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**MODELING LEVEL CROSSINGS' TRAVEL TIME AND DELAY
CHARACTERISTICS OF ADDIS ABABA LIGHT RAIL TRANSIT (AA-LRT)**

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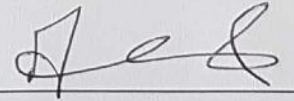
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DEDICATION
SENIT NEGASI
THEO DARIC

ABBREVIATIONS

AACRA-Addis Ababa City Road Agency
AADT-Average Annual Daily Traffic
AA-LRT-Addis Ababa light rail transit
ACBE-Anbesa City Bus Enterprise
AARTB- Addis Ababa Road Transport Bureau
BRT-Bus Rapid Transit
CREC-China Railway Group Limited
CSA-Central Statistics Agency
DC-Direct current
EIRR-Economic internal rate of return
ERA-Ethiopia Road Authority
ERC-Ethiopia Railway Corporation
FDRE-Federal Democratic Republic of Ethiopia
FHWA-Federal Highway Administration
GDP-Gross domestic product
GIS-T-GIS application in transportation system
HCM-Highway Capacity Manual
HRT-Heavy Rail Transit
IHDP-Integrated Housing Development Program
Km-Kilometer
LRT-Light Rail Transit
LRV-Light Rail Vehicle
MoT-Ministry of Transportation
MTA- Metropolitan Transport Authority
MUTCD-Manual on Uniform Traffic Control Devices
NCHRP-National Cooperative Highway Research Program
NETSIM-Network simulator Emulator
NPV-Net Present Value
OAU-Organization of African Unity
O-D-Origin-Destination

PPH- passengers per hour

Pphpd-passengers per hour per direction

RXR-level crossing

TCRP-Transit Cooperative Research Program

TMA-Traffic Management Agency

TPMO-Transport Planning Management Office

UNECA- United Nations Economic Commission for Africa

WSDOT-Washington State Department of Transportation

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ABSTRACT

Traffic modeling is simplified representation of a part of traffic reality that provides a better understanding and interpreting of the complex traffic interactions. The objectives of this study is modeling level crossings travel time and delay characteristics of Addis Ababa light rail transit (AA-LRT) using simulation and mathematical models and evaluate the operational characteristics of the level crossings. In the process of achieving the objectives, the study investigate about peak period vehicle volumes, compositions, routings, LRV arriving frequency ,speed and the delays experienced. To meet the objective of this research intersection geometry data from field and traffic flow data at selected intersections is done by video recording and manual counting. In addition travel time data using light rail transit and minibus taxi is collected by traveling using these modes to a statistical number of repetitions. Suitable data inputs in forms of traffic volume, vehicle composition, vehicle routing, speed, train headway, travel time and delay at different incidences including level crossings are prepared. These suitable data inputs are introduced into VISSIM and SPSS analysis soft wares. Finally, the results were interpreted and the key research findings were presented in two types; i.e. through VISSIM simulation and SPSS statistical models. At the CMC level crossing the baseline without LRT scenario the average delay of traffic is 134.62s/veh ,the actual scenario with 00:05:41 LRV headway the average delay of traffic is 135.2 s/veh the delay increased by 0.43% and twice arrival frequency scenario the delay is 136.22s/veh with an increase in delay of 0.76% from the actual conditions. At the Sebategna level crossing the baseline without LRT scenario the average delay of traffic is 22.31s/veh ,the actual scenario with 00:06:30 LRV headway the average delay of traffic is 23.53 s/veh the delay increased by 5.47% and twice arrival frequency scenario the delay is 33.11s/veh with an increase in delay of 40.7% from the actual conditions. Additionally as observed in the mathematical model equation, the train's travel time is dependent on running time, delay at grade intersection, open door close door time, close door start movement time and stop open door time in descending order. It is concluded that the average additional delays at level crossings increase from the base scenario and with increasing light rail crossing frequencies. In addition, delay at the level crossing is the second important variable that contributes for the variability of train travel time at peak hours.

Keywords: *Level crossings, light rail transit, modeling, interrupted flow, Simulation*

1. INTRODUCTION

1.1 Background

Urban transport plays an important role in almost all cities around the world because it provides access for people to employment, education, entertainment, health care and other services. However, with the rapid growth in private cars in recent years, traffic congestion has become a major issue in many large cities, particularly in inner cities. The level of congestion in these areas is also increasing because of a rise in population, economy, urbanization, and suburbanization of population, housing, and jobs (ECMT, 2007).

Increased concern over growing urban automobile congestion has generated interest in light rail transit (LRT) as a viable mass commuting alternative. Light rail transit (LRT) started as a modification of streetcar operation to allow higher speeds by separating it from street traffic. LRT is characterized by its versatility of operation, as it can operate separated from other traffic below grade, at grade, on an elevated structure, or together with road vehicles on the surface. Level crossings are also unique due to their multijurisdictional nature. Highway authorities and railroad companies are each legally responsible for different elements at level crossings (C. Maiet al., 2014).

