and alternative access consideration – that avoids rail-road crossing scenario.
- Elimination of the at-grade crossing – closure of existing at-grade crossing based on factors like safety and cost of operation and maintenance.

2.3.1 At-grade Rail-Road Crossing

This crossing alternative has been commonly used worldwide, especially in developing countries including Ethiopia; and this is mostly because of its cost effectiveness during construction – which makes it to be chosen by the decision making team's, depending on the possible crossing alternatives in question [16].

At-grade rail-road crossings create various economic impacts on road/railway transportation systems and such impacts include, but not limited to:

- Safety impacts - are typically expressed by accident potential, both in terms of expected frequency and severity.
- Traffic congestion impacts – occur when vehicles get delayed at the crossing.
- Road vehicle delays - Cars and trucks get delayed at rail-road crossings during times of train occurrences, as well as due to surface roughness of the crossing [16], [17].
- Vehicle operating costs - Rail-road crossings can impact vehicle operating costs through changes to fuel and oil consumption, tyre wear, vehicle maintenance and vehicle depreciation [18].
- Traffic volume changes – this impact occurs during the construction process of the crossing facility and may also cause increased car operating costs and delays in passenger travels.
- Accessibility/connectivity - mostly considered from a qualitative perspective and entails public transport access/use and connectivity to the surrounding road network.

2.3.2 Overpass Crossing

Grade separation benefits can be expressed in a quantitative or qualitative manner depending on the objective of the study, and the decision to grade-separate a rail-road crossing using a highway overpass structure requires an understanding of the economic matters; as it involves high initial cost (which serves as a deterrent for many projects) [23]. Overpasses are usually costly and are built as part of the freeway system where large traffic flows justify the cost and on busy urban highways when justified by road safety and traffic flow improvements. Therefore, it is recommended that the decision to grade-separate should look beyond the initial cost of construction and include the benefits involved e.g. Travel time saving or delay reductions; Reduction in delays of trains; Vehicle cost savings; Accident reductions; Reduced emissions from motor vehicles associated with crossing delays; Enhanced safety and traffic flow on surface streets; eliminates the cost of running at-grade control systems; and eliminates at-grade facility maintenance costs [23].

As part of a cost-benefit analysis, Taylor and Crawford [6], assumed that all accidents at a rail-road crossing, plus 25% of accidents adjacent to it, would be saved if a site were to be grade-separated by use of an overpass or underpass structure. In addition, both Corben et al. [24], and

Rail Safety and Standards Board [25], identify grade separation as the best measures for reducing crash risk.

Furthermore, through an assessment of grade separation schemes in Ontario, Canada, Dodgson [26] found that reductions in road vehicle delay due to grade separation, accounted for the largest share of benefits at 72% to 94%. And the vehicle delay included that from trains occupying the crossing as well as vehicles slowing down due to surface roughness. It also found that reductions in rail vehicle delay associated with rail-road grade separations accounted for 0-6% of total benefits.

Why Use a highway Overpass Rail-Road Crossing?

Grade separation through the use of a highway overpass bridge crossing is normally considered because, it eliminates traffic (rail and road) flow interruptions, incidents/accidents that affect safety (safety risks), congestion problems, including increased exhaust emissions from vehicles due to traffic congestion conditions [6]. Moreover, other at-grade improvement measures that can be employed, for example, at-grade crossing elimination; road traffic rerouting; and use of advanced safety protection systems at the at-grade crossing, only provide temporary measures for traffic management to ensure safety and are not sufficient enough for at-grade crossing operations. Therefore, the use of a highway overpass crossing provides a long-lasting solution to problems experienced with the use of at-grade crossings, which is why its usage has been of interest. Also, the costs associated with the elevation of a roadway are considered less than those of raising of lowering the railroad structure. On the other hand, an underpass grade separation involves relatively higher construction costs compared to constructing an overpass crossing, because underpasses require a lot of earth work and ground excavations - which may escalate the cost of construction [12].

2.3.3 At-Grade and Highway Overpass Rail-Road Crossing’s Selection

The selection of the candidate at-grade and highway overpass rail-road crossings for evaluation purpose can be achieved through comparison of the existing at-grade qualitative physical conditions [16]. This involves observation and noting of the physical conditions that influence the performance of the crossing facility and these include but not limited to: location of the crossing (distance from the railway station – influences crossing closing times); geometry of the crossing; closeness of the route to pedestrian generator, such as a civic/municipal facility or use, school, park, or community-scale retail location; installed safety protection system; at-grade crossing's surface condition like roughness; roadway type (paved or unpaved); and number of roadway lanes [16].

2.4 Economic and Transport Impacts of At-grade and Overpass Rail-Road Crossing Alternatives

Table 2-1: Cost-Benefit Streams for the At-grade and Overpass crossings

S/N	Crossing type and the associated costs/benefits	Source
1	**At-grade rail-road crossing impacts**	
	<u>Costs and Dis-benefits</u> • Capital (initial construction) cost • Operation and Maintenance costs • Traffic Congestion Impact costs - Cost of Extra Fuel Consumed - Average cost of Road vehicle travel time delay/productive time loss - Value of travel time unreliability - Cost of increased Greenhouse Gas (GHG) emissions - Noise and stress to the users and surrounding environment • Rail-road incident costs - Loss in revue collected from passenger service fares, due to LRV's operation hours lost - LRV passenger productive time lost due to delays • Discomfort to the LRV and road vehicle users **<u>Benefits</u>** • Initial investment Savings • Easy access and connectivity	1. Chris De Gruyter and Graham Currie, (2016). 2. U.S Department of Transportation (2016).
2	**Overpass crossing impacts**	
	<u>Costs and Dis-benefits</u> • Capital (initial construction) costs • Operation and Maintenance costs • Compromised access and connectivity for the unable users **<u>Benefits</u>**	

S/N	Crossing type and the associated costs/benefits	Source
	• Travel time saving for road vehicle and LRV users • Travel time reliability • LRV/road vehicle incidents Savings • Traffic Free flow benefit • Resiliency benefits for the rail-road at-grade crossing section • Agglomerated Economies and Productivity • Increased comfort to LRV users	

2.4.1 At-Grade Crossing Impacts

(i) Traffic Congestion impacts

This can be classified as recurring and non-recurring congestion depending on its occurrence; where recurring congestion includes congestion due to bottlenecks, traffic signal, and persistent higher demand, a few to mention and non-recurring congestion includes congestion caused by mainly accidents and unprecedented events [23].

Traffic congestion increasingly has economic, transportation, social, and environmental impacts on the various road users as well as the surrounding environment; and such economic and transportation impacts that may be experienced at an at-grade road-rail intersection/crossing, leading to unnecessary costs to the users due to unproductive time lost, extra fuel consumption, accidents and negative environmental impacts such as air pollution, noise and stress [14], [10].

Therefore, traffic congestion can be referred to in terms of flow rates, capacities, volumes, speeds, and delay, and the major congestion variables considered to be of importance for economic analysis in this research include: cost of travel time delay; and cost of extra fuel consumption (diesel and gasoline); although other congestion impacts may include, cost of travel time unreliability in passenger transportation; cost of Greenhouse Gas (GHG) emissions and cost of accidents [14].

Increased fuel consumption during congestion hours of the day mean increased direct exhaust emissions that affect the air quality, and the framework for the emissions from road Traffic and fuel intake is one of the elements determining the level of emissions, see Figure 2-1.

Noting that, Motor vehicles are sources of a number of air pollutants, such as carbon monoxide, nitrogen oxides, un-burnt hydrocarbons, suspended particulate matter, sulfur dioxide and volatile organic compounds. Nearly 50% of global carbon monoxide (CO), hydrocarbons (HCs) and nitrogen dioxide (NO2) emissions from fossil fuel combustion come from petrol and diesel engines; and can be responsible for about 80-90% of these pollutants in city centres and congested streets, especially in developing countries like Ethiopia, where vehicle emission monitoring is not in place [14].

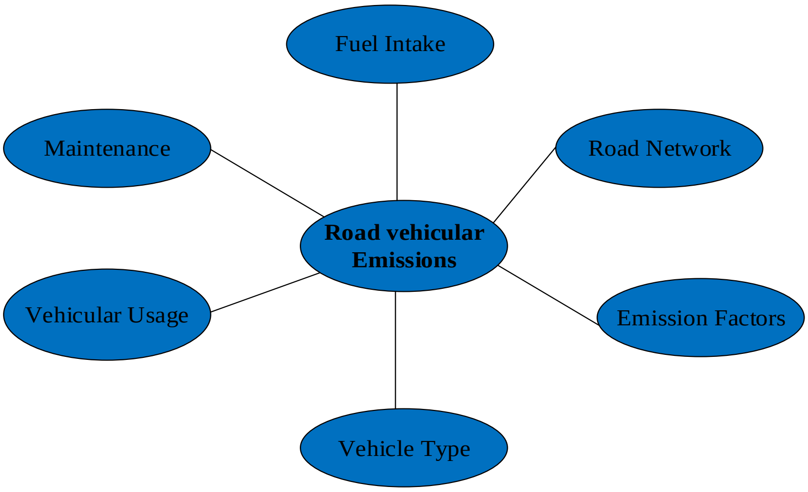

Figure 2-1: Emissions from road Traffic (Source: Taddesse, 2011)

Traffic Congestion can be measured based on different alternatives like speed, access, user costs, delay, reliability, etc. Although, the Vehicle physical condition influences the traffic flow at the at-grade sections, taking note that in Addis Ababa, most cars are old and technically unfit, and about 43.5% of vehicles are in poor operating conditions [53]; this was assumed to cause negligible impact on traffic movement at the at-grade rail-road crossing.

Furthermore, the value of time lost is an opportunity cost which is caused by the effect to drivers and passengers waiting at rail-road at-grade crossings, and this may be lost of working time (time spent at paid occupational labour) or non-working time (off the job) to them when congestion is worsening. Also, the value of time lost varies from person to person i.e., among passengers travelling, some of them may be business men, intellectuals whose time impact is influential and for other passengers, the value of time lost may not be crucial, hence, reducing the productivity of the city.

According to Mitiku et al. [13], he used the MMAS cellular automata and queuing theory to simulate the average waiting time of vehicles, and he found that the average waiting time of vehicles at roundabouts and cross intersection to be 0.2618 hours and 0.0995 hours respectively and the cost of extra fuel consumed. The cost of time lost for a roundabout and cross intersection were estimated according to the average waiting time, and he concluded that much of the time and fuel was lost at roundabout than intersections. He then recommended further studies to be conducted on additional components like accident cost, construction and maintenance costs.

The suitable traffic data collected for this purpose includes: vehicle volumes, vehicle mix, speeds and capacities [43]. As part of estimating vehicle operating costs associated with rail-road crossings, energy consumption, usually expressed in kWh, may be reported separately [31].

However, Travel Time Costs are highly variable, including a small portion of travel with very high time values, to a significant portion of travel with little or no *cost*, since travellers enjoy the experience and would pay nothing to reduce it. High-time-value travel includes: Paid travel, Urgent personal trips, Travel under congested or uncomfortable conditions, Unexpected delays, and Longer trips (more than 20 minutes) or high daily mileage (more than 90 daily minutes). Therefore, the possible causes and resulting impacts of traffic congestion at a road section [27] are seen in Figure 2-2.

Notably, in order to fully express traffic congestion, it is usually necessary to understand the four components or dimensions, i.e.; duration, extent, intensity and reliability; which have been considered in the analysis of traffic congestion impacts [27].

Also, road vehicle fuel lost due to congestion can be estimated by obtaining the fuel consumptions for peak-hours and off-peak hours, in order to obtain the average vehicle's fuel consumption. This the difference in fuel consumption for the two periods (in liters) is determined and multiplied by the cost of fuel per liter, to get the average cost of fuel consumption during peak congested periods of the day [15].

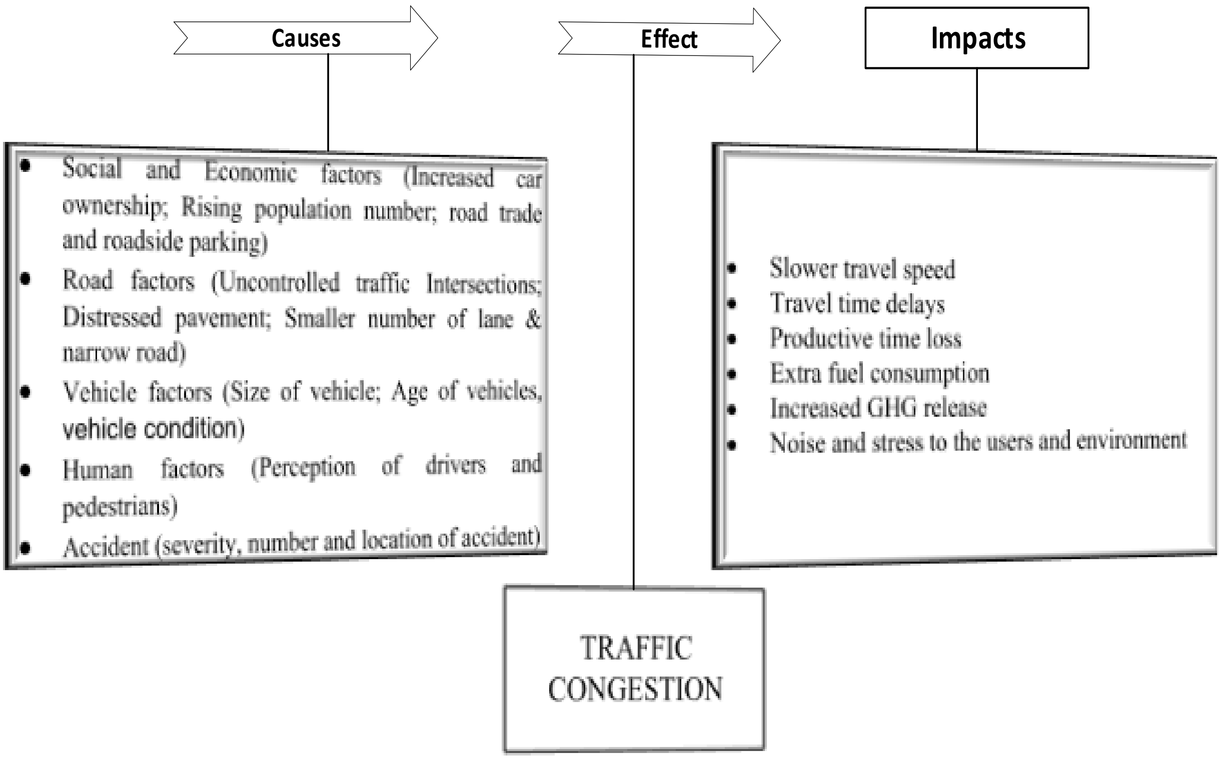

Figure 2-2: Traffic congestion impacts and their possible causes

(Source: Taddesse, 2011)

(ii) Accident/Incident Impact

Incidents are non-recurring events that can cause traffic congestion and operational losses to both, AALRT EW line LRV users and the road users. The general public perception is that the accidents at level crossings are primarily a railway sector problem, but statistical analysis of accidents show that the main cause of all accidents is human factor of road users (motor vehicle drivers, cyclist and pedestrians) [25].

Which explains why even the most technically advanced protection systems will not be sufficient to ensure safety, provided the road drivers do not obey or are not aware of the proper traffic rules applied at the at-grade crossings. Hence, the national programs and educational campaigns such as Operation Lifesaver in USA [26] and ILCAD – International Level Crossing Awareness Day [30], that promote road-user awareness on level crossing dangers by conducting educational lectures and workshops, round tables, creating multimedia games, posting educational posters and influencing social media.

These accident/incident costs are usually evaluated based on the historic accident records using BITRE and RTA costing approaches developed, especially in the United States (U.S) [23]. However, the use of the RTA estimates has been recommended for use by Richard Tooth &

Also, WTP figures provided by the RTA are intended to incorporate the medical and care costs associated with casualties. Although the WTP approach has become generally accepted as the more appropriate method (from a theoretical point of view) for estimating crash costs, data collection is costly and it assesses the cost only for the particular year in which the surveys are conducted and Table 2-2 [2] gives the different costs incurred at railway level crossings in case of an incident.

Furthermore, the Human Capital (HC) analysis method allows for the calculation of cost trends over a number of years based on historic data, and it provides more trustworthy estimates of the social cost of Road Traffic Costs (RTCs) than the WTP method [32].

Also, Maycock & Summersgill recommend the use of *multiple regression model* - which accounts for the crossing characteristics, to evaluate the number of accidents expected at the at-grade crossing [33]. The model development needs two databases: Number of accidents at crossings and the crossings' inventory for the years considered. More details on the method are given by Gitelman and Hakkert [34]; and the three crossing characteristics mostly applicable in the multiple regression model as explanatory variables are: Traffic volume categories; Train numbers' categories; and a protection level (gates, lights, or signs only). The other crossings' characteristics that can be used are; Road type (urban road or in rural area—highway, regional, local, or unpaved road), and Number of rail tracks (one, two, or more).

Table 2-2: Rail-road accident associated incident costs (source: BITRE 2000)

Cost of railway level crossing incidents		
	Borne by companies/individuals involvement	**Borne by others**
Human costs	Treatment (medical, ambulance, rehabilitation and long-term care) Lost labour (workplace and household) Loss of life and quality of life Legal costs Premature funeral expenses	Publicly funded treatment Correctional services Coroner, funeral Workplace disruption Additional local air pollution Plan and suffering of friends and relatives

Cost of railway level crossing incidents		
	Borne by companies/individuals involvement	**Borne by others**
Property damage and recovery	Fixed structure, rolling stock and road vehicle repairs and replacement Unavailability of vehicles Lost and damaged freight Site and passenger recovery	
Other costs	Insurance administration (company) safety investigation	Travel delays Police, fire and emergency services (regulator/ATSB) safety investigation

(iii) Road Vehicle Delays

Based on traffic counts of vehicle arrivals and departures at the at-grade crossing, estimation of road vehicle delay can be performed. For example, Okitsu et al. [35], developed a simulation-free method for calculating rail-road crossing delay by modifying Webster's model of uniform delay to account for crossings that are pre-empted with connected traffic signals. However, this could also be estimated from traffic congestion analysis and quantification.

(iv) Rail vehicle delay

Rail vehicles can be delayed due to permanent speed restrictions over crossings or any temporary speed restrictions that may be imposed following incidents or track component damage at the at-grade section [11]. This in turn can result in additional rail operating costs associated with acceleration and deceleration but also additional time costs for rail passengers.

Estimation of rail vehicle delay has typically been derived through the application of default unit costs [40] and values of time to affected rail passengers. However, Taggart et al. [37], recommends the development of a detailed profile of existing (and planned) rail operations at the specific crossings under investigation, depending on the type of the train the rail delay cost can be measured.

(v) Crossing operation costs

Costs associated with operating at-grade rail-road crossings can include items such as signage, protection equipment (e.g. automatic boom gates, flashing lights and bells) and surface maintenance costs and requirements for crossing attendant staff [23]. And in a cost-benefit analysis of grade separation schemes in Canada, Dodgson staff [24] found that reductions in crossing maintenance costs accounted for less than 5% of total benefits.

(vi) Lower cost of installation/construction

At-grade crossings have relatively lower cost of construction compared to that of the grade separated highway overpass crossing structures [34]. This explains why they are most times preferably used internationally [25].

2.4.2 Highway Overpass Crossing Impacts

(i) Traffic volume changes

Traffic volume changes can arise from physical changes implemented at rail-road crossings, such as overpass crossing construction process. The extent of traffic diversion and reassignment arising from physical changes made to rail-road crossings can be typically estimated using Traffic modelling [45]. Also, Equation 2-1 can be used to estimate the cost of traffic volume changes due to say, rerouting during the construction process. Note: the average fuel consumption per km is estimated to be 0.05 L/km and the average distance travelled per kilometre is estimated to be 40 Km/hr [14].

$$\begin{aligned} &Cost\ of\ vehicle\ rerouting \\ &\quad = Affected\ vehicles \times Rerouting\ time \\ &\quad \times Cost\ of\ vehicle\ operation \end{aligned} \qquad \text{Equation 2-1}$$

(ii) Accessibility/connectivity

Highway overpass crossings create accessibility problems for people with disabilities due to the vertical gradient required to pass/reach the platforms, and it may permit for higher speed limits which can actually reduce safety due to weaving and perceived sense of safety.

This has been considered mostly from a qualitative perspective unlike other transport and economic impacts of rail-road crossings accessibility/connectivity impacts. For example, Taylor and Crawford [6], subjectively assessed the extent to which grade separation of a rail-road crossing would improve or worsen public transport access/use and connectivity of the surrounding road network. Schrader and Hoffpauer [19] developed an ‘accessibility factor’ to provide a simple quantitative measure of accessibility based on the difference in distance between a route using an at-grade crossing and a route using the nearest grade-separated crossing. Also Taggart et al. [37], recommended mapping activity patterns in the area of interest and quantifying the extent to which travel times/distances are affected for different modes of transport.

In this case, the Megnagna highway overpass crossing, crossing was noted to be characterized with the usage of higher speed limits, and yet this may compromise the safety of the pedestrians who may want to use the crossing. Also, the crossing heights limit accessibility of the highway by pedestrians and the unable persons.

(iii) Construction, Operation and Maintenance Costs

Costs associated with grade separation of a rail-road crossing typically include items such as design, construction, relocation of utilities, lighting, land acquisition, provision of traffic management and train replacement services during construction periods (plus any impacts to passenger train operations), and ongoing maintenance costs associated with bridges/subways [23]. These costs are normally measured by their market values when performing economic analysis. Moreover, costs are liable to variations over time when specific localized data is not incorporated; costs that are highly susceptible to fluctuations; or lack of specific data like geologic or geotechnical; and geographical locations (e.g. lowering/raising the rail line is generally more expensive than lowering/raising the road) [23].

However, estimating the construction cost accurately and efficiently is critical for transportation agencies to properly allocate funds and assign appropriate time and resources; yet there are several problems associated with the estimation of design effort such as lack of predictive tools, inaccurate forecasts and misallocation of efforts. Also, the possible scope changes and actual work-hour variation from the planned may affect the construction cost value estimate [45].

- ***Capital Expenditures***

The sum of the monetary resources needed to build the project or program and/or acquire the project's assets are called capital cost of a project, and they generally include the cost of all materials and labour used in the construction/installation work.

Furthermore, capital costs may also include costs for project planning and design, environmental reviews, land or real estate acquisition, or transaction costs for securing financing. For example, according to Gitelma et al. [41], an average construction cost of US$2.4 million per grade separation in Israel, while Washington State DOT [8] report costs ranging from US$29 million to an upper estimate of US$94 million per grade separation in the United States. In New Zealand, a number of options for grade separating a rail-road crossing are estimated at only NZ$2.5 million to NZ$10.9 million (approximately US$1.7 million to US$7.3 million). Cost can also vary by construction approach used.

- ***Operating and Maintenance Costs***

Operating and maintenance (O&M) costs cover a wide array of costs required on a continuing basis to support core road vehicle overpass functions [23].

$$Labor\ Costs = Number\ of\ employees\ \times Wage\ rate \times Fringe\ benefits \qquad \text{Equation 2-2}$$

(iv) Value of Travel Time Savings

The U.S. DOT's published guidance that can be followed on appropriate value of travel time savings (VTTS) for use in evaluating the benefits of transportation infrastructure investment [44] (see Table 2-2).

$$VTTS\ (existing) = value\ of\ time\ \times change\ in\ trip\ time \times Affected\ trips \qquad \text{Equation 2-3}$$

$$VTTS\ (new) = value\ of\ time\ \times \frac{1}{2} \times change\ in\ trip\ time \times Affected\ trips \qquad \text{Equation 2-4}$$

Also, Taylor et al. and Crawford [6], estimated travel time savings based on the expected delays to road traffic resulting from at-grade crossing closures and he assumed that every vehicle that arrives at a level crossing when it is closed experiences a delay equal to the level crossing closure time. However, this approach underestimates the true cost of congestion as it does not take account of network effects such as, those caused by the interaction of crossing closures with neighboring traffic signals; and time delays (and vehicle operating costs) caused by people diverting to avoid the level crossing [6]. Therefore, the total vehicle delay can be obtained using the Equation 2-5.

$$D = \sum_i V_i\, P_i t_{close}\ , \qquad \text{Equation 2-5}$$

$where,\ \ P_i = \frac{n_i t_{close}}{T_i}$; D = Total vehicle delay; V_i = Traffic volume in time period i; P_i = Probability of being delayed at a level crossing in time period i; t_{close} = Average level crossing closure time; n_i= Number of level crossing closures in time period i; T_i= Total duration of period i.

Note: Time period i = peak and/or off-peak time periods

(v) Rail-road incident elimination - Safety Benefits

The U.S. DOT provides guidance on the monetized values for the value of reducing accidental fatalities in transportation incidents (the "value of a statistical life", or VSL), injuries, and property damage [8]. Where, severity of prevented crashes are measured through the number of injuries and fatalities, and the extent of property damage, and it recommends converting injuries to the Abbreviated Injury Scale (AIS) in order to monetize the value of reducing them [8].

Estimated annual safety benefits from removing the rail-road at-grade crossing (by using an overpass grade separated crossing), can be obtained using Equation 2-6.

$$Safety\ Benefits = Baseline\ Safety\ Risk \times Expected\ Consequences \qquad \text{Equation 2-6}$$

Remember: Removing the rail-road at-grade crossing (using overpass crossing) means 100% at-grade crossing risk reduction.

(vi) Value of Reliability

Reliability refers to the predictability and dependability of road vehicle or train service. Notably, estimating its discrete quantitative value in economic analysis can be challenging and unlikely, since users may have significantly different preferences for different trips and for different origin and destination pairs [47]. Therefore, based on the FRA public and stakeholder outreach conducted during its passenger rail planning efforts, participants uniformly valued reliability of service as either "the most important", or "one of the most important", aspects of the quality of service. Hence, FRA recommends that reliability benefits be described qualitatively in the BCA until such time as future guidance is issued [8].

(vii) Reduced GHG emissions - Environmental benefit

Transportation activities account for about one-third of all greenhouse gas emissions produced in the United States annually, and other emissions from transportation vehicles also contribute significantly to 25 localized air pollution [8]. The Greenhouse Gas emissions - GHG emissions include majorly: Carbon Dioxide (CO2); Methane (CH4); Nitrous Oxide (N20); Hydrofluorocarbons (HFC); Perfluorocarbons (PFC); Sulfur Hexafluoride (SF6). These benefits may result from a variety of actions, including reducing idling or traffic congestion.

According to the Railroad Grade Crossing Evaluation Report by the California Department of Transportation [42], GHG emissions can be reduced by the construction of grade separations, which decreases emissions by reducing idling time while vehicles wait for trains to pass through the crossing. Noting reduction in annual metric tons of carbon dioxide by constructing grade separations at the crossings examined to range from a low of 107 for Bellevue Avenue in Atwater, to a high of 5,059 at Rosecrans/Marquardt in Santa Fe Springs.

(viii) Free flow of traffic

A highway overpass crossing solves the problems and reduces vehicle operation costs associated with traffic congestion/road vehicle delays that are experienced on at-grade crossings since fewer interruptions can be experienced. This as well reduces the risk of accidents and allows higher overall speed limits.

(ix) Agglomeration Economies and Productivity

These benefits are realized from improved usage of roadway and railway brought about by grade separation at the rail-road crossing. However, according to the U.S. Department of Transport, quantification guidelines of such benefits have not yet been developed. Therefore, this are recommended not to be quantified when performing economic analysis [8].

(x) Resilience

An overpass crossing will achieve resiliency benefits when the road vehicle stress impacts on the track components at the rail-road at-grade crossing will have been eliminated. Benefits for increasing resilience are usually difficult to calculate due to the unpredictable occurrence of disruptive events [8].

2.5 **Financial Analysis of** Crossing Alternative

The primary purpose of doing a financial analysis of a project is to evaluate the project's profitability or cost-effectiveness relative to another alternative project(s) or investment.

Sometimes projects are mutually exclusive, but only one project will be selected and the task is solely to determine which of the choices is best. Several different financial criteria have been proposed for comparing different projects but only the commonly used have been considered in this case i.e. Benefit Cost Analysis (BCA), Net Present Value (NPV), Benefit/Cost Ratio (B/C), and Internal Rate of Return (IRR).

However, in ambiguous cases where different financial criteria point toward different conclusions, the factors not included in the financial analysis may tip the balance toward one project or the other.

BCA: The Benefit Cost Analysis technique (BCA), also known as the Cost-Benefit Analysis (CBA) method is can be used to perform economic analysis of a potential project(s). BCA is a systematic method that estimates first order net benefits that result from transportation projects by accounting for losses, costs, cost savings, benefits, and transfers of transportation time savings, investment costs, improved safety, reduced infrastructure maintenance costs, etc. [8]. The goal of undertaking a BCA in this case was to determine whether the benefits of the proposed highway overpass rail-road crossing outweigh the estimated costs.
Notably, to perform economic analysis of a project, the financial costs are converted into economic costs so as to cater for the distortion in prices due to market imperfections, by incorporating a Standard Conversion Factor (SCF) of 0.85 [18]. This SCF has been recommended for use by the Ministry of transport, Ethiopia and it is as well noted to be generally used across Africa when performing economic evaluation of transport project [18].

Therefore, this method helps to establish information about the two rail-road crossing alternatives including: (1) The profits to be earned – by converting all costs to be invested and all benefits into monetary form, after which, all costs are subtracted from the monetary value of all benefits to obtain result; (2) Time value of the product – by calculating the current value of profits that are expected to be earned after a certain period of time, because inflation erodes value of money, and so its factor shall be considered while doing the calculation; and (3) Basis for comparison – by performing the BCA on both at-grade and grade separated crossings, and then compare the profits in their present value. The crossing alternative which gives the highest financial benefit will be chosen or recommended for the AALRT crossing section identified. A positive value for net project benefits indicates that the sum of its quantified benefits exceeds the costs, whereas a negative net project benefit indicates that its costs exceed the expected benefits [8].

The BCR method: The BCR which involves dividing the sum of benefits by costs and if the BCR is greater than 1.0, then the NPV of expected profits is greater than the costs and it should be considered; if the BCR is equal to 1.0, the ratio indicates that the NPV of expected profits equal the costs; and if a project's BCR is less than 1.0, the project's costs outweigh the benefits and it should not be considered [40]. The BCR is used as analysis tool in conjunction with other types of analysis to make a well-informed decision [16].

The NPV/worth analysis method: It involves Discount Cash Flow (DCF) calculations and it takes into account all revenues, expenses, and capital costs associated with an investment in its Free Cash Flow (FCF); and also takes into account the timing of each cash flow that can result in a large impact on the present value of an investment [16]. The cash flows discounting ie necessary for two main reasons, i.e., (1) to account for the time value of money (TVM), and (2) to adjust for the risk of an investment opportunity [24].

However, the NPV analysis has got some drawbacks e.g. assumes a constant discount rate over time; and accurate risk-adjustment is challenging to perform (hard to get data on correlations, probabilities)

The Internal Rate of Return (IRR) analysis: The economic return rate method simplifies projects to a single number that management can use to determine whether or not a project is economically viable. Where, a company may want to go ahead with a project if the IRR calculated is more than the company's required rate of return or it shows net gain over a period of time. On the other hand, a company may want to reject a project if IRR value falls below the expected rate of return or it projects a loss over a period of time [16].

The result obtained from this analysis type is usually simple, which is why it is still commonly used in capital budgeting. However, for any project that is long-term, that has multiple cash flows at different discount rates or that has uncertain cash flows, like the at-grade and highway railroad crossing projects, IRR alone is not always an effective measurement tool because it does not take into account the life duration difference of projects [24].

CHAPTER 3: METHODOLOGY

3.1 Area of Study

The AALRT E-W line, located on the East-West Corridor of the Addis Ababa transportation system network, and serves the major residential and real estate development locations of Ayat, CMC, Gurdshola and the areas west of Torhailoch. This corridor was observed to be characterised with a well-established road transportation system that happens to be crossed by the AALRT E-W line railway transportation system at different points e.g. CMC round about, Meri, Management institute roundabout, etc.

The different methods used to achieve the objectives of this study included: manual traffic counts technique, document review, field observations, queuing model, and NPV, IRR, BCR analysis methods, sensitivity analysis technique, etc.

3.1.1 Selection of At-grade and Highway Overpass Rail-road Crossing through Field Observations and Document Review

<u>The at-grade rail-road crossing</u>

The at-grade rail-road crossing was selected by considering the physical conditions of the existing at-grade rail-road crossings (see details in Appendix A), seen in Figure 3-1.

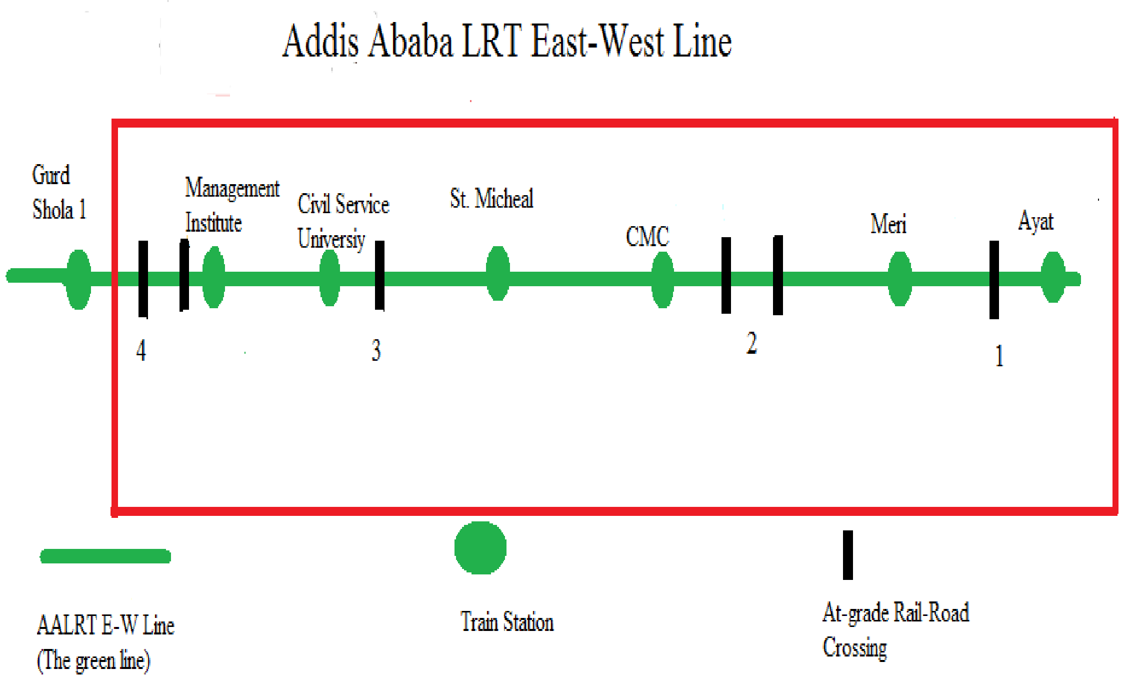

Figure 3-1: Rail-Road at-grade crossing points considered in the study scope

The at-grade rail-road crossing observed to have adequate space that would allow installation of a highway overpass crossing as an improvement option for the existing at-grade railroad crossing, and has the highest record of road traffic volume – which may pose serious traffic congestion problems at the crossing during the peak hours of the day and possible safety risks, was selected.

At-grade rail-road crossing 2 – characterised with two crossing points and located at CMC roundabout was considered for evaluation. Because, it was observed to have adequate space that could possibly allow installation of an overpass crossing as an improvement option, and it was also noted to have the greatest road traffic volume. This crossing also, had only traffic light signals, signs, and warning alarm bell, but not gated and without a permanent attendant. Hence, the improvement of this at-grade crossing using an overpass crossing would allow undisrupted operation of the LRVs that are observed to forcefully brake at the crossing sections especially during peak hours, as a result of uncontrolled road traffic.

However, at-grade crossing 1, 3 and 4 did not have adequate space available around them to possibly allow for the installation/construction of a highway overpass crossing as an improvement option, and this disqualified them from being selected.

Highway Overpass Crossing

The highway overpass crossing that was observed to be physically suitable and could practically be constructed at the identified at-grade crossing location, was selected. This was done by considering the selected at-grade rail-road crossing parameters observed, for example, available space for the installation of an overpass structure; crossing's estimated ADT volume conditions; and the less effective user safety protection system currently installed at the at-grade crossings. In this case, the Megenagna highway overpass crossing was selected for evaluation, because it was observed to be physically suitable and can practically be installed at CMC roundabout and would allow for safe separation of LRV traffic from road traffic by facilitating an overpass bridge for road traffic, leaving the at-grade crossing points to be utilised only by the LRV traffic.

Assumption made:

The difference in location between the highway overpass crossing and the at-grade railroad crossings identified, has been assumed not to cause variation on installation, operation and maintenance costs involved since these selected crossings are both located on the East-West corridor of the Addis Ababa transportation network, and have related economic activities.

3.2 Research Design

This study involved the use of mathematical formulas, theories (e.g. the queuing theory) for quantification of at-grade and highway overpass crossing transport and economic impacts. The process of measurement that provides the fundamental connection between empirical observation and mathematical expression of an attribute was utilised. Primary data collected from the field and secondary data obtained from existing literature were used to achieve the research objectives.

Flowchart Summarizing the Steps followed when achieving the research objectives are seen in Figure 3-2.

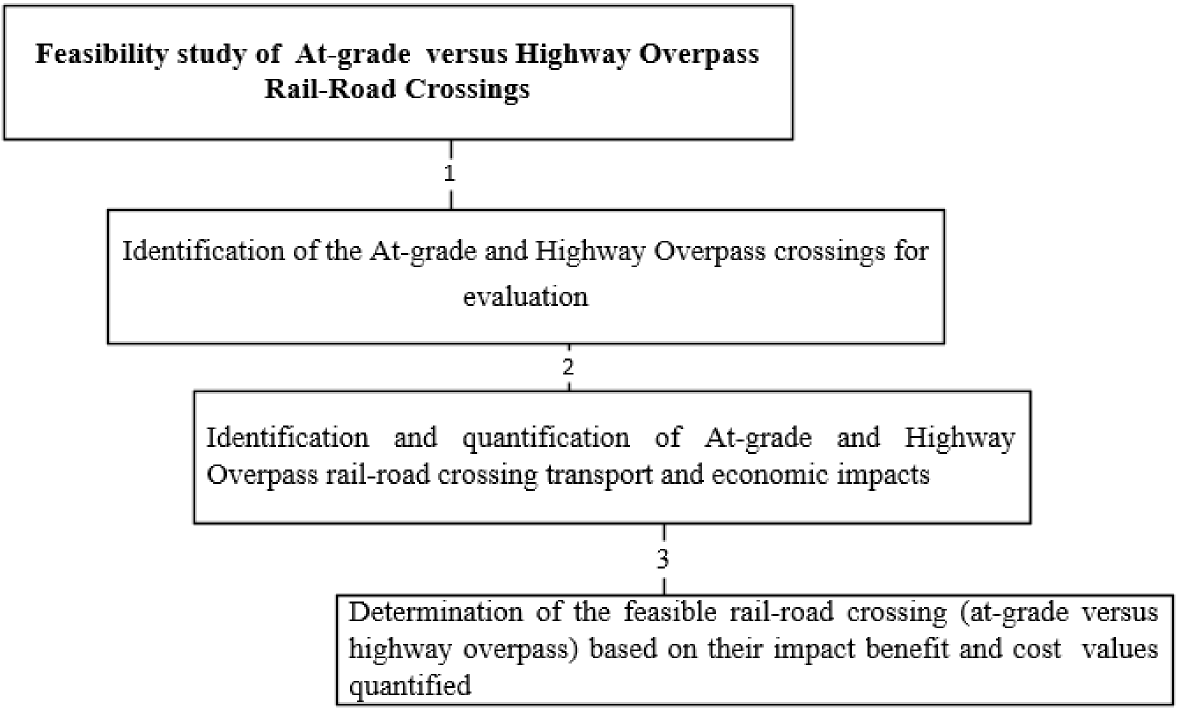

Figure 3-2: Research methodology flow diagram

3.3 Data Collection Techniques and Data Collected

The different data sets required for the quantification of the at-grade and overpass rail-road crossing economic and transport impacts, the respective data collection methods have been summarised in Table 3-1.