Light rail transit is considered an effective solution to deal with growing urban automobile congestion (Vuchic, 1999). LRT's attractiveness lies in its potentially lower implementation costs versus the much higher costs of a heavy rail system. Because of power supply hazards and operational objectives, heavy rail systems are usually totally grade separated from surrounding automobile traffic, making the initial capital costs very high (Rymer et al., 1982). Light rail systems can be found in a variety of land use contexts, from suburbs to high-density central business district (CBD) areas, and can be operated under different right-of-way types (Chandler and Hoel, 2004). With the flexibility of light rail systems in congested cities, they can attract a significant share of urban car trips and reduce car use on congested road networks.

By comparison, the lower costs of an LRT system result from the less stringent design requirements. One of the key factors is the lack of an absolute requirement for the complete grade separation of an LRT line. LRT can be run in the traveled way, in roadway medians, or on semi-exclusive rights-of-way. Although these arrangements use level crossings, the possible impact of the light rail vehicle (LRV) on crossing automobile traffic has not been

adequately evaluated (Rymer et al.,1982).As per Oxford dictionary , a level crossing is a place where a railway and a road ,or two railway lines cross at the same level .In addition, Addis Ababa City Road Authority manual(AACRA,2013) defines railway level crossings as the crossing of high ways, roads, and streets with rail lines and is a concern for safety and operational reasons. Therefore from here forward level crossing will refer to railway and roadway traffic grade crossings.

A concern that sometimes arises among citizens and public officials during the planning for a new LRT system is that level crossings will create unacceptable delays for regular street traffic. In order to accommodate scheduling and as an incentive for people to use transit, light rail vehicles might be given a priority when they arrive at an intersection. This result in delays to vehicle traffic and these problems become more serious when the frequency of LRVs' and traffic volumes increase.

The introduction of LRT system in existing road corridors has the advantage of reducing the demand for vehicles, increase safety of train users, decrease pollution of air, waiting time, travel cost and time of train users but it will induce additional delays on vehicles, pedestrians and other public transport users due to interval on crossway and at grade crossings and increase mobility. Priority given to LRV will also cause additional delays. If delays are unacceptable, transport and traffic management strategies are required to improve the situation and pedestrian crossing with acceptable distance. (Azmeraw, 2015) The LRT project also induced huge traffic in all roundabouts where the LRT line is on the ground level and near all train stations (Kassahun et al., 2017). Therefore, it would be advantageous to know how LRT facilities might have an effect on regular street traffic. If delays are unacceptable, grade separation or other mitigation measures may be required, potentially increasing time and money costs. It may be advantageous for transit agencies and planners to have an idea of the necessary measures that may be needed early in the process. However, at present, there has been little research that has attempted to quantify the effects of the interactions between light rail vehicles and street traffic for general cases. The concept of light rail vehicles (LRVs) operating at grade and alternately sharing the right of-way perpendicular to the flow of automobile traffic is an attractive transit idea because of the potential cost savings to transit agencies (Rymer et al.,1982).

Trains can be delayed by both scheduled and unscheduled events. Scheduled delays are incorporated into the timetable as buffer time to allow for conflicts with other traffic. Unscheduled delays are stochastic and are a leading factor in unreliability and instability of a network. Unscheduled delays can be caused by numerous events including: mechanical failures, malfunctioning infrastructure, weather conditions, excessive boarding times of passengers, and delays at level crossings. Delays to one train can lead to a cascading effect of delays to other trains. The amount of delay is related to the volume and type of traffic on a route. With more traffic the number of meets (level crossings) and passes increases, increasing the probability of a delay causing additional delays to other traffic (Dingler et al., 2010). Travel time, waiting time, and the uncertainties associated with both have been shown to affect customer perceptions of transit service quality (Reed, 1995). To improve service quality from the customer's viewpoint, transit agencies should focus their efforts on reducing the inconsistency in performance over time (Kimpel, 2001).

Therefore, the impact of the level crossing should also be evaluated from the travel time angle it has on the light rail facility. Because one of the most important quality indicators of public transportation is punctuality, deviations from schedule reduce the level of service (Nagy and Csiszár, 2014).

A travel time study determines the amount of time required to travel from one point to another on a given route. In conducting such a study, information may also be collected on the locations, durations, and causes of delays. When this is done, the study is known as a travel time and delay study. These data also aid the traffic engineer in identifying problem locations, which may require special attention in order to improve the overall flow of traffic on the route (Garber 2010). Analyzing data, exploring and categorizing the causes of delays correlations can be determined. In our research the schedule deviations on level crossings have been investigated based on the manually registered information of the AA-LRT. Time keeping of schedule is important both on operational and passenger side.

The main motivation towards studying this idea is to understand the interaction of two different modes of transportation in an urban setting. There are two ways of studying the interaction of the two modes in Addis Ababa, network wide and at isolated intersections. To study the interaction network wide requires network wide extensive and quality data in addition to unlimited access of the simulation software. But the second way the amount of data

requirement is less comparatively and can be analyzed using the simulation software in the limited given time. The desire to understand causal relationships between implementation of AA-LRT and its effect on roadway traffic ,and cause and effect relationships between level crossings and train travel time.

Additionally as a motive of any traffic study should be, this study also attempts to attracting and convincing the public to use the public transit system (light rail transit system) instead of private cars and taxis. And if this was achieved it would lead to tremendous advantages such as reducing the number of vehicles using the road network, reducing the cost of transportation for the public, increasing the efficiency of the road network, improving traffic operations and traffic flow, increasing safety and reducing air pollution. This is done through comparing the travel time reliability of the light rail transit to the mostly used transportation mode of the city, minibuss taxi transportation.

Finally, the basic parameters in the management of transportation efficiency are the careful management of travel time and the delay associated with it. In order to manage it carefully, substantial knowledge and information should be available on the subject matter in order for decision makers to consider it the future improvements planned. As a result, this study thoroughly models the performance of AA-LRT routes and representative level crossings with roadway traffic through the evaluation of delay and travel time as basic parameters in order to contribute a little insight on the subject matter.

1.2 Statement of the Problem

Mobility in the developing world is often characterized by travel demand that far exceeds supply (Darido, 2003). The city of Addis Ababa is not an exception to this reality. Demand for urban public transport services is growing in the same way as in other third-world cities (Jacobs et al., 1986). The city's growth in economy, geographical area and population, brings urgent attention and needs additional mass transport service provision supported by capacity and technology. Therefore, understanding this major challenge and giving special attention to the issue, a great effort is made by the government to realize technology transfer in mass transport by introducing Light Rail Transit (LRT), Bus rapid Transit (BRT) and Trolley Bus transport services (FDRE, Transport policy of Addis Ababa,2011).The city of Addis Ababa developed and launched its first LRT system in September 20, 2015 as a response to the transportation problem which is one of the most important issues. It is stated with a capacity of

60,000–80,000 passengers per hour (PPH) in four directions. Since its operationalisation, the system has been helping in alleviation of the acute transportation problems in the two corridors (East–West and North–South) (Mohapatra, 2015).

Road transportation has been the only transportation mode in Addis Ababa for a significant past before the implementation of AA-LRT. With the expected growth in population and economy the motorization rate will increase further. As per the design document AA-LRT was planned to be completed in 2011 and forecasting year is proposed to be that of initial stage is 2014, short-term is 2021 and long-term is 2036. In reality the AA-LRT got functional on 2015 and it has been only four years and that it is passing through very congested level crossings at peak hours and this happened within the initial forecasting period years. Therefore, the impact it has created on the roadway traffic at level crossings should be studied at this initial forecasting period because the increase in roadway traffic and the decrease rail transit service headway are expected in the short and long term forecasting periods. These changes obviously will create adverse effects on both transport modes at the level crossings.

In addition, the travels of the light rail vehicles are interrupted at these level crossings because the intersections are at capacity at peak hours and are not operated by coordinated signal system. As a result, 20–30% of the time the rail vehicles are forced to stop until vehicles on the road are cleared of the track. This in turn will have an effect on the travel time of the transit line. Therefore these effects the level crossings are imposing on either of the transportation modes should be studied to understand their impacts for future such infrastructures implementation and for improvement of the level crossings performance using different traffic improvement techniques.

Indeed, at the current low rates of motorization, the frequent and ubiquitous congestion in the city suggests substantial shortcomings in how traffic is managed, rather than a fundamental mismatch between transport supply and demand. And this poor traffic management affects not only car drivers, but also pedestrians and public transport passengers, both by making travel times by public transport longer (since public transport vehicles are also stuck in congestion), and more expensive (since congestion drives up the cost of public transport service provision for the operators) (World Bank, 2014).

Different researches done on AA-LRT that explore a wide range of topics that span from economics researches that evaluate its impacts on private business firms along the route to

engineering papers that explore about its impact on pedestrian walking distance are explored. Even though the researches are interesting, helpful and shade light in their own objectives, there are few researches done on travel time and delay on light rail transit. There have been no study that have attempted to quantify the delays resulting from AA-LRT level crossings and the associated effect it has on train travel time. This study uses VISSIM 9.0 simulation software to quantify the delay effects of the level crossings on the roadway traffic and SPSS statistical software to formulate a mathematical regression model to show the train travel time impacts of the level crossings. Therefore, this research intends to contribute on travel time and delay modeling of a light rail transit infrastructure.

1.3 Objectives

1.3.1 General Objectives

The general objective of this study is modeling level crossings travel time and delay characteristics of Addis Ababa light rail transit (AA-LRT) using simulation and mathematical models.

1.3.2 Specific Objectives

The specific objectives of this thesis are:

- To evaluate the operational characteristics of the level crossings using VISSIM micro-simulation model;
- To develop a statistical model on the impact of level crossings on the travel time characteristics of the light rail transit using multiple regression in SPSS.

1.4 Research Questions

The main research questions of this study are the following:

- What is the average additional delay on roadway traffic at level crossings caused due to the implementation of AA-LRT?
- What is the effect of the level crossing on the travel time characteristics of AA-LRT?

1.5 Scope of the Study

The scope of this study covers travel time and delay associated with AA-LRT corridors and level crossings with the use of different modeling tools. The various variables that affect the time and delay characteristics of AA-LRT routes are evaluated using mathematical modeling. The level crossings the transit service share with roadway traffic is considered as one of the

variables .On the other hand, the level crossings are evaluated using simulation modeling giving the transit a priority and checking for delays defining different operational scenarios for the intersections. It covers the AA-LRT routes, stations, trains, parallel road route, level crossings, alignments, grades, roadway vehicles, roadway geometry and other feature of the infrastructure necessary for making a clear image of the subject matter.