Table 3-1: Data collection techniques and the form of data collected

Data collected	Method used	Data type
ADT and VO	Manual Classified Traffic Count Technique	Primary data
The average at-grade crossing time duration taken by a road vehicle		
At-grade crossing closure duration during train occurrences		
The average number of closure times due to train occurrences		
The average number of vehicles waiting at the crossing during closure periods of train occurrence		
The vehicle travel speeds at the crossing		
Average vehicle fuel costs in Adds Ababa	Personal interviews	
Accident/incidents records	Document review	Secondary data
Current operating conditions of the LRV (speed of operation, number of LRV, and capacity of LRV)		
Crossing construction, operation and maintenance costs		
Train/LRV operating hourly costs		
Average hourly wage rate in Addis Ababa		
The inflation rate for Ethiopia (2018 value)		

3.3.1 Primary Data Collection Techniques

(i) Traffic Count Technique

(a) Manual Classified Traffic Counts

These technique was used to collect data on ADT volume for both at-grade and highway overpass crossings/intersections identified, because it less costly to apply than the use of video counts. This was performed for three consecutive days of the week (excluding public holidays, Monday and Friday – which could be affected by holiday and weekend travels), and spanning for a 16 hour period (from 06:00 am to 21:00 pm). The 16-hour period was used because the study was focused on knowing how LRV operations (operate from 6:00 am to 10:00 pm) affect the movement of the road vehicles at the rail-road crossing sections, since they are given priority at the level crossings than road vehicles. And one week's data was considered representative for this purpose.

Also, the average at-grade crossing time duration taken by a road vehicle to cross the section; at-grade crossing closure duration during LRV occurrences, the average number of closure times due LRV occurrences; the average number of vehicles that wait at the crossing during closure periods of train occurrence; and the vehicle travel speeds at the crossing, were as well recorded for the three consecutive days of traffic counting; and then their respective averaged values obtained for use in the quantification of the at-grade crossing impacts.

Notably, manual classified traffic count technique involved the use of the procedure outlined below for the collection of the directional traffic volume at both, at-grade and overpass crossing sections/sites:

- Traffic count tally and summary sheets, and other items required for data recording like and vehicle category identification sheets (see Appendix B), clipboards, pencils, rubber, and sharpeners, were prepared;
- The research assistants/enumerators were recruited and educated on how to carry out traffic data recording in the field;
- On the day of data collection, the researcher and the enumerators arrived at the counting locations at least 30 minutes before the start of the counting time, the enumerators stood in their positions (2 persons on each side of the road), to record classified directional traffic volumes by tallying in the tally sheets;
- The traffic volume data recorded on the daily tally sheets was then summarised by the researcher by feeding it into excel summary sheet created, so as to obtain the directional traffic volume per category per day, see the sample of summarised directional traffic count data for one day in Appendix B;
- The ADT volume counted was then calculated by applying Equation 3-1.

$$ADT = \frac{1}{n}\sum_{i=1}^{n} VOLi, \qquad \text{Equation 3-1}$$

Where; VOL_i = daily volume in the i^{th} day, and n = the number of whole days of counting.

The detailed data collected from the field has been summarised and presented in Table 4-1.

(b) Vehicle Occupancy (VO) Manual traffic Counts

Data on vehicle occupancy was collected using manual traffic counts that were performed at the at-grade rail-road crossing during peak hours of the day, as noted from ADT volume flow data collected from the Classified Manual traffic counts. The peak hour periods noted were from 6:00 AM to 9:00 PM and 4:00 PM to 7:00 PM for both morning and evening peak hour periods respectively. This data was preferably analysed and utilized in traffic congestion intensity analysis of the at-grade rail-road crossing.

VO sample size determination

The sample size for VO data for the at-grade rail-road crossing section was determined using Equation 3-2.

$$Sample\ size\ (n) = \left[\frac{t^2 * C.V^2}{e^2}\right] \qquad \text{Equation 3-2}$$

Where, t= tolerated confidence interval; C.V = coefficient of variance; and e = relative error.

Considering peak hour periods characterised with traffic congestion conditions for the identified rail-road at-grade crossing, a 95% confidence interval and $\pm 5\%$ error were recommended by the VO data collection Handbook [23]; and the minimum sample size was calculated to be 20 vehicles for 15-30 min count. Hence, 20 vehicles were sampled every 15-minute time interval during the field traffic counts.

The VO in terms of number of passengers (including driver) that occupy every first 20 vehicles passing through the at-grade rail-road crossing section during the 15-minute time interval of the field manual traffic counting were recorded. The VO data was recorded by categorising the road vehicles into: passenger vehicles (large, mini and micro buses, cars, and taxis), and goods vehicles (utility, large trucks, medium and small trucks); and the detailed data collected from the field is given in Appendix B.

(ii) Personal interviews

Personal interviews are one of the commonly used types of interviews, where the questions were asked personally directly to the respondent; and their responses on the fuel costs (diesel and petrol) were recorded in the designed survey structured table, seen in Table 3-2.

Table 3-2: Unit cost of fuel in Addis Ababa

S/N	Fuel providing company	Type of fuel	Cost of fuel (ETB/litre)
1	TOTAL	Petrol	a
		Diesel	b
2	Shell	Petrol	a
		Diesel	b

3	Oilibya	Petrol	a
		Diesel	b

Based on the data collected from the three major fuel providing companies in Addis Ababa, the researcher obtained the average unit cost of vehicle fuel using the Equation 3-3.

$$Average\ vehicle\ fuel\ cost = \frac{a+b}{2} \quad \text{Equation 3-3}$$

Where; a, and b = unit price of petrol and diesel fuel types respectively

3.3.2 Secondary data collection technique(s)

Document Analysis method

This involved review of documents, e.g.: books; journals; and periodicals; level crossing construction, operation and maintenance reports; AALRT safety (incident) records, a few to mention. These were reviewed to obtain the required data on historic accident/incidents that have happened on the CMC roundabout rail-road at-grade crossing section; current operating conditions of the LRV (speed of operation, number of LRV, and capacity of LRV); crossing maintenance costs, train operating costs, and at-grade maintenance schedules and associated costs.

Furthermore, this method was also used to determine the average hourly wage rate for persons working in Addis Ababa, and the annual wage rates were obtained for the years 2016, 2017 and 2018 for which the AALRT E-W line has been in operation. Hence, the annual wage rates were used to determine the average hourly wage rate by simply applying Equation 3-4; which assumes 5 working days in a week and 8 hours per day [49].

$$Hourly\ wage = Annual\ Salary/(52 * 5 * 8) \quad \text{Equation 3-4}$$

3.4 Analysis and Quantification of At-grade Rail-Road Crossing and Highway Overpass Crossing Transport and Economic Impacts

3.4.1 Quantification of At-grade Rail-Road Crossing Transport and Economic Impacts

A. <u>Costs and Dis-benefits</u>

(1) Traffic Congestion Impacts

(i) Travel time delay, cost of extra fuel consumed, and the cost of travel time delay determination using the Queuing Theory.

Queuing theory is a mathematical study of queues having a waiting line especially of persons or vehicles waiting for services [44], while Queues are waiting lines which occur whenever units must wait for a facility because the facility may be busy and therefore it is unavailable to render service required [13].

General Features of a Queuing System

Typically any queuing system is composed of units, referred to as customers, needing some kind of service and who arrive at a service facility, join a queue if service is not immediately available, and eventually leave after receiving the service. This then permits a number of different possible con-figurations to describe vehicular traffic flow as a queuing system [44], i.e.:

- Customers are vehicles using the road infrastructure at intersection/crossings for which the traffic light in use to regulate vehicular flow through the intersection is the server.
- Vehicles arrive randomly as units and form a single file of waiting line until they are served by a server.
- Vehicles are served individually in parallel, according to the order in which they arrived.
- *The Arrival Pattern*: The manner in which arrivals occur, indicted by the inter-arrival time between any two consecutive arrivals.
- *Arrival Rate* λ: The average number of vehicles arriving per unit time.
- *The Service Pattern:* The manner in which the service is rendered and is specified by the time taken to complete a service, and distribution of the service time must be specified under stochastic modelling considerations.
- *Service Time* μ: This gives the average number of vehicles served per unit time.
- *Server Utilization* ρ: This gives the average utilisation of the server, given by $\lambda \rho \mu$
- *Mean Service Time* τ*:* The time to serve a designated customer.
- *Mean Waiting Time T*: The average time spent in the queue by a customer who receives a service. Mean Queue Size N: The Average number of customers in the system for service

The quality of service one receives could be judged, at least in part, by the length of time one waits in the queue for service and this is very much influenced by what constitutes the configurations of the system. For example, M/M/2/FCFS/ 6/∞ refers to a queuing system that possesses a Markovian Poisson arrivals, Markovian exponential service, two servers, first come first served (FCFS) queue discipline, a limit of six customers in the queue and an unlimited source of customers in the population [45].

Time dependent transitions

Time dependent transitions applied to queuing problems are obtained from the Markovian queuing system using initial value problem approach and to deduce various performance measure characteristics i.e. average waiting time in the queue, average waiting time in the system, and average waiting time in service [45]

Markov Chain: Suppose that we observe the state of the vehicular traffic at discrete time points t = 0, 1, 2,… for which successive time points define a set of random variables (RVs) X_0, X_1, X_2. The values assumed by the RVs X_n are the states of the system at time n. And suppose that X_n assumes the finite set of values 0, 1,…,m; then X_n= i means that the system's state at time n is i. The family of RVs $\{ X_n, \geq 0\}$ is therefore a stochastic process with discrete parameter space n = 0,1,2, … and discrete state space S={0,1,,…,m }. Where a stochastic process {Xn, ≥0} is called a *Markov chain* if for every X∈S, Equation 3-5 is satisfied such that its right hand side is also defined [46].

$$Pr\{X_n = x_n|X_{n-1}\, x_{n-1}, X_0\, x_0\}\ \mathrm{Pr}\{X_n x_n|X_{n-1} x_{n-1}\} \qquad \text{Equation 3-5}$$

Equation 3-5 indicates a relation of dependence between the RVs X_n and intuitively it means that given the present state of the system, the future state is independent of that of the past. The conditional probability $Pr\{X_n = k|X_{n-1}\ \ j\}$, gives the transition probability from state j to state k [44] as denoted by Equation 3-6

$$P_{jk} = Pr\{X_n\ \ k|X_{n-1} = j\} \qquad \text{Equation 3-6}$$

Given that the state space S satisfies the Markov chain property of Equation 3-5 then if we let F(x(s)) denote all the information with respect to the history of x up to the time s and let J∈S such that s ≤ t, then Equation 3-7 is a *Markov chain* known as *continuous time Markov chain*. And if the Markov property also satisfies Equation 3-8 then the process becomes time-homogeneous. Thus, a time homogeneous continuous Markov Chain.

$$Pr\{X(t) = \ j|F(x(s)) = j\}\ Pr\{X(s,t)j|X(s)\} \qquad \text{Equation 3-7}$$

A discrete time Markov chain in which transitions can happen at any time is known as *continuous time Markov chain* [46]. Hence, given the non-deterministic nature of the observed vehicular traffic, such stochastic description of the queuing build-up is realistic and appropriate for dynamics of the traffic congestion as a queuing system.

$$Pr\{X(t) = \ j|X(s)\}\, Pr\{X(s,t)j|X(0)\} \qquad \text{Equation 3-8}$$

Time Dependent Transitions for M/M/1 Queue*:* Suppose that N(t) gives the number of vehicles in the system (in this case the number in the queue plus the number being served, if any) at time t measured from a fixed initial moment (t =0) and its probability distribution given by Equations 3-9 This implies initially the number of arriving vehicles is i [44].

$$P_n(t) = \Pr\{N(t) \ \ M\}, n = 0,1,2 \ldots. \qquad \text{Equation 3-9}$$

$$P_i(0) = 1 \quad P_j(0) = 0; j\forall\neq$$

Where; i = 0,1,2, i. For this practical problem of vehicular traffic congestion a complete description of {N(t), t ≥ 0} is necessary in order to find a time-dependent solution P_n (t),n ≥0 for equilibrium state the system after a sufficiently long period of operation. In other words we seek the limiting behaviour of P_n (t) as t →∞ and so if we denote P_n by $\lim_{t\to\infty} P_n(t)\,, n = 0,1,2\ldots\ldots$

Whenever the limit exists, then P_n gives the limiting probability that there are n vehicles in the system, irrespective of the number at time 0. Whenever the limit exists, the system is said to reach a steady state, and P_n is called the *steady-state probability* at which there are n vehicles in the congestion [44]. At this state $\{P_n\}$ is independent of time and so has a steady- state distribution, given as the long-run proportion of time that the system contains exactly n vehicles [44]. Thus we say that 0 p denotes the proportion of time when the system is empty from which it follows that $\sum_{n}^{\infty} P_0 = 1$ thereby satisfying probability law [45].

If we consider two sets of limiting probabilities $\{a_n \geq 0\}$and $\{d_n \geq 0\}$ such that a_n be the probability that arriving vehicles find *n* other units in the congestion when they arrive and d_n also be the probability that departing vehicles leave *n* units in the system when they depart, then it implies that a_n is the long-run proportion of vehicles which, when they arrive, find *n* other vehicles in the congestion queues system, while d_n is the long-run proportion of vehicles who, when they depart, leave *n* other vehicles in the system. Intuitively, the three quantities P_n, a_n, and d_n, may not always be all equal and so for such vehicular queue system in equilibrium in which arrivals and departures occur one by one independently, $a_n = d_n$ for all $n \geq 0$ For a queuing system of many vehicles and one server, suppose N(t) is the number of individual vehicles at time *t* , in front of a server waiting to be served [44]. Let N(t) have two possible states of 1 and 0 respectively for the states of being served and completed being served. As such N(t)=1, implies a vehicles is being served and N(t)=0, implies the vehicles has been served. This system exhibits a Markov Chain property.

N(t)= implies the vehicles has been served. This system exhibits a Markov Chain property.

To obtain the time-dependent transition probabilities for this Markov chain, let $X_t = \begin{bmatrix} p(t) \\ q(t) \end{bmatrix}$ be the time-dependent distribution vector for the states "being served" and "finished being served" so that $p(t) = P(N(t)\ 1)$ and $q(t) = P(N(t)\ 0)$. Then it follows that $q(t) = 1\ p(t)$ and so, $\lim_{t\to\infty} P_n(t) = 0$. Thus the time dependent distribution vector becomes $\lim_{t\to\infty} X_t = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$. If we let P(served in Δt) = μΔt and P(not served in Δt) = 1-μΔt, then the transition matrix for each Δt time step is given by $A = \begin{bmatrix} 1 - \mu\Delta t & 0 \\ \mu\Delta t & 1 \end{bmatrix}$ which in compact form becomes $X_{t+\Delta t}$ $=AX_i$ from which we obtain the corresponding matrix equation in 3-10

$$\begin{bmatrix} p(t+\Delta t) \\ q(t+\Delta t) \end{bmatrix} = \begin{bmatrix} 1 - \mu\Delta t & 0 \\ \mu\Delta t & 1 \end{bmatrix} \begin{bmatrix} p(t) \\ q(t) \end{bmatrix} \qquad \text{Equation 3-10}$$

Performing matrix multiplication then we have $p(t+\Delta t) = (1 - \mu\Delta t)\mathrm{p}(t)$ from which $\frac{p(t+\Delta t)}{\Delta t} = \mu p(t)$. Applying differential calculus and taking limits so that $\Delta t \to 0$ yields a differential Equation 3-11 and considered as an initial value problem [46]

$$p(t)' = \lim_{t\to\infty} \frac{p(t+\Delta t)}{\Delta t} \qquad \text{Equation 3-11}$$

$$= -\mu \mathrm{p}(t)$$

and whose solution using Initial Value Problem approach, is given by Equation 3-12

$$p(t) = P[N(t)1] \qquad \text{Equation 3-12}$$

$$= \ p_0 e^{-\mu t}$$

Since we assumed that there is an individual initially being served, then for initial conditions $N(0) \to 1, p(0) = 1$. This means that $p_0 = 1$ and substituting p_0 as the initial value into Equation 3-12 yields Equation 3-13.

$$p(t) = P[N(t)\ 1] \qquad \text{Equation 3-13}$$

$$= e^{-\mu t}$$

Also since $q(t) = 1\ p(t)$ then it follows, from total probability law, that to complete the service we would have a corresponding probability of $q(t) = 1\ e^{-\mu t}$.

Therefore, the performance measure characteristics i.e. average waiting time in the queue, average waiting time in the system, and average waiting time in the service and can be easily determined and are defined in a queuing system as follows [13]:

$L_s = The$ Average number of vehicles waiting in system (at-grade crossing); L_q = average number of vehicles in the queue; L_r = average number of vehicles in service; W_s = average waiting time in the system; W_q= average waiting time in the queue; and W_r = average service time. Therefore, L_s in terms of λ and μ was determined using Equation 3-14.

$$L_s = \frac{\lambda_n}{\mu_n - \lambda_n} \qquad \text{Equation 3-14}$$

Note:

λ , Should be less than μ ($\lambda < \mu$). Otherwise L_s is negative which is meaningless or does not show the physical meaning of the reality.

L_r, L_q, W_q, and W_r , were not of interest in this thesis and so their determination was of less importance; however, they could be determined from Equation 3-15.

$$W_r = \frac{1}{\mu_n} \; ; \; W_s = \frac{1}{\mu_n - \lambda_n} \; ; \text{and } \; W_q = \frac{\lambda_n}{\mu_n(\mu_n - \lambda_n)} \qquad \text{Equation 3-15}$$

Where**,**

n = Total number of vehicles in the system/at-grade crossing during the crossing closure periods; i.e., number of vehicles in queue plus in service; and this was observed and noted form the field during manual classified traffic counts;

$\lambda_n =$ Arrival rate given *n* vehicles in the system i.e., arrival rate is the rate at which vehicles are expected to arrive at the road intersections within a specified period of time, assuming that there are *n* vehicles in the system, and this was observed and noted during field manual classified traffic counts;

$\mu_n =$ Service rate given *n* vehicles in the system i.e., service rate specifies the average number of vehicles that can be serviced during a time period, and it was obtained through the review of the at-grade crossing capacity design.

Application of the queuing theory

In this case, the close form formula method that applies a time dependent M/M/1 queue; other than the WinQSB software method was used [13]. And considering the parameter values obtained from the field i.e.: n = Total number of vehicles in the system/at-grade crossing during the crossing closure periods, $\lambda_n =$ Arrival rate given n vehicles in the system, and $\mu_n =$ Service rate given n vehicles in the system; the average waiting time/vehicle delay time at the at-grade crossing (W_s), and the Average number of vehicles waiting in system (L_s) were calculated using Equation 3-14 and 3-15.