1.6 Limitation of the Study

Due to different reasons like limited research budget, unorganized data from government agencies and time constraints, this study was conducted based on the minimum required traffic count data for simulation and only selected representative locations are considered for modeling, software data analysis and processing. As a result, the consideration of these sampled level crossings for analysis is difficulty in generalizing for the whole level crossings available. And from the different performance parameters, only delays and basic traffic performance parameters are considered for efficiency evaluation. In addition other considerations to be taken as limitations of this research can be;

- Selected representative locations are considered for modeling,
- Only the South-North transit line is evaluated for the mathematical regression modeling.
- From the different performance parameters, only delays and basic traffic performance parameters are considered for efficiency evaluation.
- Unavailability of all the different vehicle types in the simulation software counted in the data.(Example; Bajaj)
- The software license used for analysis at TPMO office doesn't allow for the analysis of pedestrians at full capacity.

1.7 Significance of the Study

The data obtained from travel time and delay studies may be used in any one of the following traffic engineering tasks;

- To study the delay due to using the public transit system, and study the variables affecting this delay to find the best solution to minimize this delay in order to reduce the trip travel time to minimum value.

- Improving the transportation system in Addis Ababa and give feedbacks in the performance of the Addis Ababa light rail transportation system.
- Identification of locations with relatively high delays and the causes for those delays.
- Compilation of travel time data on specific AA-LRT routes that may be used in trend studies to evaluate the changes in efficiency and level of service with time for future studies.
- Attracting and convincing the public to use the public transit system instead of their private cars. And if this was achieved it would lead to reducing the number of vehicles using road network, increasing the efficiency of the road network, increasing safety and reducing air pollution.

2. LITERATURE REVIEW

2.1. Introduction

Modeling the characteristics of level crossings requires the understanding of the characteristics of different types of roadway intersections and in addition how these intersections behave when the railway crossing is included in the geometry. In addition from the point of view of the transit, the level crossing impact on the total travel time and delay patterns of the train require understanding the intersection from railway and roadway perspectives.

The review is organized from defining light rail transit system, classifications of LRT, when it is necessary to implement it from capacity and right of way points, and direct and indirect impacts it has on the urban environment of the city are discussed. The implementation of the AA-LRT and its features are additional introduction parts of the review.

In the middle part of the review government publications, institution publications, thesis, contribution to conference proceedings, books, journal articles and different other literature that focus on types of traffic flow studies, interrupted traffic modeling, travel time and delay modeling of level crossings as part of the interruption at level crossings are discussed. In addition previous researches done using simulation and mathematical modeling of transit infrastructures specifically light rail transit are presented. Different researches done on AA-LRT that explore a wide range of topics that span from economics researches that evaluate its impacts on private business firms along the route to engineering papers that explore about its impact on pedestrian walking distance are explored. Even though the researches are interesting, helpful and shed light in their own objectives, there are few researches done on travel time and delay on light rail transit. Therefore, this research intends to contribute on travel time and delay modeling of a light rail infrastructure from two different angles. The literature review is organized from a general, wider view of the literature being reviewed to the specific focus of this research.

2.2. Definition of Light Rail Transit

According to the Transportation Research Board's Committee on Light Rail Transit, LRT is defined as "a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights of way at ground level, on aerial structures, in

subways or, occasionally, in streets, and to board and discharge passengers at track or car-floor level” (Schumann, 1995).

2.2.1. Classification of Light Rail Transit Systems

Light rail systems can be found in a variety of land use contexts, from suburbs to high-density central business district areas, and they can operate in a range of right-of-way types. Because of the wide variations in operating characteristics among LRT systems, researchers have attempted to create classification schemes for comparison purposes. Operating speeds and alignment types are two characteristics of LRT systems that can be used for classification (Korve, 1996).

2.2.2. Speed-based classification

Many early classifications of light rail transit systems used the average operating speed as the basis for grouping. According to Transit Cooperative Research Program 2 (TCRP) Report 17, the use of average speed is acceptable in that it can reflect the diversity of LRT systems. On systems that use primarily one type of right-of-way, the use of average speed could be a good way to differentiate among systems that use different types, since higher speeds can be obtained with a greater degree of exclusivity. However, this classification scheme does not fully account for the use of multiple alignment types and speed changes from block to block that can be found in some of the more recently constructed LRT systems (Korve, 1996).

2.2.3. Alignment-based classification

The alignment classification system recommended by TCRP 17 includes three basic alignment classes: exclusive (type a), using full grade separation; semi-exclusive (type b), with level crossings as well as segments of separate right-of-way; and non-exclusive (type c), which includes the light rail operating in a shared right-of-way with motor vehicles, other transit vehicles, or pedestrians. From these three classes, TCRP 17 further defines nine types of alignments, which are listed in Table 2-1.