Also, the Cost of Time (C_T) lost or Road Vehicle travel time delay costs, and Cost of Extra Fuel Consumed due to Waiting at the Rail-Road at-grade crossing, were obtained accordingly.

Cost of Time (C_T) lost or Road Vehicle travel time delay costs

To determine the cost of time lost due to congestion at the rail-road crossing, the following parameters were considered:

The average waiting time lost by vehicles at the rail-road at-grade crossing, W_s - calculated using Equation 3-15;

Value of time (t_a): This was considered as the average hourly wage rate and it was obtained from the average monthly wage for a person working in Addis Ababa; which was calculated to be 36 ETB [49]; and

The Average Vehicle Occupancy (AVO): The raw data on vehicle occupancy per vehicle category obtained from manual traffic counts was used to obtain the average Vehicle Occupancy for the at-grade crossing.

Therefore, the Cost of Time Lost (CTL) per hour, due to vehicles travel time delay at the rail-road at-grade crossing was calculated using Equation 3-16.

$$C_T = L_s \times W_s \times t_a \times V_p \qquad \text{Equation 3-16}$$

Where, W_s = average vehicle waiting time at the rail-road at-grade crossing; L_s = average number of vehicles waiting at the rail-road at-grade crossing; $t_a =$ Average value of time; and $V_p =$ Average Vehicle Occupancy.

Hence, the Annual Cost of travel Time Lost/vehicle travel time delay cost resulting from traffic congestion at the crossing ($ACTL$) was then calculated by incorporating the annual conversion factor, as seen in Equation 3-17.

$$ACTL = C_T \times ACF \qquad \text{Equation 3-17}$$

Where, $ACTL$ = Annual cost of time lost at the rail-road at-grade crossing; C_T = Cost of time lost per hour; and ACF = Annual Conversion Factor (1300) [13].

Cost of Extra Fuel Consumed due to Waiting at the Rail-Road at-grade crossing

The cost of extra fuel consumed by vehicles was calculated by defining the following variables:

The average vehicle waiting time (W_s) at the rail-road at-grade crossing was obtained from Equation 3-15;

The average number of vehicles (L_s) waiting at the rail-road at-grade crossing, was also obtained using Equation 3-14;

Weighted average fuel consumption (F_c) of the different vehicles used in Addis Ababa was obtained through document review [14]; and

The average unit cost of fuel per litre (C_u) in Addis Ababa was obtained from personal interviews carried out by the researcher.

Therefore, the Expected Cost of Extra Fuel Consumed (ECEFC) per hour at the rail-road at-grade crossing was then determined using Equation 3-18.

$$ECEFC = C_u \times F_c \times W_s \times L_s \qquad \text{Equation 3-18}$$

Thus, Annual Cost of Extra Fuel Consumed due to congestion was obtained by multiplying the value of $ECEFC$ obtained from Equation 3.5 with the ACF [13], as given in Equation 3-19.

$$ACEFC = ECEFC \times ACF \qquad \text{Equation 3-19}$$

Where, $ACEFC$ = Annual Cost of Extra Fuel Consumed;

$ECEFC$ = Expected Cost of Extra Fuel Consumed – obtained from Equation 3-12; and

ACF = Annual Conversion Factor (1300) [13].

Note: the cost of fuel lost rapidly increases when vehicles wait for a longer time at the at-grade crossing.

Assumptions Made:

- Estimation of road vehicle delays from nonrecurring traffic congestion resulting from incidents, security checks, vehicle breakdowns, random minibus stops, and random pedestrian crossings, pose negligible effect on the travel time delay of the at-grade rail-road crossing road users. Therefore, only recurring (e.g. peak hour traffic congestion) impacts were considered.

- The vehicle mechanical conditions and age cause negligible effects to traffic flow and fuel consumption rate of vehicles at the rail-road at-grade crossing sections.
- All the road and LRV passengers are assumed to be working and so the time lost during travel delays is equal to productive time, and the value of individual's working time will be based on the average hourly wage rate paid in Addis Ababa city of Ethiopia.

(ii) Travel Time Unreliability due to traffic congestion

The Coefficient of Variation of Travel time (COV) in observed travel speeds of traffic at the at-grade section was used as travel time reliability measure; because, this measure directly uses the outcomes of the traffic count exercise.

Steps followed:

- The road vehicle travel speeds, v and travel time, t through the at-grade rail-road crossing were recorded during the traffic count exercise, for every hour for the 16-hour period, of the three consecutive days of counting.
- The mean and standard deviation values of travel time and speeds recorded were then calculated using Equations 3-20, 3-21.

$$Mean = {}^{Sum\ of\ n\ values}\!/_{n}$$ Equation 3-20

$$\text{SD}= \sqrt{\left[\frac{\sum(V-V\,mean)^2}{n-1}\right]} \text{ and } SD= \sqrt{\left[\frac{\sum(t-t\,mean)^2}{n-1}\right]}$$ Equation 3-21

- The COV was determined by dividing standard deviation with mean travel time; giving the disutility of a minute standard deviation of travel time in terms of minutes of mean travel time, as given by Equation 3-22.

$$COV_i = {}^{STD_i}\!/_{\bar{T}_i}$$ Equation 3-22

Where, STD_v = The Standard Deviation of travel speeds;

STD_T = Standard deviation of travel time = ${}^{L}\!/_{STD_v}$; $\bar{T}$ = the mean travel time; L = at-grade section length; and i = at-grade crossing number.

- Therefore, the monetary value for travel time unreliability at the rail-road at-grade crossing was then computed by combining COV with the value of time, t_a.

(2) Incident related costs

The data on the various incidents records for the AALRT E-W and N-S lines was availed by the AALRT Safety and Security Department; and those incidents that have particularly happened at CMC roundabout from the time the AALRT E-W line started operation (September 2015 to December 2018), was extracted and summarised (see Appendix C for details). The extracted details obtained include, the number of operation hours lost, track/infrastructure and rolling stock repair costs, and LRV passenger service fare collections lost every year.

The direct estimation of incident impacts on the AALRT E-W line operations and facility was done; and related operation costs were estimated directly from the LRVs operational passenger service time lost and the related Rolling Stock and railway track infrastructure repair expenses (based on the cost of material, tools and equipment, labour, and transportation expenses met), in cases where damage was registered.

Assumption made: All passengers have been assumed to have similar hourly wage rates irrespective of the trip purpose, passenger age or gender.

(i) LRV passenger service fare lost and infrastructure/rolling stock repair costs

The monetary losses incurred due to incident disrupted operations and infrastructure/rolling stock damage, were estimated by summing the amount of passenger fare lost during incident disrupted operation and the Rolling stock/railway track infrastructure repair expenses.

(ii) LRV passenger productive time lost due to LRV-road vehicle incidents caused delays

The estimation of LRV passenger travel time delay implicated monetary losses have been typically derived through the application of travel unit costs and value of time to affected rail passengers [26] [22].

These was determined for the three years (2015/2016, 2017, 2018) of the AALRT E-W line operation; by multiplying the average passenger flow per hour, the number of delay hours that have been recorded due to incidents at CMC rail-road at-grade crossing, and the average hourly wage rate paid for a person working in Addis Ababa – calculated from the average annual wage rates for a person working in Addis Ababa (obtained using equation 3-4), i.e., (Average hourly wage rate/year * Average Passenger flow per hour/year * operation hours lost /year).

Hence, the aggregated LRV passenger travel time delay monetary loss due to incidents at CMC roundabout that result to lost productive time, was computed by adding the implicated costs for the three years of operation.

(3) Construction, Operation and Maintenance

(i) Construction cost

Considering the fact that the AALRT E-W line was constructed under a lump sum contract, the construction costs for an at-grade crossing was therefore well known only to the contractor. However, in this case, the construction cost was estimated with the help of the AALRT infrastructure experts, based on the cost of construction materials used (e.g. concrete paving, tough rubber, rail, signage, warning bell, and traffic lights); labour costs/human resource costs; construction tools and equipment required; related transportation costs; and the dimensions of the at-grade crossing being evaluated (length and width dimensions). The construction cost estimated was checked for validity, by comparing it to the at-grade construction costs applied in other African countries with the same kind of transportation system

(ii) Operation and maintenance cost

These costs were obtained through document review of the maintenance and operation records obtained from AALRT Operation and Maintenance Department [47].

The operational costs have been estimated by considering the different operational expenses incurred from the daily usage of an at-grade rail-road crossing e.g. road traffic control attendant/personnel, and traffic lights and warning bell power consumption expenses; and this tend to increase the cost of operation of the at-grade crossing. And the maintenance costs recorded are from regular maintenance required costs, and at-grade crossing infrastructure maintenance costs in case of incidents caused damages.

1. Benefits

(i) Accessibility/connectivity

This aspect could not be quantitated due to inadequate information available on the subject and so, it was only evaluated by mentioning the possible benefits of using an at-grade railroad crossing e.g.: ease of accessed by people with disabilities and facilitates connectivity and mobility of all users since there are no vertical gradient differences installed at such crossings.

(ii) Initial Construction Saving

When the estimated construction expenses of an at-grade rail-road crossing was compared to that of the proposed highway overpass crossing, and the at-grade crossing initial construction/investment costs are seen to be relatively lower than those of the highway overpass crossing. This makes it more cost effective and a cheaper option to construct; hence, the difference in the construction cost of the two crossing options was considered as economic benefit for preferred usage of the at-grade railroad crossing over the overpass crossing option during decision making process.

3.4.2 Traffic Data Analysis

(i) Conversion of the traffic data collected from vehicles/day to PCU/day

Traffic volumetric data collected from the field was converted from vehicles per day to PCU per day, through the application of the Passenger Car Unit equivalencies normally used in Ethiopia, see Table 3-3. This was done to enable its use in congestion impact analysis and these traffic volume values (in PCU/day) were useful in the determination of the peak flow rates and peak periods, to assess the relationship between traffic volume and congestion, and determination of the equivalent cost of traffic congestion impacts [14].

Table 3-3: PCU equivalencies used (source: HCM 2000)

Passenger vehicles					**Goods Vehicles**	
Vehicle/Traffic Category	Car	Minibus/ Microbus	Large bus	Motorcycle /baby taxi	LCV (small truck, utility/pickups, 4X4 WD)	Medium/Heavy Truck
PCU Equivalencies	1.0	1.5	3.0	0.5	1.5	3.0

The detailed data recorded from the field has been presented in Appendix B.

(ii) AVO

The raw data on vehicle occupancy per vehicle category obtained from manual traffic counts was used to obtain the AVO for the road vehicles that use the CMC roundabout rail-road at-grade crossing, and Equation 3-23 was applied.

$$\text{Average Vehicle Occupancy, AVO} = \frac{\sum_i^n V_{i,t} VO_{i,t}}{\sum_{i,t}^n V_{i,t}} \qquad \text{Equation 3-23}$$

Where, $VO_{i,t}$ = The Vehicle Occupancy of the ith vehicle category at time interval t,

$V_{i,t}$ = Traffic Volume of ith vehicle category at time interval t.

3.4.3 Quantification of Overpass Crossing Economic and Transport Impacts

A. <u>Costs and Dis-benefits</u>

(1) Costs due to Traffic volume changes during rail-road (highway overpass) crossing construction

Traffic volume changes that may arise from physical changes like Vehicle rerouting/diversion during the implementation/construction of the highway overpass rail-road crossing was estimated using Equation 3-24.

$$\begin{aligned} &Cost\ of\ vehicle\ rerouting \\ &\quad = Affected\ vehicles \times Rerouting\ time \\ &\quad \times Cost\ of\ vehicle\ operation \end{aligned} \qquad \text{Equation 3-24}$$

Where,

Affected vehicles = ADT Volume of the at-grade crossing and was obtained through classified manual traffic counts;

Rerouting time = the time that it will take the vehicle to cover the rerouting distance and it was obtained by taking note of the travel distance from CMC roundabout crossing area to Ayat roundabout that will facilitate safe rerouting option for the daily traffic that uses the at-grade crossings at CMC roundabout [7]; and

The cost of vehicle operation: this was determined by considering the amount of fuel consumed by a vehicle per hour to cover the rerouting distance in Km and multiplying it by the cost of fuel per litre (L). Noting that, fuel consumption is influenced by the age and model of the car, and the distance travelled by a car in an hour is typically influenced by the driver’s travelling speed, quality of the driveway, and the vehicle model [14].

Therefore, the expected cost of vehicle rerouting per day was determined, and multiplied by the assumed construction period, so as to obtain the monetary value lost by road users over the highway overpass crossing construction period.

(2) Construction, Operation and Maintenance Costs

(i) Construction costs

Based on document analysis of existing Megenagna highway overpass crossing designs, construction reports, and the operation and maintenance reports, that were obtained from the Addis Ababa Transportation Bureau, the highway overpass crossing's construction, operation and maintenance costs were obtained. This highway overpass crossing in this case is designed to have four lanes, with two lanes for each directional traffic flow and 0.8 km long with a head room of 6 metres from the ground level. It is composed of suspended reinforced concrete slab, masonry bridge abutments at extreme ends, and reinforced pier supports at intermediate points. The construction cost also includes the material transportation costs, labour, and legal costs that maybe involved in the construction process.

(ii) Operation and maintenance cost

These have been estimated by considering the different operational expenses incurred from the usage of an at-grade rail-road crossing e.g. road traffic control attendant/personnel, and traffic lights and warning bell power consumption expenses; and this tend to increase the cost of operation of the at-grade crossing. Notably, the maintenance costs result from the regular maintenance expenses required for continual usage of the crossing.

B. <u>Benefits</u>

(1) Travel Time saving

Travel time saving benefit was determined by considering the expected delays caused to road vehicle users as a result of at-grade rail-road crossing closures during train occurrences. It was also assumed that every vehicle that arrives at a level crossing when it is closed, experiences a delay equal to the level crossing closure time [6]. Hence, the total vehicle delay was estimated using Equation 3-25, and the value obtained can be seen in Table of results.

$$D = \sum_i V_i \, P_i t_{close} \qquad \text{Equation 3-25}$$

$where,$ D = Total vehicle delay;

T_i = Total duration of period i of traffic count;

t_{close} = Average level crossing closure time duration during train occurrence, and it was observed and noted during field traffic counts;

n_i = the Average number of level/at-grade crossing closure times during period i of the traffic counts, and it is also equivalent to the average number of travel trips done by the AALRT E-W line LRV per day;

$P_i = \frac{n_i t_{close}}{T_i}$, and P_i = Probability of being delayed at a level crossing in period i; and

V_i = ADT volume in period i, obtained through Manual traffic counts done at the at-grade crossing.

Therefore, the total vehicle delay (D), experienced by traffic vehicles that use at the at-grade rail-road crossing was estimated using equation 3-19; and multiplying the value of D by the hourly wage rate paid for a person working in Addis Ababa [43], the cost of travel time delay at the at-grade rail-road crossing for each day was obtained, and then multiplied by the ACF to obtain the annual cost of travel time.

Then by taking the assumption that, when the proposed highway overpass rail-road crossing is used to improve the existing at-grade rail-road crossing, the vehicle delays experienced will be 100% eliminated, implying 100% travel time saving for the overpass crossing road vehicle users.

(2) Value of travel time reliability

In this case, the value of a highway overpass crossing travel time reliability was determined by obtaining the value of a highway overpass crossing travel time unreliability - based on travel time, speed and length of the crossing; and then subtracted it from the at-grade crossing value of travel time unreliability. Therefore, the difference obtained from the two values was considered to be equal to the value of travel time reliability for the overpass highway crossing.

(3) LRV-road vehicle incidents elimination

The LRV-road vehicle incidents impact experienced by the railway and road users at the at-grade rail-road crossing could be eliminated through grade separation, using a highway overpass rail-road crossing. Grade separation allows undisrupted operation of both road vehicle and LRV users, hence, creating a safety benefit for the AALRT through elimination of incidents that may cause financial losses due to their occurrence at the at-grade rail-road crossing. Therefore, the savings obtained from the use of a highway overpass rail-road crossing is equal to 100% of the at-grade rail-road incident costs that will be eliminated.

(4) Free flow of traffic

This was estimated by obtaining the value of traffic congestion impact for both at-grade and highway overpass rail-road crossings; and then subtracting the highway overpass crossing congestion impact value from that of the at-grade rail-road crossing. The difference in the traffic congestion impact value for the two crossing types, was considered as the free flow impact value achieved through the use of a highway overpass rail-road crossing.

The at-grade crossing congestion impacts were obtained using the queuing theory in section 3.5.2 (A. 1), whereas that of the highway overpass crossing was obtained by using the following procedure:

- The average time taken by a typical vehicle to travel through the highway overpass crossing section during peak and off-peak hours of the day, were recorded during traffic counts.
- The travel time delay/waiting time during peak hours was obtained by subtracting the vehicle travel time during off-peak period from the vehicle travel time during peak period.
- By applying the queuing model equations, traffic congestion impacts, i.e., annual cost of extra fuel consumed; loss in productive time due to waiting at the crossing; and the value of travel time unreliability, were determined.
- Finally, the value of traffic free flow was obtained by subtracting the highway overpass traffic congestion impact value from the at-grade crossing's traffic congestion impact value.

3.4.4 Determination of the Feasibility of At-grade versus Highway Overpass Crossing through Financial Analysis

Project(s) description

Analysis of two mutual crossing alternatives was of interest in this case, i.e., the at-grade rail-road crossing (existing project) and the highway overpass rail-road crossing (proposed at-grade rail-road crossing improvement option).

Purpose of the projects and use of the results

Both the at-grade and highway overpass crossing alternatives provide LRV and road vehicle movements at rail-road intersections; and this analysis helps to determine if the benefits of the proposed highway overpass crossing are sufficient to justify the capital investment for improvement of the existing at-grade rail-road crossing.

Base case and alternative considered

The base case used in this analysis is the at-grade rail-road crossing that is currently in place and located at CMC roundabout, and alternative proposed to improve it is the highway overpass crossing.

Analysis types considered

The benefit-cost ratio, net present worth, and rate of return methods were considered for analysis.

Time period for analysis

The time period for the analysis is from 2016 to 2045, which covers 30 years of AALRT E-W line operation; and a base year of 2015 is used for cost and benefit comparison, with values discounted to 2015 USD, since it is the year when the At-grade crossing project's construction was completed and commenced operation. A 30 year analysis period was considered to avoid over estimation of impact values associated with the usage of the facility.

A discount rate/minimum acceptable rate of return (MARR) of 15% was assumed for use in this case based on the current inflation rate (2018) for Ethiopia, which is 10.4% [49]. This discount rate was used in the financial analysis because after removing the effects of inflation, it reflect the real cost of funds to an investor, meaning the investor will gain a financial value equal to MARR minus inflation rate.

The Analysis Steps followed

To perform the BCA of the at-grade and highway overpass rail-road crossing projects, the following steps were followed:

- The crossing project's cash inflows and outflows were categorized in terms of benefits and costs.
- The net benefit/loss value for each of the projects was obtained by subtracting the aggregated costs from the aggregated benefits, and the BCR was then calculated using Equation 3-26.

$$\frac{\sum(NPV\ of\ Benefits)}{\sum(NPV\ of\ Costs)} = Benefit\ Cost\ Ratio \qquad \text{Equation 3-26}$$

- Based on 2018 impact values obtained the value of impacts for the previous years (2016-2017) and those of the future years (2019-2045) were determined using Equation 3-27.

$$FV = CV * (1 + r)^n \qquad \text{Equation 3-27}$$

Where,

FV = Future Value (2019-2045); CV = Current Value (2018 values);

r = the average Inflation rate for Ethiopia (for year 2018), and this was obtained from document review to be 10.4%; and n = Evaluation Time period (i.e., n = 1, 2, 3, 4,……….., 30 years).

- Taking a discount rate of 15%, all the benefit and cost values were discounted to obtain Present Values (PV) for every year in the analysis period and also facilitate the calculation of the Net Present Value (NPV) for each crossing project; using Equation 3-28.

$$PV = Net\ Benefits\ (Cash\ Inflows) - Net\ costs(Cash\ outflows) \qquad \text{Equation 3-28}$$

$$NPV = \sum PV - \sum Initial\ Construction\ or\ investment\ costs$$

- After obtaining the NPV for each crossing project, the IRR of cash flows was then obtained.

3.4.5 Validation of the Feasibility Results Using Sensitivity Analysis or What-If Analysis

Since both at-grade and highway overpass rail-road crossing alternatives are complex in nature, their viability was further checked though sensitivity analysis, because of the uncertainties surrounding many of the variables such as; traffic volume forecasts, LRV-road vehicle incidents, and crossing facility construction (material, labour, transportation) cost changes, and operation and maintenance cost changes, etc.

Sensitivity analysis or what-if analysis is a tool used in financial modelling to analyse how the different values of a set of independent variables affect a specific dependent variable under certain specific conditions. Therefore, it is commonly used by financial analysts to predict the outcome of a specific action when performed under certain conditions and in this case, it was applied in this case to help predict how change in some of the impact values affect the feasibility/economic strength of a rail-road at-grade or highway overpass crossing.

Considerably, the sensitivity analysis was achieved by either increasing, decreasing or increasing and decreasing the cost and benefit values of each crossing project. Then, by following the same steps applied when performing the BCA, the different analysis results were obtained. Hence, variation in the impact cost and benefit values was done by considering each project "with" or "without";

i) Increase in cost by 10, 20 and 30 percent

ii) Decrease in benefits by 10, 20 and 30 percent

iii) Increase in cost and decrease in benefits by 10, 20 and 30 percent

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Traffic Data Analysis Results

4.1.1 ADT Volume for both at-grade and overpass crossings

Once the at-grade and highway overpass crossings were selected, the ADT volume data obtained from field traffic counts was also converted from vehicles/hour to PCU/hour, as seen in Table 4-1.

Table 4-1: At-grade and Highway Overpass Rail-Road Crossing Summarized ADT Volume

Hours Counted	**At-grade Rail-Road Crossing**		**Highway Overpass Crossing**	
	ADT Volume (vehicles/hour)	**ADT Volume (in PCU/hour)**	**ADT Volume (vehicles/hour)**	**ADT Volume (in PCU/hour)**
6:00	2938.67	3852.67	1161.67	1510.50
7:00	3411.33	3996.67	1527.00	1978.83
8:00	2736.00	3124.50	1445.67	1905.00
9:00	2069.33	2355.00	1189.33	1533.17
10:00	1604.00	1833.17	967.00	1205.83
11:00	1538.33	1794.17	791.00	975.17
12:00	1372.00	4572.50	597.33	746.50
13:00	1580.00	1809.83	522.00	681.83
14:00	1689.33	1940.00	684.67	963.17
15:00	2485.33	2793.67	818.00	1090.00
16:00	2409.00	2790.00	1349.33	1743.33
17:00	2575.67	2930.00	1550.33	2051.17
18:00	2365.33	2632.17	1204.00	1580.83
19:00	1704.67	1887.50	915.00	1122.33
20:00	1293.67	4257.00	629.33	741.00
21:00	1127.67	1333.50	372.00	450.50
ADT Volume/day	**32900.33**	**43902.33**	**15723.67**	**20279.17**

4.1.2 Traffic volume peak hour periods

Traffic flow representation seen in Figure 4-1 and 4-2, for at-grade and highway overpass crossings respectively show peak hour periods when the traffic flow reaches the peak. This include morning peak periods (6:00 am to 9:00 am) and evening peak periods (4:00 pm to 7:00 pm), for both at-grade and highway overpass rail-road crossings.

The at-grade peak hour periods were characterized with heavy traffic flow which limited travel speeds and led to traffic congestion problem at the rail-road crossing and the joining routes. Whereas, the highway overpass crossing peak hour periods were noted to have very minimal traffic congestion, and it was observed to have traffic congestion only at points where the highway overpass traffic joins the connecting ring road and other routes. Hence, this was noted not to affect the overpass traffic travel speeds as much.

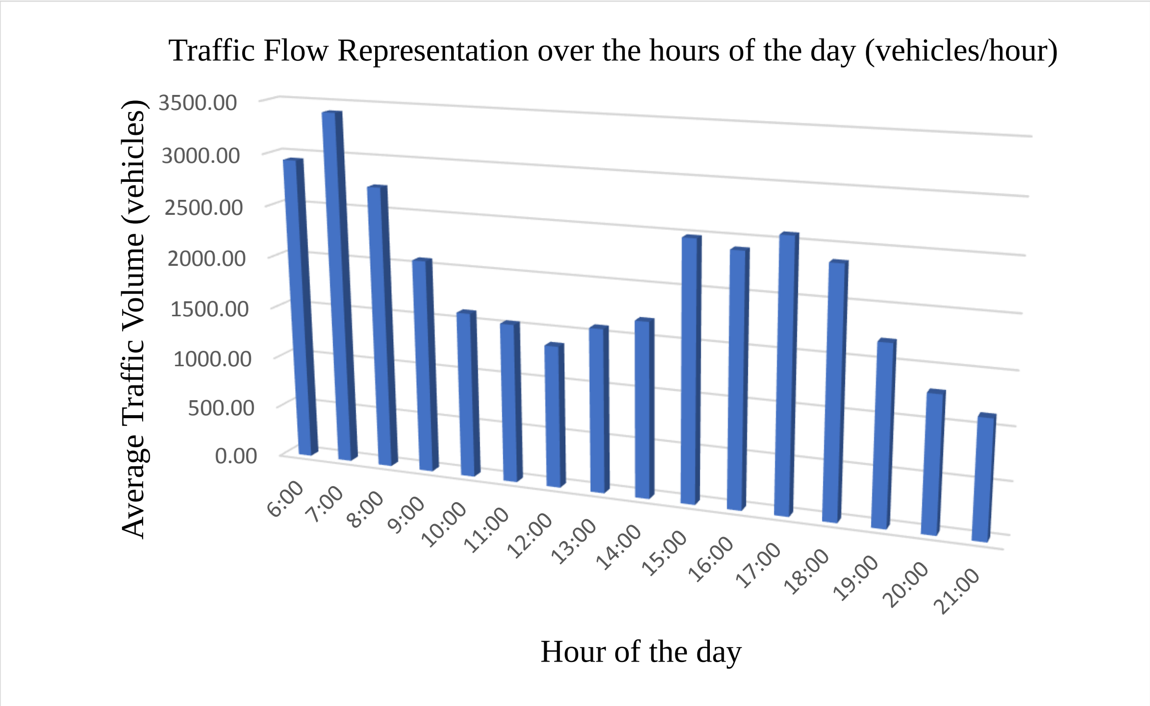

Figure 4-1: At-grade crossing traffic flow representation

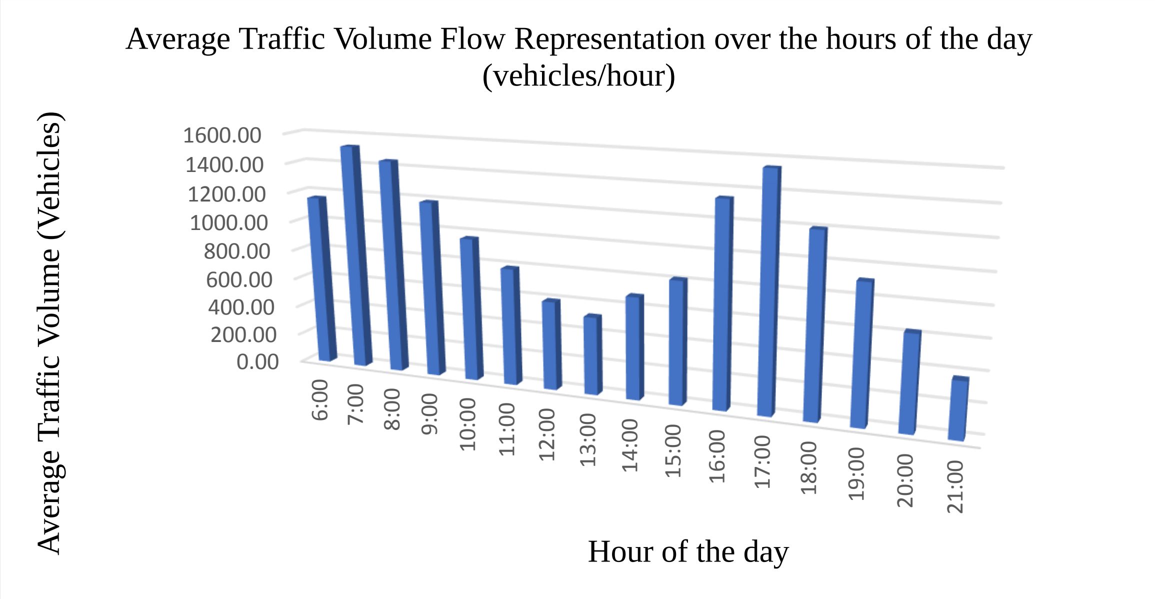

Figure 4-2: Overpass traffic volume flow representation

4.2 Quantification Results

4.2.1 At-grade and overpass transport and economic impacts quantification parameters and values obtained

Various quantification methods given in chapter 3, were used to collect the relevant primary and secondary data that was utilised in the quantification of the economic and transport impacts of both, at-grade and highway overpass rail-road crossings into monetary form; so that the feasibility of both crossing alternatives could be done by considering the economic aspects of both. The different values obtained are presented in Table 4-2.

Table 4-2: At-grade and highway overpass crossing economic and transport impacts quantification parameter values

Quantification parameter	Value Obtained	
	At-grade crossing	Highway overpass crossing
Train operation duration/ traffic count period, i (hours)	16	
Average unit cost of vehicle fuel in Addis Ababa, C_u (ETB/Litre)	20.02	20.02
Annual wage rates for persons working in Addis Ababa for 2016, 2017 and 2018, respectively (ETB)	72384, 72800 and 74880	72384, 72800 and 74880
Average hourly wage paid in Addis Ababa - for 2015/2016, 2017, and 2018 respectively (ETB/hour)	34.8, 35, and 36	34.8, 35, and 36
Value of time, t_a (ETB/hour)	36	36
Annual Conversion Factor, ACF	1300	1300
Weighted average fuel consumption (F_c) of the different vehicles used in Addis Ababa (Litres/hour)	1.25	1.25
Number of hours of data collection, n	16.0	16.0
Road vehicle travel speed and travel time respective mean values	4.13 and 7.56	57.5 and 23.2
Road vehicle travel speed and travel time respective Standard Deviation, SD values	5.9 and 6.5	33.6 and 13.4
Hourly Coefficient of Variation of Travel time, COVi	437.62	77.11
Annual value of travel time unreliability	5750299.52	1013265.75
Annual cost of Extra fuel consumed	121801.61	59120.76
Annual cost of travel time delay	1892366.31	52102.47
Percentage of traffic flow at the crossing section (%)	82.6	17.4
Average number of vehicles in the system/at-grade crossing during the crossing closure periods, n (vehicles/hour)	351	n/a

Quantification parameter	**Value Obtained**	
	At-grade crossing	**Highway overpass crossing**
Service rate given n vehicles in the system, μ_n (vehicles/minute)	92	n/a
Arrival rate given n vehicles in the system, λ_n (vehicles/hour)	360	n/a
The Average number of vehicles waiting in system (at-grade crossing, L_s (vehicles/hour)	243	n/a
Average waiting time in the system, W_s (hours/vehicle)	0.015	n/a
Average number of at-grade crossing closure times during a 16-hour period of traffic counts, n_i (times)	130	n/a
Probability of being delayed at a level crossing in period i, P_i	0.125	n/a
Total vehicle delay, D experienced at the at-grade rail-road crossing (vehicle-hours per day)	63	n/a
AVO	10.8	n/a
Expected Cost of Extra Fuel Consumed by road vehicles using the rail-road at-grade crossing, ECEFC (ETB/hour)	78.89	n/a
LRV Operation hours lost due to LRV-road vehicle incidents at CMC roundabout at-grade crossings for 2015/2016, 2017, and 2018, respectively	30.5, 8, and 13	n/a
Average LRV passenger service fee (ETB)	3.07	n/a
Average LRV passenger flow per hour for 2015/2016, 2017, and 2018, respectively (persons/times/hour)	5178, 5210, and 4898	n/a
Average LRV passenger service fare on the AALRT E-W line per hour (ETB/hour)	13,089	n/a
Distance to the rerouting/alternative route (km)	n/a	4.4551
Average travel time required to cover rerouting distance (hours)	n/a	0.111
Assumed highway overpass construction period (working days)+	n/a	160

Quantification parameter	Value Obtained	
	At-grade crossing	Highway overpass crossing
Average time taken by a typical vehicle to travel through the overpass crossing during peak and off-peak hours of the day, respectively	n/a	0.007 and 0.006
Average waiting time during traffic congestion/peak periods (hours)	n/a	0.001
Average number of vehicles waiting to use the crossing during peak hour/traffic congestion periods	n/a	109.7
Length of highway overpass crossing (km)	n/a	1000
Extra fuel cost due to traffic congestion (ETB/year)	n/a	59120.76
Waiting time cost/loss in passenger productive time (ETB/year)	n/a	40398.2034

4.2.2 At-Grade and Highway Overpass Rail-Road Crossing Impact Monetary Values

The transport and economic impacts quantified for both crossing types were categorised into costs/dis-benefits and benefits, see Table 4-3. The impact monetary values obtained were and in ETB currency and they were then converted into U.S dollars by multiplying the values with 2018 forex exchange rate ie 1 U.S dollar = 28.56 ETB. These results were then used to perform the financial analysis of the two crossing alternatives.

Table 4-3: Monetary values of at-grade and overpass rail-road crossings impacts

	At-grade and Overpass Crossing Impact Monetary values Quantified		
S/N	**Crossing Type and Impacts**	**Impact Value Quantified (ETB)**	**Impact Value Quantified (USD)**
1	**At-grade Crossing Impacts Quantified**		
A	**costs and Dis-benefits**		
1	Traffic Congestion Impacts		
a	Annual Cost of Extra Fuel Consumed	121801.61	
b	Annual Average cost of Road vehicle travel time delay	1892366.31	
c	Value of travel time unreliability (per year)	5750299.52	
	Aggregated traffic congestion impact value	**7764467.45**	**271865.1066**
2	LRV-road vehicle Incidents at CMC rail-road at-grade crossing		
a	LRV passenger service fare lost and Infrastructure/Rolling stock repair costs	1290696.89	
b	LRV passenger productive time lost due to LRV-road vehicle Incidents caused delays	3082331.07	
	Aggregated LRV-road vehicle Incidents Costs	**4373027.96**	**153117.2254**
3	At-grade rail-road crossing Construction cost	**50,665,661**	**1,774,008**
4	Operation and Maintenance costs	**11,832,133**	**414,290**
	Total at-grade rail-road crossing costs/dis-benefit	**74635289.14**	**2,613,280**
B	**Benefits**		
1	Initial investment Savings	2,782,339	97,421
2	Easy access and connectivity	6,010,315	210,445
	Total at-grade rai-road crossing benefits	8,792,654	**307,866**
	Highway Overpass crossing impacts quantified		
A	**costs and Dis-benefits**		
1	Construction costs	53,448,000	1,871,429
2	Operation and Maintenance expenses	267,240	9,357
	Total highway overpass rail-road crossing costs/dis-benefit	**53,715,240**	**1,880,786**
B	**Benefits**		
1	Annual Travel time saving for road and LRV users	**2959233.79**	**103614.63**
2	Annual Travel time reliability value	4737033.77	**165862.53**
3	LRV/road vehicle incidents Savings	4373027.96	**153117.23**
4	Road traffic free flow benefit value	6639978.46	**232492.24**
5	Annual Increase in revenue collections from LRV passenger service payments, on average	3082331.067	107924.7572
	Total highway overpass rail-road crossing benefits	**21791605.05**	**763011.3811**

From the results given in Table 4-3, graphical representation of at-grade rail-road and highway overpass crossing economic and transport impacts quantified were drawn (see Figure 4-3 and 4-4.