Table 2-1: Light rail transit alignment classification types

Class	Category	Description of access control
Exclusive	Type a	Fully grade separated.
	Type b.1	Separate right of way
Semi-exclusive	Type b.2	Shared right of way protected by 6 inch high curbs and fences.
	Type b.3	Shared right of way protected by 6 inch high curbs.
	Type b.4	Shared right-of-way protected by mountable curbs, striping, and/or lane designation
	Type b.5	LRT/Pedestrian mall adjacent to a parallel roadway.
	Type c.1	Mixed traffic operation
Non-exclusive	Type c.2	Transit mall
	Type c.3	LRT/Pedestrian mall

(Source: TCRP 17, 1996)

Table 2-2: AA-LRT alignment classification based on TCRP standards

Alignment type	East-West		South-North		TCRP classification
	Distance (m)	Percentage	Distance (m)	Percentage	
Elevated section(m)	6,062	39.68%	3,910	23.32%	Type a
Under-ground section(m)	463	3.03%	247	1.47%	Type a
Grade section(m)	8,753	57.29%	12,608	75.20%	Type b.2
Total distance(m)	15,278		16,765		From starting station to end station.

(Source: AA-LRT Vertical and Horizontal alignment design drawings)

When designing a new LRT system, the type of alignment that is eventually selected often is a result of the design goals of the system and the area surrounding the LRT tracks, including costs, service considerations, and operational features. From a planning and operations point of view, similar alignment classes have similar features and concerns with respect to safety and effects on traffic (Korve, 1996).

2.2.4. Light Rail Transit Selection Criteria

The capacity of Bus Rapid Transit (BRT) is mostly between 5,000-10,000 pphpd as a rule. It takes more right-of-way on a corridor than HRT/LRT due to overtaking lanes requirement. It

is also operated by fossil fuel consumption that has very high emission impacts on environment. Buses, midi-buses and mini-buses can help, but they use the same roads as other commuters, and don't offer a congestion free commute (TCRP 17, 1996).

The capacity of LRT which may go up to 30,000 pphpd (passengers per hour per direction) Secondly, as stated earlier under BRT, LRT requires less road space (2-3 lanes) than BRT (3-4 lanes) because overtaking facility is not needed . Although advances in diesel technology have radically improved bus emissions, LRT systems still produce less regional or urban emissions than BRT systems (TCRP, 1996).

Metro rail can serve corridors with demand level more than 30,000 pphpd(passengers per hour per direction)(TCRP, 1996).To satisfy the high demand, power supply hazards and operational objectives, heavy rail systems are usually totally grade separated from surrounding automobile traffic, making the initial capital costs very high. By comparison, the lower costs of an LRT compared to HRT system result from the less stringent design requirements. One of the key factors is the lack of an absolute requirement for the complete grade separation of an LRT line. LRT can be run in the traveled way, in roadway medians, or on semi-exclusive rights-of-way. Although these arrangements use level crossings, the possible impact of the light rail vehicle (LRV) on crossing should be evaluated properly (Rymer. et al., 1982).In selecting from amongst the three more commonly used transit five factors have to be kept in mind; safety, environment, energy and land conservation and flexibility. LRT helps in all five features and offer the best safety, minimum pollution, conservation of fossil fuel and minimum land requirement (Korve, 1996).

2.3. Introduction of AA-LRT

The need to meet mobility, environmental, and energy objectives place demands on public transit systems. As a result the, federal government of Ethiopia plans for a modern light rail transit mass transport system for the capital city of Addis Ababa as an alternative mode of transport to the passengers is an appropriate and also a decision in right direction. The first concrete step in the launching of a Light Rail Transit System (LRT) for Addis was taken when an Ethiopian Railway Corporation (ERC) took charge of LRT in March 2008. CREC presented the conceptual design and cost estimates in July 2009 and the loan agreement was signed with China Export-Import Bank in June 2011.The Project has commenced on Jan. 31,

2012, its construction period 3 year and provisional completion in Jan.31, 2015. During implementation of the project some of the delivery challenges encountered are project financing, right of way and relocation of utility lines (900 mm diameter water pipe over 9 km length, high and medium voltage electric lines, telecom cables, delay in getting land for Depot construction), lack of skilled human power, design integration process with city roads authority and insufficient traffic diversion roads (absence of grid road network) (Bogale, 2018).

2.3.1. AA- LRT Features

According CREC,(2012) and Mohapatra,(2015) the features of AA-LRT are as follows;

Route Length

The metropolitan electric railway in Addis Ababa have 34.25 km with a North-South line of 16.9 km and East- West line 17.35 km. East-West line will cover area such as Ayat Village to Tor Hailoch passing through Megenagna, Legehar and Mexico Square and North-South will pass through Menelik II Square, Merkato, Lideta, Legehar, Meskel Square, Gotera and Kaliti. Both line will share a common track of 2.7(2.662) km.

Capacity

It will have a high capacity of 15,000 passengers per hour per direction (pphpd). Maximum capacity in all the four directions will be 60,000 pphpd. Initially the LRT will cover 39 stations with initial injection of LRV numbers of 41 with carrying capacity of 286 passengers per train. The headway will be 6 minutes at the beginning with reduction to 90 seconds thereafter. The working hours has been targeted up to 16 to 18 hours per day.