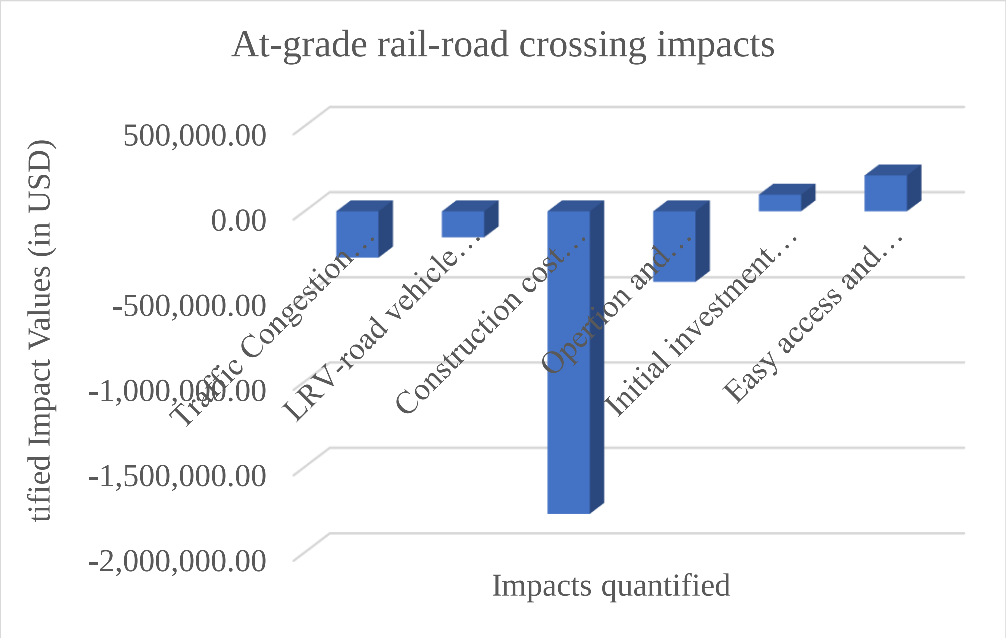

Figure 4-3: At-grade rail-road crossing impacts quantified

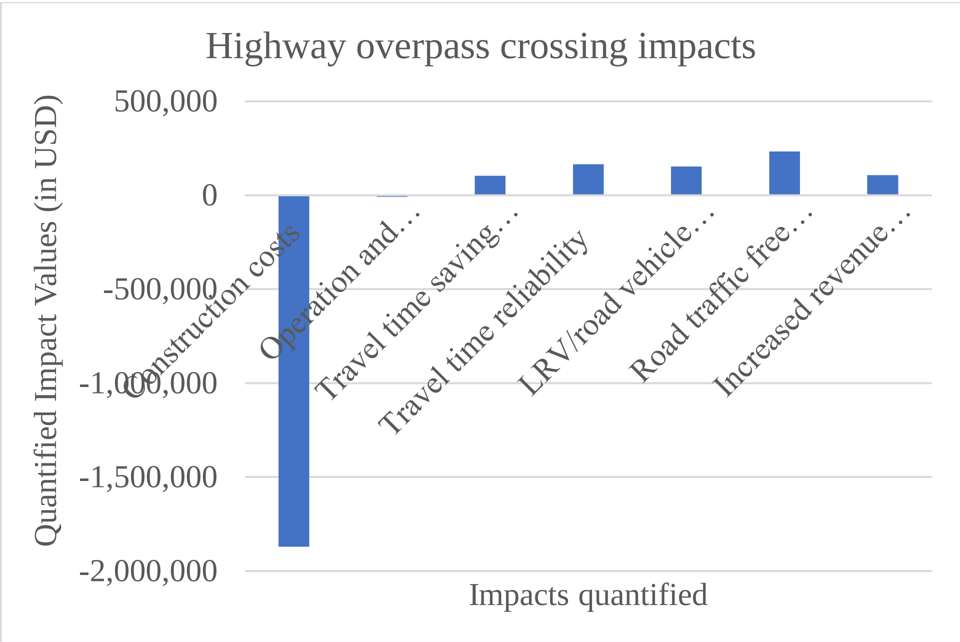

Figure 4-4: Highway Overpass crossing impacts quantified

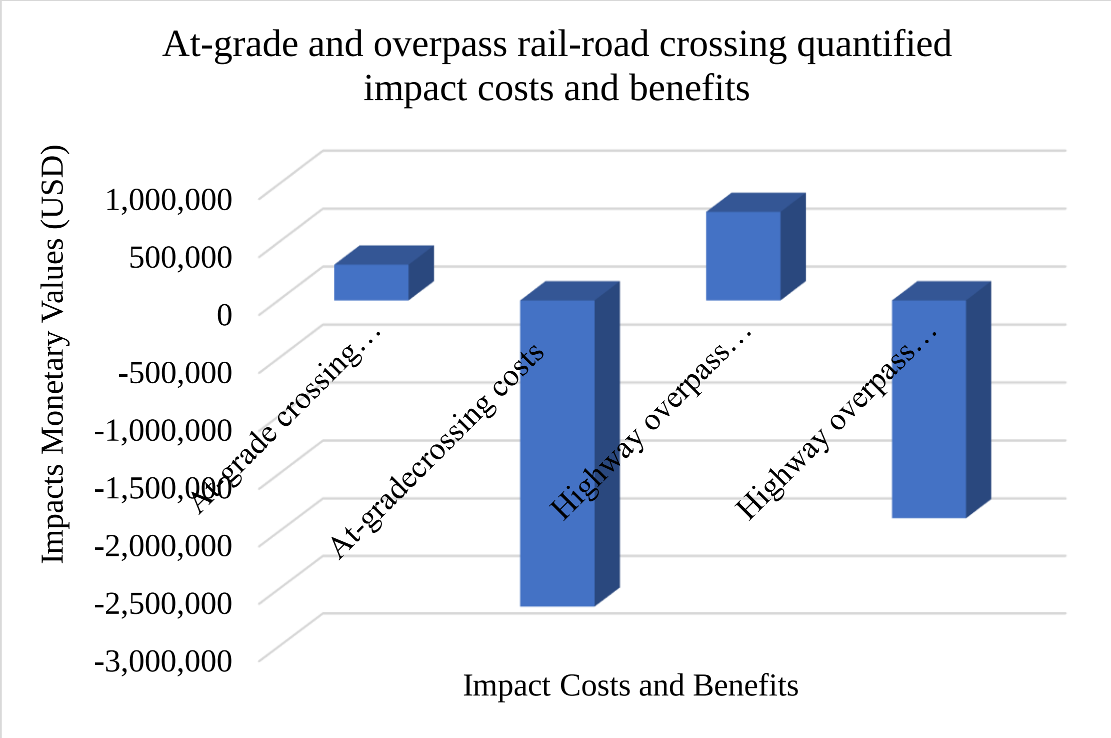

Figure 4-5: at-grade and overpass rail-road crossing Costs and benefit quantified

The aggregated at-grade and highway overpass Crossing benefits and costs/dis-benefits quantified have been represented in Figure 4-5. The highway overpass crossing costs/dis-benefits are noted to be higher than those of the at-grade crossing alternative. This could be due to relatively higher initial construction cost involved with the use of a highway overpass crossing as a rail-road crossing alternative. The relatively lower at-grade crossing initial construction cost might have influenced its selection during cost effective decision making process, but its continual usage generates a variety of negative impacts (e.g. traffic congestion, LRV-Road vehicle incidents, etc.) that normally lead to cash outflow, hence, increasing usage cost during its operational life time.

The initial construction savings of an at-grade rail-road crossing (obtained from comparing the estimated initial construction costs involved with the two crossing alternatives) were noted to be relatively high, which explains why the at-grade aggregated benefit value obtained is high.

Also, the overall benefits associated with the usage of a highway overpass crossing alternative were noted to be of long-term effect, which make it feasible over long-term usage. In general, the highway overpass crossing alternative is feasible since its benefits are observed to be more positive over long-term, while the at-grade railroad crossing is less feasible since it has more cost impacts that cause cash outflow over a long time.

4.3 Financial Analysis Results and discussion

Table 4-4 depicts the at-grade and highway overpass crossing economic impact values used for financial analysis, and these were extracted from Table 4-3. The BCR, NPV IRR values obtained are given in Table 4-5; and the DCF calculations are seen in Appendix D.

Table 4-4: Summary of crossings' impacts economic values

	At-grade and Highway Overpass Crossing Impact Monetary values Quantified	
S/N	**Crossing Type and Impacts**	**Impact Value Quantified (ETB)**
1	**At-grade Crossing Impacts Quantified**	
A	**costs and Dis-benefits**	
i	Traffic Congestion Impacts	271865.1066
ii	LRV-road vehicle Incidents at CMC rail-road at-grade crossing	153117.2254
iii	Construction cost	1,774,008
iv	Operation and Maintenance costs	414,290
B	**Benefits**	
i	Initial investment Savings	97,421
ii	Easy access and connectivity	210,445
2	**Highway Overpass crossing impacts quantified**	
A	**costs and Dis-benefits**	
i	Construction costs	1,871,429
ii	Operation and Maintenance expenses	9,357
B	**Benefits**	
i	Travel time saving for road and LRV users (per year)	103614.63
ii	Travel time reliability (per year)	165862.53
iii	LRV/road vehicle incidents Savings	153117.23
iv	Road traffic free flow benefit value	232492.24
v	Increased revenue collections from LRV passenger service payments, on average (per year)	107924.76

Note: Impact costs equivalent economic value = Financial cost value (in USD) *0.85; costs represent cash outflows; and benefits represent cash inflows.

Table 4-5: BCA BCR, NPV Analysis and IRR results

Analysis outcome	**Rail-road Crossing Projects**	
	At-grade crossing (existing)	Highway overpass crossing (proposed)
Discount rate	15%	15%
NPV of the Project	-$3,427,488.39	$119,875.45
Net benefits/loss	-$7,753,428.07	$6758782.17
BCR	0.2576	3.3704
Internal Rate of Returns (IRR)	<0	15.87%

4.3.1 BCR Results discussion

The highway overpass crossing has a net benefits value of $6758782.17, whereas the at-grade rail-road crossing has a net loss of -$7,753,428.07. Implying that, the highway overpass crossing has more benefits than the at-grade rail-road crossing, making it feasible.

Also, the highway overpass rail-road crossing gives a BCR value greater than 1.0; implying that the crossing alternative has benefits that outweigh the costs incurred, and it would be beneficial to invest in. Also, a BCR>1 means a project is expected to deliver a positive NPV and an IRR which is above the discount rate used in the DCF calculations.

On the other hand, the at-grade rail-road crossing gives a BCR less than 1.0; implying that the costs being incurred through the use of tis crossing alternative outweigh the benefits and it should be considered for improvement.

4.3.2 NPV Results discussion

The highway overpass crossing has a NPV value of $119,875.45, and this positive NPV implies that the project creates value and can be more beneficial to invest in; and this makes it feasible. However, the at-grade rail-road crossing, gives an NPV of -$3,427,488.39 and IRR value less than the discount rate used (IRR < discount rate, NPV <0). The negative NPV implies that the expected rate of return earned on this project is less than the discount rate. This may not necessarily mean the project "loses money."; it may very well generate accounting profit (net income), but, since the rate of return generated is less than the discount rate, it is considered to destroy value, and hence, the project loses value over time of its usage.

4.3.3 IRR Results discussion

Based on the IRR values obtained from the analysis, the existing at-grade rail-raid crossing gives a value that is less than zero and less than the discount rate used, whereas the proposed overpass rail-road crossing project gives an IRR value of 15.87%, which is greater than the discount rate of 15% used in the DCF calculations. Therefore, the highway overpass rail-road crossing alternative is justified to be feasible and can be used to improve the existing at-grade rail-road crossing alternative, seen to be less feasible for use at the CMC roundabout area.

4.3.4 Sensitivity analysis results

From the sensitivity analysis/what-if analysis results given in Table 4-6 show the NPV, BCR, and IRR analysis values obtained by considering any possible impact value variations, i.e., increase in costs, decrease in benefits; and with both increase in costs and decrease in benefits.

Considering a possible increase in the project costs by 10%, 20% and 30%, the NPV of the highway overpass crossing still remains positive, and the BCR also remains greater than 1.0, and the IRR obtained is less than the discount rate used; and vice versa for the at-grade rail-road crossing alternative. These imply that the highway overpass crossing still proves to be feasible for use as a rail-road crossing alternative.

Also, when the possible decrease in benefits was considered, the NPV and BCR values were noted to decrease but still remained positive; unlike those for the at-grade crossing.

The decrease in NPV, BCR, and IRR values, was noted to be gradual with the increase in variation percentages considered for both crossing alternatives; although the highway overpass crossing remained positive while the at-grade rail-road crossing remained negative.

Therefore, this sensitivity analysis results prove that the highway overpass crossing is still feasible for use as a rail-road crossing than the at-grade rail-road crossing; and since the at-grade crossing already exists at CMC roundabout, its improvement using the highway overpass crossing would be a feasible option.

Table 4-6: Sensitivity Analysis Results

	At-grade rail-road crossing (existing)			**Highway overpass rail-road crossing (proposed)**		
	Increase in Costs					
Variation percentage	**10%**	**20%**	**30%**	**10%**	**20%**	**30%**
Net Present Value of future cash flows	($2,036,488.89)	($2,299,991.22)	($2,563,493.54)	2797243	$2,792,228.73	$2,787,214.87
NPV of the Project	($3,856,440.90)	($4,285,393.40)	($4,714,345.91)	($153,376.51)	($426,628.47)	($699,880.43)
Net Benefits/Loss	($8,797,788.51)	($9,842,148.94)	($10,886,509.38)	$6,473,651.73	$6,188,521.29	$5,903,390.85
BCR	0.2342	0.2147	0.1981	3.0640	2.8087	2.5926
Internal Rate of Returns (IRR)	<0	<0	<0	13.99%	12.41%	11.06%
	Decrease in Benefits					
Variation percentage	**10%**	**20%**	**30%**	**10%**	**20%**	**30%**
Net Present Value of future cash flows	($1,930,075.42)	($11,809,889.61)	($2,086,730.50)	$2,517,016.95	$2,231,777.44	$1,946,537.94
NPV of the Project	($3,584,577.25)	($11,926,143.71)	($3,741,232.32)	($165,364.05)	($450,603.56)	($735,843.06)
Net Benefits/Loss	($8,103,963.67)	($17,601,788.86)	($8,623,883.82)	$5,797,773.51	$4,836,764.86	$3,875,756.20
BCR	0.2240	0.1057	0.1742	3.0334	2.6963	2.3593
Internal Rate of Returns (IRR)	<0	<0	<0	13.80%	11.71%	9.59%
	Increase in costs and Decrease in benefits					
Variation percentage	**10%**	**20%**	**30%**	**10%**	**20%**	**30%**
Net Present Value of future cash flows	($2,192,774.17)	($2,534,693.32)	($2,876,612.47)	$2,512,003.09	$2,221,749.72	$2,257,469.18
NPV of the Project	($4,012,726.17)	($4,520,095.51)	($5,027,464.84)	($438,616.01)	($997,107.48)	($1,229,626.12)
Net Benefits/Loss	($9,147,399.99)	($10,451,823.18)	($11,756,246.37)	$5,512,643.07	$4,266,503.97	$4,118,609.34
BCR	0.2037	0.1660	0.1341	2.7576	2.2469	2.1111
Internal Rate of Returns (IRR)	<0	<0	<0	12.09%	8.87%	7.99%

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- The at-grade and highway overpass crossings were selected for analysis based on the physical conditions like crossing road type, crossing geometry, and available space for expansion around the crossing area, among others.
- Based on the methodology, different economic and transport impact cost and benefit values were obtained and used in the feasibility study of at-grade versus highway overpass crossings, with the highway overpass crossing generating a net benefit of $6758782.17, unlike the at-grade rail-road crossing that gave a net loss of -$7,753,428.07. The aggregated at-grade and highway overpass rail-road crossing cost values of $2,613,280 and $1,880,786, respectively; and benefit values of $307,866 and $763,011.38, respectively, were obtained.
- The feasibility of highway overpass crossing over the at-grade rail-road crossing was determined based on the NPV, BCR, IRR analysis results. Where, $119,875.45 NPV, 15.87% IRR and 3.3704 BCR value for highway overpass crossing; and -$3,427,488.39 NPV, 0.2576 BCR and a negative IRR for at-grade rail-road crossing. These results show that the highway overpass crossing is feasible than the at-grade crossing.
- Based on observed actual field conditions and ADT volume data, the CMC roundabout at-grade rail-road crossing is in serious traffic congestion problems during peak hours of the day.
- The traffic police have to regulate the traffic at the CMC roundabout rail-road crossing points since traffic control devices in place cannot function or regulate the traffic as required.
- The highway overpass crossing experiences very minimal traffic congestion problems, and the vehicle travel speeds are relatively higher than those used at the at-grade rail-road crossing.
- Incident at the at-grade rail-road crossing are caused by road poor driver behaviour, driving practices and lack of awareness on the utilisation of the rail-road at-grade crossing.
- The sudden braking by the LRV drivers at the at-grade rail-road crossing sections, especially during peak hour periods cause discomfort problems to the LRV passengers.

5.2 Recommendations

5.2.1 General recommendation

From the BCA results, the author recommends the use of a highway overpass crossing as an improvement option for the existing CMC roundabout at-grade rail-road crossing needs to be put into consideration by the Addis Ababa transportation decision making body to ensure much efficient and effective road and AALRT E-W line transportation systems.

Since the at-grade rail-road crossing at CMC roundabout was noted to have heavy traffic congestion problems that affect the smooth LRV Operation, especially during peak hour periods, sensitisation and awareness campaigns on utilisation of the at-grade rail-road crossing sections need to be done to minimise any possible incidents at these sections.

5.2.2 Recommendations for further research

Further researches and studies need to be done to:

- Investigate and understand other possible improvement options (e.g. removal of the at-grade crossing and use of an underpass crossing) should be considered, so that the most feasible option can be selected;
- Quantify and analyse the traffic congestion of the CMC roundabout using the WinQSB software versus the close form formula method;
- Investigate the impact of vehicle mechanical conditions and age, on the road vehicle traffic flow and fuel consumption rate at rail-road/road at-grade crossing sections;
- Quantify accessibility/connectivity and environmental aesthetic impacts of highway overpass crossing.

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APPENDIX

Appendix A: Findings on identification of the at-grade rail-road crossings

At-grade crossing 1 physical and transportation parameters observed

At-grade crossing physical and transportation parameters				
Crossing Identity No.	**At-grade parameters**	**Description**	**Findings**	**Comments**
1 B/n Ayat and Meri	Location of the crossing	Distance from the nearest railway station – influences the crossing closing times	About 0.8 km east to Ayat train station and 0.5 km west to Meri train station	Less impact on train speed minimization at crossing
	Intersection and crossing geometry	Influence road traffic flow through the crossing and they include;		Good crossing area and crossing conditions provided for crossing road vehicles
		a. Crossing angle	Perpendicular	
		b. Length of crossing	5.4 m	
		d. Intersection width	7 m	
		c. Pedestrian side-walks	Available	
	e. Sight clearance	This affects the sight view of the road vehicle drivers.	Observed to be poor for road users approaching from the eastern direction.	Needs improvement action
	f. Approach grades and parallel streets	It contributes to the number of road vehicles that may use the crossing and possibility of diverting crossing road traffic.	Available	Possible to divert road traffic using the crossing
	Closeness of the route to pedestrian generator	These include: civic/municipal facility or use, school, park, or community-scale retail location	yes	Pedestrian crossing safety at a risk

	Distance to alternative route	Provides a justification for improvement of the crossing by closing/removing it	About 2 km east of Ayat train station.	Possible to improve by closing of the crossing.
	At-grade crossing's surface condition like roughness	These influence road vehicle rideability and flow at the crossing	Rough tough rubber and a concrete finishing	Not good and so, cause road vehicle delay problems.
	Roadway type	Paved or unpaved road – influence road vehicle speeds at the crossing	Paved road type	Good road vehicle rideability conditions
	Number of roadway lanes	Influence traffic flow through the crossing	3 vehicle lanes	Wide enough to support the current traffic volume
	Road traffic volume	this affect the crossing usage during peak and off-peak hours of the day	About 8814 Average Daily Traffic	Liable to heavy traffic congestion conditions over time
	Installed protection system	This affect the safety and risk severity of the crossing users	Light signals, warning bell alarm, and crossing signs.	Better safety protection still needed e.g. automated gates
	Number of tracks, trains, and maximum train speed	Influence the LRV operating effectiveness	2 tracks; and 30 kph maximum speed	Operational speed needs to be increased
	Space available for improvement by use of an overpass crossing	Adequate space necessary for possible installation of an overpass crossing	Not available	Other improvement options need to be explored
Conclusion	The crossing does not qualify for improvement by use of an overpass crossing due to limited available apace for installation and possibility of being eliminated in the future.			

At-grade crossing 2 physical and transportation parameters observed

At-grade crossing physical and transportation parameters				
Crossing Identity No.	**At-grade parameters**	**Description**	**Findings**	**Comments**
2 B/n Meri and CMC	Location of the crossing	Distance from the nearest railway station – influences the crossing closing times	About 0.5 km East to CMC train station and 0.2 km West to Meri train station	Less impact on train speed minimization at crossing
	Intersection and crossing geometry	Influence road traffic flow through the crossing and they include;		Good crossing area and crossing conditions provided for crossing road vehicles
		a. Crossing angle	Perpendicular	
		b. Length of crossing	5.4 m	
		d. Intersection width	7 m	
		c. Pedestrian side-walks	Available	
	e. Sight clearance	This affects the sight view of the road vehicle drivers.	Good	Has no effect the road vehicle users
	f. Approach grades and parallel streets	It contributes to the number of road vehicles that may use the crossing and possibility of diverting crossing road traffic.	Available	Possible to divert road traffic using the crossing
	Closeness of the route to pedestrian generator	These include: civic/municipal facility or use, school, park, or community-scale retail location	yes	Pedestrian crossing safety at a risk
	Distance to alternative route	Provides a justification for improvement of the crossing by closing/removing it	No close alternative routes	Not a good candidate for closure/removal
	At-grade crossing's surface condition like roughness	These influence road vehicle rideability and flow at the crossing	Rough tough rubber and a concrete finishing	Not good and so, cause road vehicle delay problems.

	Roadway type	Paved or unpaved road – influence road vehicle speeds at the crossing	Paved road type	Good road vehicle rideability conditions
	Number of roadway lanes	Influence traffic flow through the crossing	3 vehicle lanes	Wide enough to support the current traffic volume
	Road traffic volume	this affect the crossing usage during peak and off-peak hours of the day	About 34257 Average Daily Traffic	Liable to heavy traffic congestion conditions over time
	Installed protection system	This affect the safety and risk severity of the crossing users	Light signals, warning bell alarm, and crossing signs.	Better safety protection still needed e.g. automated gates
	Number of tracks, trains, and maximum train speed	Influence the LRV operating effectiveness	2 tracks; and 30 kph maximum speed	Operational speed needs to be increased
	Space available for improvement by use of an overpass crossing	Adequate space necessary for possible installation of an overpass crossing	Available	Possible to install an overpass crossing as an improvement option
Conclusion	The crossing qualifies for improvement by use of an overpass crossing due to the availability of adequate space for its installation and the need to provide a better crossing option that will manage the increasing traffic volumes even in the future.			