Loading Capacity

Initial Stage: one unit of the tramcar is arranged to be operated. The rated passengers are 286 persons in one tramcar (with 64 seats and 6standing persons per m²). Long-term: two units are coupled together to form one train. The rated passengers of the train are 572 person with 128 seats and 6 standing persons per m².

Design period

AA-LRT was planned to be completed in 2011and forecasting year is proposed to be that of initial stage is 2014, short-term is 2021and long-term is 2036.

Tramcar Size

The outside dimension of the tramcar should conform to the metro gauge requirements; Tramcar Length: 28400mm; Tramcar Width: 2650mm; Tramcar Height: 3700mm; Tramcar Body Length (couplers and articulation are not included) : 11,780mm.

Tramcar Performance

The Highest Speed: 80Km/h; Weight of Tramcar: 43t; Weight of Axis: $\leq 11t$; Average Acceleration for Start-Up: $1m/s^2$ (0-40 Km/h); Average Deceleration of Normal Braking with Rated Load (including control response time) : $\geq 1.0m/s^2$; Average Deceleration of Emergent Braking with Rated Load (including control response time) : $\geq 1.5m/s^2$; Wheel Base: 1900 mm for power bogie and 1600 mm for driven bogie .

Alignment

Gauge: 1435mm; minimum Curve Radius: 50m for mainlines, 30m for parking garage; minimum Vertical Curve Radius: 1000m; maximum Gradient: 50 %.

Power Supply

Rated Voltage: DC1500V; Current Collection Method: Overhead Contact System. The Addis Ababa railway line is double track and it is a homogeneous system, i.e. the trains are all the same as well as the track lines are uniform and all are electrified track lines.

Fare system

The fare system has been passenger-km based. The operation of train adopts the mode of manned visual driving. The battery capacity can support failed train for at least 30 minutes for the functions of door control, emergency lighting, onboard equipment, and communication system.

Project cost

The total project cost is estimated as 475 million US\$. 85% of the total project cost will be financed through external debt from China Export-Import Bank and 15 % will be financed by raising equity in the open market by Ethiopian government. The debt and equity ratio thus is 85:15 (Mohapatra, 2015).

2.4. Direct and Indirect Impacts of Impacts of LRT

2.4.1. Automobile substitution

Light rail transit directly affects transportation through modal shift especially through high automobile substitution. Numerous studies indicate that people who live or work in areas with high quality rail transit tend to own fewer automobiles, drive less, and rely more on alternative modes than in more automobile-oriented areas (Evans and Pratt, 2007). These reductions are much larger than just the trips shifted to rail: they also include shifts to walking, cycling and bus, and shorter vehicle trips due to more accessible land use. Bus transit tends to provide smaller impacts and benefits (Litman, 2010).

The effect of AA-LRT on the total road network was not manifested in causing high automobile substitution rates. Because majority of passengers are part of the lower and middle segments of Addis Ababa's middle class (middle-income civil servants-employees, small traders, and small business owners), as well as more precarious socio-economic positions (low wage-earners, the unemployed and workers) (Nallet 2018). It is possible to say that the AA-LRT have diverted the passenger traffic associated with different types of buses in use in the city. Senior (2009) and Lee et al. (2013) questioned the effect of LRT on car ownership and car use. They argued that rail ridership increases come from bus trips that are diverted to rail. This is what happened to AA-LRT, even if the motorization rate is still low but the number of vehicles in the city has increased after the introduction of the LRT. The AA-LRT effect on traffic congestion is that most of passengers that would have used mini-buses, midi-buses or higher buses are currently using the infrastructure; automobile substitution rate is very low. This can be seen from the economic class of the users and automobile growth rate of the city.

2.4.2. Road and Parking Cost Saving

Light rail transit reduces automobile ownership and use; it can provide road and parking facility cost savings. In general, reductions in vehicle ownership reduce residential parking costs, and reductions in vehicle trips reduce roadway costs and parking costs at destinations (Fekadu, 2014). As a matter of fact that the automobile substitution rate of AA-LRT is very low based on the fact that most of its users are from the lower and middle income passengers (Nallet 2018), its effect on private car road and parking cost savings is not significant. But the passengers that would have used other public buses have been diverted to the light rail transit

and the associated parking savings at the central business districts associated with buses is reduced.

2.4.3. Improved Accessibility for Non-Drivers

Rail transit can help improve accessibility for people who, due to disability, poverty, or legal constraints, cannot drive an automobile. Many low incomes people rely on rail transit and benefit from its relatively high service quality compared with conventional bus transit. Transit-oriented development increases land use accessibility and modal integration that benefits non-drivers, with improved walking, cycling and taxi services; more accessible land use development, and more socially acceptability of alternative modes (Fekadu, 2014).

It seems that the service meets one of the ERC's aims, to provide mobility to those "with limited resources", particularly students, as a priority. Indeed, travelling by tram is cheaper than by minibus-taxi. One of the ERC's other social priorities is to provide access for people with reduced mobility (Nallet, 2018).

2.5. Traffic Flow Studies

Traffic has been extensively studied since the beginning of the 20th century. And with the advent of enormous automobiles, increasing number of vehicles began to filter onto the road infrastructure and the introduction of different modes of transportation in the urban setting. This resulted in increase of congestion problems. And from the 1920's through 1950's, several researchers attempted to model these new phenomena. Based on these initial traffic models, new research field emerged and continues to this day (Miller, 2011).