At-grade crossing 3 physical and transportation parameters observed

At-grade crossing physical and transportation parameters				
Crossing Identity No.	**At-grade parameters**	**Description**	**Findings**	**Comments**
3	Location of the crossing	Distance from the nearest railway station – influences the crossing closing times	About 0.5 km to the East of Management Institute train station and 0.45 km to the west of Gudshola train station	LRV can operate at constant operating speed
	Intersection and crossing geometry	Influence road traffic flow through the crossing and they include;		Good crossing area and crossing conditions provided for crossing road vehicles
		a. Crossing angle	Perpendicular	
		b. Length of crossing	5.4 m	
		d. Intersection width	7 m	
		c. Pedestrian side-walks	Available	
	e. Sight clearance	This affects the sight view of the road vehicle drivers.	Good	Has no effect the road vehicle users
	f. Approach grades and parallel streets	It contributes to the number of road vehicles that may use the crossing and possibility of diverting crossing road traffic.	Available	Possible to divert road traffic using the crossing
	Closeness of the route to pedestrian generator	These include: civic/municipal facility or use, school, park, or community-scale retail location	yes	Pedestrian crossing safety at a risk
	Distance to alternative route	Provides a justification for improvement of the crossing by closing/removing it	No close alternative routes	Not a good candidate for closure/removal

	At-grade crossing's surface condition like roughness	These influence road vehicle rideability and flow at the crossing	Rough tough rubber and a concrete finishing	Not good and so causes road vehicle delay problems.
	Roadway type	Paved or unpaved road – influence road vehicle speeds at the crossing	Paved road type	Good road vehicle rideability conditions
	Number of roadway lanes	Influence traffic flow through the crossing	3 vehicle lanes	Wide enough to support the current traffic volume
	Road traffic volume	this affect the crossing usage during peak and off-peak hours of the day	About 9598 Average Daily Traffic	Liable to heavy traffic congestion conditions over time
	Installed protection system	This affect the safety and risk severity of the crossing users	Light signals, warning bell alarm, and crossing signs.	Better safety protection still needed e.g. automated gates
	Number of tracks, trains, and maximum train speed	Influence the LRV operating effectiveness	2 tracks; and 30 kph maximum speed	Operational speed needs to be increased
	Space available for improvement by use of an overpass crossing	Adequate space necessary for possible installation of an overpass crossing	Not available	Other improvement options need to be explored
Conclusion	The crossing qualifies not for improvement by use of an overpass crossing due to lack of adequate space available, so, another crossing improvement option needs to be explored in order to cope up with the increasing road traffic volumes.			

Appendix B: Manual Traffic Count Vehicle Category Identification Sheets and primary data collected

Vehicle Category Identification Sheets

Vehicle Identification Sheet (Trucks and busses)

No.	CATEGORY	CHARACTERISTICS		TYPICAL	VEHICLES	
1	HEAVY TRUCK	3 OR MORE AXLES				
2	MEDIUM TRUCK	2 AXLES OVER THREE TONNES UNLOADED WEIGHT				
3	LIGHT TRUCK	2 AXLES UNDER THREE TONNES UNLOADED WEIGHT				
4	LARGE BUS	OVER 39 SEATS				
5	MINI BUS	16-39 SEATS				

Vehicle Identification Sheet (Light Motorized Vehicles)

No.	CATEGORY	CHARACTERISTICS		TYPICAL	VEHICLES	
6	MICROBUS	LESS THAN 16 SEATS				
7	UTILITY	PICK UPS AND FOUR WHEEL DRIVE VEHICLES				
8	CAR	ALL CARS AND TAXIS				
9	BABY TAXI	BABY TAXIS AND MISHUKS				
10	TEMPO	AUTO TEMPOS AND AUTO VANS				

Vehicle Identification Sheet (Non-Motorized Vehicles)

No.	CATEGORY	CHARACTERISTICS		TYPICAL	VEHICLES	
11	MOTOR CYCLE	ALL TWO WHEELED MOTORISED VEHICLES				
12	BICYCLE	PUSH BICYCLE				
13	RICKSHAW STANDARD	ALL THREE WHEELED NON MOTORISED VEHICLES				
14	RICKSHAW VAN	ALL THREE WHEELED NON MOTORISED VEHICLES				
15	CART	ALL ANIMAL AND PERSON DRAWN/PUSHED CARTS				

Sample Traffic Count Tally Sheet data recorded

TRAFFIC COUNT TALLY SHEET **Date: 23rd / 01/ 2019**

Crossing Name: CMC Roundabout Rail-Road crossings

Direction of count: From - Teara/Ayat/Magnagna To: Sammit/Magnagna/Torhailoch

Enumerator: gezegn Supervisor : Josepine Aguti

Hours Counted	Motorized																		Total Traffic Volume Per Hour (vehicles/hour)
	Heavy truck		Medium Truck		Small Truck		Large Bus		Mini Bus		Microbus		Utility		Car		Baby Taxis/ Motor cycles		
	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	
6:00:00 to 6:15:00 AM	3	5	22	20	14	10	19	22	14	15	55	51	49	41	183	98	43	39	3113
6:15:00 to 6:30:00 AM	6	7	21	17	13	11	14	19	15	13	53	58	52	55	164	152	41	27	
6:30:00 to 6:45:00 AM	4	4	8	14	9	8	18	22	13	11	81	78	50	57	171	131	72	58	
6:45:00 to 7:00:00 AM	8	5	3	3	7	7	5	8	5	9	83	79	81	81	188	155	83	53	
7:0:00 to 7:15:00 AM	8	10	5	4	10	9	9	7	10	7	92	83	82	79	196	162	85	79	3636
7:15:00 to 7:30:00 AM	5	3	0	7	0	12	5	5	8	10	105	85	54	68	215	197	71	84	
7:30:00 to 7:45:00 AM	3	2	4	8	6	13	5	2	3	3	98	96	75	53	195	191	68	87	
7: 45:00 to 8:00:00 AM	1	0	18	6	8	10	4	0	12	0	81	80	69	50	192	186	65	71	
8:00:00 to 8:15:00 AM	0	0	9	5	5	19	1	1	2	0	75	77	57	62	187	174	66	98	2912
8:15:00 to 8:30:00 AM	0	0	5	11	2	30	0	1	0	2	65	60	51	59	189	179	52	80	
8:30:00 to 8:45:00 AM	2	0	7	0	6	15	0	0	1	0	56	53	53	45	193	153	47	64	
8:45:00 to 9:00:00 AM	0	0	5	2	9	6	0	0	0	1	48	39	45	35	182	147	45	29	

Hours Counted	Motorized																		Total Traffic Volume Per Hour (vehicles/hour)
	Heavy truck		Medium Truck		Small Truck		Large Bus		Mini Bus		Microbus		Utility		Car		Baby Taxis/ Motor cycles		
	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	
9:00:00 to 9:15:00 AM	1	0	7	6	11	11	1	0	1	0	47	26	57	33	169	161	43	49	**2116**
9:15:00 to 9:30:00 AM	0	0	6	10	10	14	1	2	0	1	45	23	49	32	154	106	50	47	
9:30:00 to 19:45:00 AM	2	1	8	6	18	5	0	0	1	0	43	20	45	40	132	116	39	37	
9:45:00 to 10:00:00 AM	0	2	6	7	7	8	0	0	0	0	32	18	51	29	98	106	28	38	
10:00:00 to 10:15:00AM	0	0	5	6	13	10	1	0	0	0	46	26	51	22	99	97	35	50	**1596**
10:15:00 to 10:30:00 AM	0	0	3	5	11	5	0	0	0	0	31	19	34	23	87	86	31	43	
10:30:00 to10: 45:00 AM	0	0	3	10	8	6	0	0	2	0	32	17	37	27	86	77	27	44	
10:45:00 to 11:00:00 AM	0	0	5	12	15	12	1	0	0	1	25	14	30	24	98	73	29	42	
11:00:00 to 11:15:00 AM	2	0	8	5	12	11	2	0	1	0	27	15	42	20	99	87	31	31	**1561**
11:15:00 to 11:30:00 AM	1	0	10	6	13	9	2	0	2	2	29	20	38	27	93	88	25	38	
11:30:00 AM to 11:45:00 PM	0	0	7	7	6	6	2	0	0	1	33	18	52	26	93	84	30	40	
11:45:00 to 12:00:00 PM	1	1	3	5	7	8	0	0	0	0	29	26	37	15	89	70	26	43	
12:00:00 to 12:15:00 PM	0	2	4	2	6	6	0	0	1	0	22	18	35	24	85	90	25	33	**1391**
12:15:00 to 12:30:00 PM	0	1	7	3	8	10	1	0	2	0	15	17	38	22	87	74	27	33	
12:30:00 to 12:45:00 PM	1	0	3	3	6	8	1	0	1	0	21	14	27	12	83	68	34	40	
12:45:00 to 13:00:00 PM	2	2	7	3	6	9	0	0	0	1	20	15	33	18	85	99	32	39	

Hours Counted	Motorized																		Total Traffic Volume Per Hour (vehicles/hour)
	Heavy truck		Medium Truck		Small Truck		Large Bus		Mini Bus		Microbus		Utility		Car		Baby Taxis/ Motor cycles		
	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	
13:00:00 to 13:15:00 PM	2	1	7	2	5	8	1	0	2	1	22	29	37	35	98	96	34	47	1599
13:15:00 to 13:30:00 PM	1	1	5	12	11	11	2	0	1	7	32	26	50	35	99	86	33	44	
13:30:00 to 13:45:00 PM	0	0	2	6	5	7	1	4	0	6	21	29	42	20	96	60	35	30	
13:45:00 to 14:00:00 PM	0	1	4	9	7	8	0	0	0	1	24	18	37	18	102	63	28	32	
14:00:00 to 14:15:00 PM	2	1	3	9	8	15	0	0	0	4	31	30	45	27	105	95	30	36	1812
2:15:00 to 14:30:00 PM	0	0	10	5	6	6	1	1	2	5	32	22	53	26	123	95	35	32	
14:30:00 to 14:45:00 PM	0	0	7	0	8	5	0	0	0	2	37	27	46	20	130	103	28	20	
14:45:00 to 15:00:00 PM	1	0	2	2	10	1	4	0	0	4	33	24	45	35	165	109	31	18	
15:00:00 to 15:15:00 PM	0	0	7	8	14	8	0	1	1	9	40	61	65	30	168	122	55	29	2509
15:15:0 to 15:30:00 PM	0	1	5	5	15	6	1	1	2	3	46	50	51	46	184	134	52	38	
15:30:00 to 15:45:00 PM	0	0	5	5	11	9	1	0	3	5	45	30	43	34	187	180	37	32	
15:45:00 to 16:00:00 PM	1	1	8	1	12	11	2	0	5	0	50	25	45	28	189	182	40	24	
16:00:00 to 16:15:00 PM	2	0	5	2	13	4	2	0	1	2	46	48	38	38	193	179	39	36	2471
16:15:00 to 16:30:00 PM	1	0	3	1	9	6	1	0	2	2	53	28	42	29	183	170	34	28	
16:30:00 to 16:45:00 PM	0	0	1	4	6	5	3	1	1	5	43	20	35	42	176	164	28	34	
16:45:00 to 17:00:00 PM	1	0	3	0	9	7	4	3	2	2	55	48	40	50	178	163	26	72	

Hours Counted	Motorized																		Total Traffic Volume Per Hour (vehicles/hour)
	Heavy truck		Medium Truck		Small Truck		Large Bus		Mini Bus		Microbus		Utility		Car		Baby Taxis/ Motor cycles		
	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	From	To	
17:00:00 to 17:15:00 PM	1	2	5	2	8	1	5	1	3	5	54	30	37	37	167	165	31	32	**2476**
17:15:00 to 17:30:00 PM	1	0	2	3	7	7	15	0	6	0	45	36	46	53	170	157	29	40	
17:30:00 to 17:45:00 PM	1	1	2	2	6	8	1	1	7	3	50	31	43	58	197	154	35	47	
17:45:00 to 18:00:00 PM	1	1	1	2	13	5	5	0	2	3	50	32	58	35	185	156	43	34	
18:00:00 to 18:15:00 PM	2	0	1	6	7	3	3	0	7	2	48	23	61	44	182	153	44	36	**2306**
18:15:00 to 18:30:00 PM	1	0	3	0	10	3	2	0	3	0	39	28	50	33	184	151	35	39	
18:30:00 to 18:45:00 PM	1	0	1	4	13	2	1	0	1	0	41	20	52	22	174	149	32	36	
18:45:00 to 19:00:00 PM	2	0	3	4	8	4	3	0	5	3	46	12	63	19	164	154	33	31	
19:00:00 to 19:15:00 PM	0	0	1	2	5	5	7	0	1	1	26	9	36	21	120	111	40	32	**1560**
19:15:00 to 19:30:00 PM	0	0	3	1	7	0	3	0	4	0	41	11	40	23	118	102	36	30	
19:30:00 to 19:45:00 PM	0	0	1	0	5	0	4	0	1	1	21	12	32	16	113	101	31	28	
19:45:00 to 20:00:00 PM	1	0	2	0	3	2	0	0	1	1	26	15	37	19	104	99	25	23	
20:00:00 to 20:15:00 PM	0	0	0	0	2	2	1	0	1	0	26	11	25	18	95	92	25	26	**1289**
20:15:00 to 20:30:00 PM	1	0	1	0	2	1	4	0	4	0	1	6	32	20	98	90	30	24	
20:30:00 to 20:45:00 PM	0	0	1	3	3	2	2	0	2	1	29	10	25	21	86	84	28	17	
20:45:00 to 21:00:00 PM	2	2	1	1	4	3	3	3	2	0	31	19	35	27	84	78	27	15	
21:00:00 to 21:15:00 PM	1	1	2	3	3	2	1	0	1	0	35	20	33	22	89	80	38	17	**1199**
21:15:00 to 21:30:00 PM	2	1	3	4	1	1	2	3	1	2	30	19	35	21	79	86	29	15	
21:30:00 to 21:45:00 PM	0	1	0	1	2	0	0	0	0	1	23	16	30	25	78	80	30	18	
21:45:00 to 22:00:00 PM	0	0	1	0	1	1	0	0	0	0	14	12	21	19	52	63	18	10	
Total per vehicle category	**78**	**60**	**310**	**302**	**505**	**457**	**177**	**108**	**168**	**158**	**2675**	**2032**	**2879**	**2145**	**8807**	**7713**	**2454**	**2518**	
Total vehicle traffic Volume per day																		**33546**	

CMC Roundabout Rail-Road At-Grade Crossing Road Vehicle Characteristics during LRV Occurrences

At-grade Rail-Road Crossing Traffic Congestion Impacts Quantification Parameters Observed from the Field

S/N	Time	Directional 3 Day's Average number of vehicles waiting during crossing closure periods of train occurance			Average crossing closure time during train occurance (seconds)	Road Vehicle travel speed at the crossing (kph)
		Sammit/Ayat to Teera/Megnagna	Megnagna/Teera to Smmit/Ayat	Average Number of Vehicles at Peak Hour		
1	6:00 AM	153	143	177.50	47.0	4.0
2	7:00AM	186	183		54.0	3.0
3	8:00AM	197	193		61.0	3.0
4	9:00 AM	192	191		52.0	2.0
5	10:00 AM	99	101		45.0	5.0
6	11:00 AM	93	97		40.0	5.0
7	12:00 PM	87	94		55.0	7.0
8	13:00 PM	97	93		58.0	4.0
9	14:00 PM	101	87		41.0	6.0
10	15:00 PM	131	91		46.0	4.0
11	16:00 PM	170	178	173.25	55.0	2.0
12	17:00 PM	186	184		60.0	3.0
13	18:00 PM	183	178		62.0	2.0
14	19:00 PM	127	153		52.0	2.0
15	20:00 PM	110	95		45.0	3.0
16	21:00 PM	89	87		42.0	4.0
	Total	**2201**	**2148**	**350.75**	**Average**	
					50.9	**3.7**
Average Number of train occurances/ rail-road at-grade crossing closure times per day					130.0	

	AVG no of cars waiting	**271.8125** vehc/hour	68	veh/15 minutes

Average crossing time during free flow/non-peak hour periods (seconds)
5.2 seconds

Average crossing time during peak hour periods (seconds)
7.8 seconds

Avg.crossing time (seconds)
6.5 seconds

Average crossing closure time during peak hour periods (seconds) of train occurance
55.4 seconds

Average crossing closure time during oof-peak hour periods of train occurrence
46.5 seconds

VO Classified Manual Traffic Count Data Collected from CMC Roundabout At-Grade Rail-Road Crossings (in PCU)

Time of Counting	Vehicle/Traffic Category									Total in PCU/15 minutes	Total in PCU/ hour
	Passenger vehicles					Goods Vehicles					
	Car	Microbus	Minibus	Large Bus	Motorcycle/ baby taxi	Utility	Small truck	Medium truck	Heavy Truck		
Morning Peak Hours											
6:00 to 6:15 AM	7.0	4.5	3.0	9.0	1.0	1.5	1.5	3.00	0.0	**30.5**	**126.5**
6:15 to 6:30 AM	5.0	6.0	1.5	12.0	0.5	4.5	3.0	0.00	0.0	**32.5**	
6:30 to 6:45 AM	8.0	3.0	3.0	9.0	0.5	1.5	0.0	6.00	3.0	**34.0**	
6:45 to 7:00 AM	6.0	6.0	4.5	6.0	1.0	3.0	0.0	3.00	0.0	**29.5**	
7:00 to 7:15 AM	9.0	3.0	1.5	9.0	0.0	3.0	0.0	3.00	6.0	**34.5**	**120.5**
7:15 to 7:30 AM	6.0	4.5	1.5	6.0	1.5	4.5	1.5	0.00	3.0	**28.5**	
7:30 to 7:45 AM	5.0	3.0	3.0	6.0	1.0	4.5	3.0	3.00	3.0	**31.5**	
7:45 to 8:00 AM	9.0	3.0	3.0	3.0	0.5	6.0	1.5	0.00	0.0	**26.0**	
8:00 to 8:15 AM	6.0	4.5	1.5	3.0	1.0	7.5	0.0	3.00	3.0	**29.5**	**123.0**
8:15 to 8:30 AM	10.0	3.0	1.5	6.0	0.0	3.0	1.5	3.00	3.0	**31.0**	
8:30 to 8:45 AM	7.0	1.5	0.0	3.0	0.5	6.0	4.5	3.00	6.0	**31.5**	
8:45 to 9:00 AM	6.0	3.0	3.0	9.0	1.0	4.5	1.5	0.00	3.0	**31.0**	
9:00 to 9:15 AM	8.0	6.0	3.0	6.0	1.5	1.5	0.0	0.00	0.0	**26.0**	**116.0**
9:15 to 9:30 AM	6.0	4.5	0.0	9.0	1.0	6.0	1.5	0.00	3.0	**31.0**	
9:30 to 9:45 AM	7.0	4.5	1.5	3.0	0.5	3.0	3.0	6.00	3.0	**31.5**	
9:45 to 10:00 AM	5.0	6.0	3.0	3.0	1.5	4.5	1.5	3.00	0.0	**27.5**	