There are two types of traffic flow states; interrupted and uninterrupted. Uninterrupted traffic flow states exist in uninterrupted flow system elements, such as freeways; have no fixed causes of delay or interruption external to the traffic stream. Interrupted traffic flow states exist in interrupted flow system elements, such as urban streets; that have intersections, traffic control devices such as traffic signals and STOP signs that periodically interrupt the traffic stream (Edara and Smith, 2014).

Flow interruption leads to congestion and congestion leads to delays, decreasing flow, higher fuel consumption and has negative environmental effects. There are basically two types of flow interruptions: Recurring and nonrecurring (irregular occurrences) interruptions. The recurring interruptions are the ones fixed to the infrastructure such as stations, intersection

control and lateral clearance issues (fixed road side frictions). Whereas, the nonrecurring interruptions are due to: certain driver behaviors, impeding pedestrian movements, non-fixed road side frictions traffic accidents, disabled vehicles, natural causes such as adverse weather conditions, and spilled loads and hazardous materials (Gürsoy et al, 2008).

2.5.1. Types of Traffic Flow Studies

The scientific field of traffic engineering encompasses a rich set of mathematical techniques, as well as researchers with entirely different backgrounds. According to, it is a good practice to introduce four types of traffic flow study. They are: the microscopic and macroscopic characteristics of vehicular traffic flows, review on some performance indicators that allow us to assess the quality of traffic operations relations between traffic flow characteristics (Maerivoet and Moor, 2008). And according to NCHRP (2014), Traffic Forecasting and Travel Demand Modeling shall get due attention, especially when dealing with studying of the inception of road transport projects. Thus, creating project-level forecasts and for post-processing travel demand model results for use in the planning and design of highway projects, are tool boxes of techniques in guiding manuals.

2.5.2. Traffic Flow Modeling

Traffic flow modeling is a multi-disciplinary science which adopts the concepts in Traffic Engineering, City Planning, Mathematics and Computer Science in representing traffic flow conditions, congestions and safety issues of interrupted and/or uninterrupted flow states and looks at alternative solutions that prove efficient means of traffic movement. And they are used in the planning, design and operation evaluation of transportation facilities (Miller, 2011).

2.5.2.1. Types of Traffic Flow Models

Traffic stream models can be performed basically on two model types. They are: macroscopic traffic stream models and microscopic traffic stream models. In the macroscopic traffic stream modeling, the major relationship to be derived is the fundamental relationships between Speed, Flow and Density. And representative equations of these relationships are made based on observed field data of uninterrupted flow states. And these will be made by reaching at Single Regime, Multiple Regime or Family of models that can be proven to be evident. In the microscopic traffic stream models, constant, intermediate and random headways along with

their distribution models using mathematical models are the prime states to capture from available field data (May, 1990).

2.5.2.2. Interrupted Traffic Flow Modeling

In urban settings, since delays are caused by interruptions, interrupted flow condition modeling shall be studied for roadways and railways with the characteristics such as; the occurrence of interrupting intersections, accident or presence of broken down vehicles imposing closure of lanes in creating chocked flow conditions, on-street parking and/or loading/unloading stations of taxis and buses, crossing of pedestrian at or different location of at level crossing spots and irrational driving behavior affecting the flow stream being operating on adjacent lanes etc. Thus apparently, congestion problems, queue forming and dissipation at interruptions, saturation flow rate determination at intersections look for interrupted traffic flow modeling (Cambridge Systematic Inc., 2005).

2.5.2.3. Travel Time and Delay Modeling

A travel time study determines the amount of time required to travel from one point to another on a given route. In conducting such a study, information may also be collected on the locations, durations, and causes of interruptions/delays. When this is done, the study is known as a travel time and delay study. Data obtained from travel time and delay studies give a good indication of the level of service on the study section. These data also aid the traffic engineer in identifying problem locations, which may require special attention in order to improve the overall flow of traffic on the route (Garber, 2010).

Delay studies can be broken into two broad categories. The first category is delay caused by traffic flow conditions rather than by traffic control devices. The prime example of this would be delay occurring along a segment of freeway. In this case, most delay is due to slowing in response to congestion, although some stopped delay may also occur. Delay is considered to be excess time spent in the segment above what would be spent if travel were free-flow. The base free flow speed may be determined empirically, using the 50th percentile speed of low volume traffic (<1300 pc phpl), or may be taken as either the posted limit or some reasonable lower figure. For freeways, use a base equal to 70 for urban and 75 for rural and adjustments for lane width, right shoulder lateral clearance, number of lanes, and interchange density.

The second category of delay studies is that encompassing traffic control devices, particularly traffic signals at intersections. In this case, delay may be considered as excess time over free-flow (green phase, unimpeded) similar to that above, or it may be further refined to establish percent of vehicles delayed, delay per delayed vehicle, delay per all vehicles, and stopped delay per stopped or all vehicles. This refinement of delay is useful in assessing the operation of a traffic control device (Traffic Engineering Manual, 2007).