Evening Peak Hors											
4:00 to 4:15 PM	6.0	4.5	1.5	3.0	1.0	3.0	3.0	6.00	3.0	**31.0**	**122.0**
4:15 to 4:30 PM	5.0	6.0	1.5	3.0	1.0	4.5	1.5	6.00	3.0	**31.5**	
4:30 to 4:45 PM	6.0	3.0	3.0	6.0	1.5	3.0	4.5	0.00	0.0	**27.0**	
4:45 to 5:00 PM	8.0	4.5	3.0	12.0	0.5	1.5	0.0	3.00	0.0	**32.5**	
5:00 to 5:15 PM	6.0	6.0	4.5	12.0	1.0	1.5	0.0	0.00	0.0	**31.0**	**122.0**
5:15 to 5:30 PM	7.0	7.5	3.0	9.0	0.5	1.5	1.5	0.00	0.0	**30.0**	
5:30 to 5:45 PM	6.0	4.5	3.0	9.0	1.0	3.0	0.0	3.00	3.0	**32.5**	
5:45 to 6:00 PM	9.0	6.0	4.5	6.0	0.0	3.0	0.0	0.00	0.0	**28.5**	
6:00 to 6:15 PM	5.0	4.5	3.0	9.0	0.5	3.0	3.0	3.00	3.0	**34.0**	**122.0**
6:15 to 6:30 PM	5.0	3.0	4.5	6.0	1.5	3.0	1.5	6.00	0.0	**30.5**	
6:30 to 6:45 PM	8.0	4.5	1.5	6.0	2.0	1.5	0.0	0.00	3.0	**26.5**	
6:45 to 7:00 PM	6.0	3.0	1.5	3.0	1.0	4.5	3.0	3.00	6.0	**31.0**	
7:00 to 7:15 PM	4.0	6.0	3.0	9.0	1.0	4.5	3.0	0.00	0.0	**30.5**	**118.0**
7:15 to 7:30 PM	6.0	4.5	1.5	6.0	1.0	4.5	1.5	3.00	3.0	**31.0**	
7:30 to 7:45 PM	10.0	6.0	1.5	3.0	1.5	1.5	0.0	0.00	0.0	**23.5**	
7:45 to 8:00 PM	5.0	3.0	3.0	9.0	1.0	4.5	1.5	3.00	3.0	**33.0**	
Total/Category	**212.0**	**142.5**	**78.0**	**213.0**	**29.0**	**112.5**	**48.0**	**72.0**	**63.0**	**970.0**	

Appendix C: Summary of CMC rail-road at-grade crossing Incidents Recorded over the AALRT EW line operation period (2015 to 2018),

Date	Location	The accident/Incident Type	LRV Operation Hours Disrupted	Effect on the LRT operations	Total fare losses and repair costs incurred by AALRT
11/12/2015	EW3 CK7+500	Private car rear-ended dump truck damaged the guard fence	0	Did not affect operation but implicated Infrastructure repair cost	15,829
2016	Between EW2 to EW3 up line	10706(107+114) train driver report the EB icon turn to red and show speed limit 40km/h.	3.13	Train returned to deport and 3 trips were cancelled, affecting service fare collected.	40,969
2016	EW2 and EW3 station	There was heavy rain that caused water ponding in the up and down section between EW2 and EW3 station, and the train could not pass normally.	13.4	Train operation speed was limited to 5Km/h; 4 trains empty carriage, 6 trains' part route.	29,232
29/07/2016	EW 2-3 level crossing 2	Railway plastic guard fence damaged by car, with plate number 3-73458 E.T.	8	Implicated infrastructural repair/replacement expenses	12,729
18/08/2016	EW 3(CMC) level crossing 1	Railway signal and communication material damaged by car with plate number 2 -A33524 A.A.	6	Signal and communication material replacement expenses and service fare collections lost.	54,609
28/08/2016	EW2-3 level crossing 2	The concrete block fall due to a knock by a car with plate number 2-79889 A.A	0	No damage	0
19/11/2016	EW3 CMC level crossing area	Guard fence damaged by car with plate number 3-81139 A.A	0	Implicated cost of infrastructure replacement expenses	9,047
5/1/2017	EW2-EW3 Level crossing 2	Incident where the car made contact with Overhead Contact System (OCS) and caused power outage in in both EW2-EW5 up and down lines	3	3 trips cancel, 3partroutes, 1 clear passenger. LRV passenger service fare collections lost and OCS repairs.	52,288

Date	**Location**	**The accident/Incident Type**	**LRV Operation Hours Disrupted**	**Effect on the LRT operations**	**Total fare losses and repair costs incurred by AALRT**
24/01/2017	EW2 -3 level crossing 1	OCC Police report a truck fell down on the track section of EW2 level crossing 2	0	Railway Track clearance labour costs	25,000
19/01/2017	EW3-4	Guard fence damaged by car identified by plate number 01-10397 A.A	0	Infrastructure repair expenses, with no disruptions on the LRV operations.	32,331
30/10/2017	EW3-4	OCS high level protection damaged by car with plate number 3-A48785 A.A.	5	LRV passenger service fare collections lost and OCS repair expenses.	700
20/06/2018	EW2-3 Level crossing 1 and 2	Water ponding that caused water overflow on the rail surface and the train could not pass through	3.02	2 trains clear the passengers, 14 trains in part route, 1 cancel trip. Lost passenger service fare collections for one trip cancelled.	43,239
29/06/2018	EW2-3 level crossing 1	10503(104+110) train driver report social car crash with train	2.42	2 trains clear the passengers, 4 trains in part route, 3 trips cancelled.	131,675
29/9/2018	EW 2-3 level crossing 2	Guard fence damaged by car with plate number 3-32680 O.R.	1	Guard fence repair expenses and LRV passenger fare collections lost.	38,888
24/10/2018	EW 2-3 level crossing 1	Guard fence damage and operation interruption caused by car with plate number 2-14632 A.A	4	Guard fence repair expenses and LRV passenger fare collections lost.	58,402
29/6/2018	EW 2-3 level crossing 2	Train no 104 and 110 collide with car with plate number 3-92084 A.A	3	Rolling stock repair expenses and LRV passenger service fares lost.	190,747
Total Incident costs			51.53		**735,684**

Appendix D: BCA DCF calculations details

At-grade Rail-Road Crossing Alternative

	Cost and Benefit values for each year considered in the analysis						Discounted Cost and Benefit Values (DCF) calculation for the Overpass crossing						
	Cash Outflows (costs/dis-benefits) (in USD)				Cash Inflows (Benefits)		Cash Outflows (costs/dis-benefits) (in USD)				Cash Inflows (in USD)		
Year	Initial construction value	Operation & Maintenance	Congestion impact value	Incident impact value	Initial construction saving	Easy of access and connectivity	Initial construction value	Operation & Maintenance	Congestion impact value	Incident impact value	Initial construction saving	Easy of access and connectivity	**Net Cash Flows Per year**
2015	-1,654,502						-1654501.8						-1654501.822
2016		-288925.32	-189598.2171	-106783.6668	97,421	172663.6409		-251239.41	-164868.0149	-92855.36241	97420.82589	150142.2964	-261399.6627
2017		-318973.55	-209316.4317	-117889.1681		190620.6595		-241189.83	-158273.2943	-89141.14791		144136.6046	-344467.6691
2018		-352146.8	-231085.3406	-130149.6416		210445.2081		-231542.24	-151942.3625	-85575.502		138371.1404	-330688.9623
2019		-388770.07	-255118.216	-143685.2043		232331.5098		-222280.55	-145864.668	-82152.48192		132836.2948	-317461.4038
2020		-429202.16	-281650.5105	-158628.4656		256493.9868		-213389.33	-140030.0813	-78866.38264		127522.843	-304762.9477
2021		-473839.18	-310942.1636	-175125.826		283169.3614		-204853.75	-134428.878	-75711.72733		122421.9293	-292572.4298
2022		-523118.45	-343280.1486	-193338.9119		312618.975		-196659.6	-129051.7229	-72683.25824		117525.0521	-280869.5326
2023		-577522.77	-378981.284	-213446.1587		345131.3484		-188793.22	-123889.654	-69775.92791		112824.05	-269634.7513
2024		-637585.14	-418395.3376	-235644.5592		381025.0086		-181241.49	-118934.0678	-66984.8908		108311.088	($258,849.36)
2025		-703894	-461908.4527	-260151.5934		420651.6095		-173991.83	-114176.7051	-64305.49516		103978.6445	($248,495.39)
2026		-777098.97	-509946.9318	-287207.3591		464399.3769		-167032.16	-109609.6369	-61733.27536		99819.4987	($238,555.57)
2027		-857917.27	-562981.4127	-317076.9245		512696.9121		-160350.87	-105225.2515	-59263.94434		95826.71876	($229,013.35)
2028		-352146.8	-231085.3406	-130149.6416		210445.2081		-57233.7	-37557.82823	-21152.95531		34203.22967	($81,741.25)
2029		-1045643.3	-686170.7535	-386458.4288		624883.1997		-147779.36	-96975.59174	-54617.65111		88313.90401	($211,058.70)
2030		-1154390.2	-757532.5118	-426650.1054		689871.0524		-141868.19	-93096.56807	-52432.94506		84781.34785	($202,616.35)
2031		-1274446.8	-836315.8931	-471021.7163		761617.6419		-136193.46	-89372.70535	-50335.62726		81390.09393	($194,511.70)
2032		-1406989.2	-923292.7459	-520007.9748		840825.8766		-130745.72	-85797.79713	-48322.20217		78134.49017	($186,731.23)
2033		-1553316.1	-1019315.192	-574088.8042		928271.7678		-125515.89	-82365.88525	-46389.31408		75009.11057	($179,261.98)
2034		-1714861	-1125323.971	-633794.0398		1024812.032		-120495.26	-79071.24984	-44533.74152		72008.74614	($172,091.50)
2035		-1893206.5	-1242357.664	-699708.62		1131392.483		-115675.45	-75908.39984	-42752.39186		69128.3963	($165,207.84)
2036		-2090100	-1371562.862	-772478.3165		1249057.301		-111048.43	-72872.06385	-41042.29618		66363.26045	($158,599.53)
2037		-2307470.4	-1514205.399	-852816.0614		1378959.26		-106606.49	-69957.1813	-39400.60434		63708.73003	($152,255.55)
2038		-2547447.3	-1671682.761	-941508.9318		1522371.024		-102342.23	-67158.89404	-37824.58016		61160.38083	($146,165.33)
2039		-2812381.9	-1845537.768	-1039425.861		1680697.61		-98248.544	-64472.53828	-36311.59696		58713.96559	($140,318.71)
2040		-3104869.6	-2037473.696	-1147526.15		1855490.161		-94318.602	-61893.63675	-34859.13308		56365.40697	($134,705.96)
2041		-3427776	-2249370.96	-1266868.87		2048461.138		-90545.858	-59417.89128	-33464.76776		54110.79069	($129,317.73)
2042		-3784264.7	-2483305.54	-1398623.232		2261501.097		-86924.023	-57041.17563	-32126.17705		51946.35906	($124,145.02)
2043		-4177828.3	-2741569.316	-1544080.048		2496697.211		-83447.062	-54759.5286	-30841.12996		49868.5047	($119,179.22)
2044		-4612322.4	-3026692.525	-1704664.373		2756353.721		-80109.18	-52569.14746	-29607.48476		47873.76451	($114,412.05)
2045		-5092003.9	-3341468.547	-1881949.468		3043014.508		-76904.813	-50466.38156	-28423.18537		45958.81393	($109,835.57)
								-4338566.55	**-2847048.802**	**-1603487.18**		**2592755.456**	**($7,753,428.07)**

Discount rate =	0.15
Analysis period, n in years =	30
Taking an inflation rate of 10.4	0.104

($1,772,986.57)	Net Pressent Value of future cash flows
-1654501.822	Initial Invesetment
($3,427,488.39)	NPV of the Project
($3,427,488.39)	
($10,443,604.35)	Costs
$2,690,176.28	Benefits
($7,753,428.07)	Net Benefits/Loss
0.2576	BCR

this IRR value is < 0, hence negative value

Overpass Rail-Road Crossing Alternative

Costs and Benefit Values for each year considered in the analysis

Year	tflows (costs/dis-benefits) (		Cash Inflows (in USD)				
	Initial construction value	Operation & Maintenance	Travel time saving	Travel time reliability	LRV/Road incident savings	Traffic Free flow benefit value	Increased revenue collections
2015	-2,682,381.0						
2016		-11,004.1	85,012.5	136,085.0	125,627.8	190,752.5	88,548.9
2017		-12,148.6	93,853.8	150,237.8	138,693.1	210,590.8	97,757.9
2018		-13,412.0	103,614.6	165,862.5	153,117.2	232,492.2	107,924.8
2019		-14,806.8	114,390.5	183,112.2	169,041.4	256,671.4	119,148.9
2020		-16,346.8	126,287.2	202,155.9	186,621.7	283,365.3	131,540.4
2021		-18,046.8	139,421.0	223,180.1	206,030.4	312,835.3	145,220.6
2022		-19,923.7	153,920.8	246,390.8	227,457.5	345,370.1	160,323.6
2023		-21,995.8	169,928.6	272,015.5	251,113.1	381,288.6	176,997.2
2024		-24,283.3	187,601.2	300,305.1	277,228.9	420,942.6	195,404.9
2025		-26,808.8	207,111.7	331,536.8	306,060.7	464,720.7	215,727.0
2026		-29,596.9	228,651.3	366,016.7	337,891.0	513,051.6	238,162.7
2027		-32,675.0	252,431.0	404,082.4	373,031.7	566,409.0	262,931.6
2028		-36,073.2	278,683.9	446,107.0	411,827.0	625,315.5	290,276.5
2029		-39,824.8	307,667.0	492,502.1	454,657.0	690,348.3	320,465.2
2030		-43,966.6	339,664.3	543,722.3	501,941.3	762,144.5	353,793.6
2031		-48,539.1	374,989.4	600,269.4	554,143.2	841,407.6	390,588.1
2032		-53,587.1	413,988.3	662,697.5	611,774.1	928,914.0	431,209.3
2033		-59,160.2	457,043.1	731,618.0	675,398.6	1,025,521.0	476,055.1
2034		-65,312.9	504,575.6	807,706.3	745,640.0	1,132,175.2	525,564.8
2035		-72,105.4	557,051.5	891,707.7	823,186.6	1,249,921.4	580,223.5
2036		-79,604.4	614,984.8	984,445.3	908,798.0	1,379,913.3	640,566.8
2037		-87,883.2	678,943.2	1,086,827.6	1,003,313.0	1,523,424.2	707,185.7
2038		-97,023.1	749,553.3	1,199,857.7	1,107,657.6	1,681,860.4	780,733.0
2039		-107,113.5	827,506.9	1,324,642.9	1,222,854.0	1,856,773.8	861,929.3
2040		-118,253.3	913,567.6	1,462,405.8	1,350,030.8	2,049,878.3	951,569.9
2041		-130,551.6	1,008,578.6	1,614,496.0	1,490,434.0	2,263,065.7	1,050,533.2
2042		-144,129.0	1,113,470.8	1,782,403.6	1,645,439.1	2,498,424.5	1,159,788.6
2043		-159,118.4	1,229,271.8	1,967,773.5	1,816,564.8	2,758,260.6	1,280,406.6
2044		-175,666.7	1,357,116.0	2,172,422.0	2,005,487.5	3,045,119.7	1,413,568.9
2045		-193,936.0	1,498,256.1	2,398,353.9	2,214,058.2	3,361,812.2	1,560,580.1
Totals	-2,682,381.0	-1,952,896.8	15,087,136.7	24,150,939.4	22,295,119.3	33,852,770.5	15,714,726.6

Discount rate =	0.15
Analysis period, n in years =	30
Taking an inflation rate of 10.	0.104

Discounted Cost and Benefit Values for the Overpass crossing

Cash Outflows (costs/dis-benefits) (in USD)		Inflows (in USD)					Net Cash Flows per year
Initial construction value	Operation & Maintenance	Travel time saving	Travel time reliability	LRV/Road incident savings	Traffic Free flow benefit value	Increased revenue collections from	
-2682381							($2,682,381.00)
	-9568.801768	73923.93681	118334.7481	109241.6028	165871.7705	76999.00148	$534,802.26
	-9186.049697	70966.97934	113601.3582	104871.9387	159236.8997	73919.04142	$513,410.17
	-8818.607709	68128.30017	109057.3038	100677.0611	152867.4237	70962.27976	$492,873.76
	-8465.863401	65403.16816	104695.0117	96649.9787	146752.7268	68123.78857	$473,158.81
	-8127.228865	62787.04143	100507.2112	92783.97955	140882.6177	65398.83703	$454,232.46
	-7802.13971	60275.55978	96486.92277	89072.62037	135247.313	62782.88355	$436,063.16
	-7490.054122	57864.53739	92627.44586	85509.71556	129837.4205	60271.56821	$418,620.63
	-7190.451957	55549.95589	88922.34802	82089.32693	124643.9236	57860.70548	$401,875.81
	-6902.833879	53327.95765	85365.4541	78805.75386	119658.1667	55546.27726	$385,800.78
	-6626.720524	51194.83935	81950.83594	75653.5237	114871.84	53324.42617	$370,368.74
	-6361.651703	49147.04577	78672.8025	72627.38275	110276.9664	51191.44912	$355,553.99
	-6107.185635	47181.16394	75525.8904	69722.28744	105865.8878	49143.79116	$341,331.84
	-5862.898209	45293.91739	72504.85478	66933.39595	101631.2523	47178.03951	$327,678.56
	-5628.382281	43482.16069	69604.66059	64256.06011	97566.00217	45290.91793	$314,571.42
	-5403.24699	41742.87426	66820.47417	61685.8177	93663.36209	43479.28121	$301,988.56
	-5187.11711	40073.15929	64147.6552	59218.385	89916.8276	41740.10997	$289,909.02
	-4979.632426	38470.23292	61581.74899	56849.6496	86320.1545	40070.50557	$278,312.66
	-4780.447129	36931.4236	59118.47903	54575.66361	82867.34832	38467.68534	$267,180.15
	-4589.229243	35454.16666	56753.73987	52392.63707	79552.65439	36928.97793	$256,492.95
	-4405.660074	34035.99999	54483.59028	50296.93159	76370.54821	35451.81881	$246,233.23
	-4229.433671	32674.55999	52304.24667	48285.05432	73315.72628	34033.74606	$236,383.90
	-4060.256324	31367.57759	50212.0768	46353.65215	70383.09723	32672.39622	$226,928.54
	-3897.846071	30112.87449	48203.59373	44499.50606	67567.77334	31365.50037	$217,851.40
	-3741.932228	28908.35951	46275.44998	42719.52582	64865.06241	30110.88035	$209,137.35
	-3592.254939	27752.02513	44424.43198	41010.74479	62270.45991	28906.44514	$200,771.85
	-3448.564741	26641.94412	42647.4547	39370.315	59779.64151	27750.18733	$192,740.98
	-3310.622152	25576.26636	40941.55651	37795.5024	57388.45585	26640.17984	$185,031.34
	-3178.197266	24553.21571	39303.89425	36283.6823	55092.91762	25574.57265	$177,630.09
	-3051.069375	23571.08708	37731.73848	34832.33501	52889.20092	24551.58974	$170,524.88
	-2929.0266	22628.24359	36222.46894	33439.04161	50773.63288	23569.52615	$163,703.89
	-168923.4058	**1305020.574**	**2089029.448**	**1928503.072**	**2928227.074**	**1359306.409**	**$6,758,782.17**

$2,802,256.45	Net Pressent Value of future cash flows
($2,682,381.00)	Initial Invesetment
$119,875.45	NPV of the Project
$119,875.45	
15.87%	Internal Rate of Returns (IRR)
-2851304.406	Costs
9610086.576	Benefits
6758782.171	Net Benefits/Loss
3.3704	BCR