2.5.2.3.1. Simulation Modeling of Travel Time and Delay

By comparison, the lower costs of an LRT system result from the less stringent design requirements. One of the key factors is the lack of an absolute requirement for the complete grade separation of an LRT line. LRT can be run in the traveled way, in roadway medians, or on semi-exclusive rights-of-way. Although these arrangements use level crossings, the possible impact of the light rail vehicle (LRV) on crossing roadway vehicle traffic has to be adequately evaluated. One measure of this impact is the additional delay experienced by the vehicular traffic because of LRVs crossing the roadway. Delay can be used for a relative comparison of the impact with other crossings, or it can also be used in economic analyses by assigning a value to this delay time. The objective of this report is to study the vehicle delay impact to traffic of level crossings on an LRT line operating on semi-exclusive right-of-way (Rymer et. al, 1982).

Because, there is a great possibility for vehicles in the roadway traffic to experience additional delays when there is interference by LRT operations, such as in the case of level crossings or due to priority being given to LRT vehicles at signalized intersections at the expense of conflicting crossing and turning movements (Chandler et al.,2004).

Rymer.et al.,(1982) presented a partial review of an evaluation of the potential delay impacts on automobile traffic imposed by LRVs operating at grade. Vehicle delay is as one of the criteria for the grade separation of LRT and bus way crossings from the closure time and the resulting loss of capacity. The analysis centered on computer simulations using FHWA's NETSIM model. Results indicated that for light rail transit crossings located in excess of 400 ft(122m) from any adjacent intersection, the delay imposed on the motoring public warranted a grade separation only at very high traffic volumes or very short LRV headways. LRT crossing operating with unconditional preemption does not affect the traffic greatly for the

crossing conditions studied. The economic analysis suggests that most isolated crossings (more than 400 ft from a traffic signal) will not justify grade separations on the basis of delay imposed on the crossing automobile drivers and their passengers. This report can assist decision-makers in determining where grade separations are appropriate.

Gerken et al., (2001) delay and queue impacts were determined using the microscopic traffic engineering software program SimTraffic Version 4.0. Although the program was not explicitly designed to handle transit analysis, recent enhancements have enabled advanced users to program work-around to approximate the behavior of the LRT crossing controllers as well as depict the interaction of the LRT and vehicular traffic. The comparisons presented in this section are between No-LRT and the 10-minute headway operation of LRT. The only difference between the two models was that under the No-LRT scenario the clearance and LRT phases were never called. Analysis output included vehicular delay and queues for LRT and non-LRT scenarios. The overall Level of Service for the intersection went from C (33.3 seconds of delay per vehicle) to D (39.9 seconds of delay per vehicle), an approximately 12 percent increase in delay. The conflicting approaches absorbing nearly all of the delay.

Chandler et al., (2004) examined the effects of light rail crossings on average delays experienced by vehicles in the roadway traffic. Using the VISSIM 3.70 computer simulation model, four scenarios were examined: isolated crossings of two-lane and four-lane roads, a case in which light rail transit is located in the median of a street, and a larger network that includes four crossings. The effects of variable traffic volumes and light rail crossing frequencies were studied in the isolated intersection scenarios. The results of the simulated test scenarios indicate that the average additional delays from light rail transit crossings increase with increasing light rail crossing frequencies and increasing traffic volumes up to the roadway's capacity. As the road enters an over saturated condition, the average total delays continue to increase, but the difference in total delays with and without light rail decreases from the unsaturated condition. The primary measure of effectiveness used in this project is the average total vehicular delay, which is also used by the Highway Capacity Manual to evaluate the level of service at intersections.

Phuoc et al., (2016) presents a method for assessing the net traffic congestion effects associated with tram operations in Melbourne, Australia. These impacts are determined by comparing congestion measures in two scenarios: "with tram" and "without tram". Findings

show that the tram network in inner Melbourne results in a net 3.4% decrease in roadway vehicle time travelled and total delay on the road network in these areas. It also contributes to reduce the number of moderately congested links by 16%. The reallocation of road space to provide priority for trams increases tram speed and reliability however it also reduces the capacity of the road. The operation of streetcar systems can also act to create negative effects on vehicle traffic in terms of travel time and reliability. Vissim 7.0 used to simulate tram operations and identify the impact of trams on general traffic flow. In this study, the effect of trams on a particular link is the focus of analysis. The main measure used in this research is travel time. This figure is estimated by averaging the travel time of each vehicle on a segment. The reason for choosing travel time as a key measure is that travel time is also calculated on each link in VITM and used as the main criteria for assigning vehicle trips to the road network.

2.5.2.3.2. Mathematical Modeling of Travel Time and Delay

Doohee Nam et al., (2005) attempts to investigate the importance of travel time reliability and to estimate the value of travel time reliability of transportation users in order to assess the benefits gained from improving the reliability. Travel time reliability is a measure of the expected range in travel time and provides quantitative measure of the predictability of travel time. According to comparison results between model with and without reliability, model with reliability was much better than that without reliability for all tests. Total travel cost, car ownership, drive alone or shared ride, and reliability were the important factors affecting the mode choice decision. Reliability played an important role in mode choice decision for traveler.

KhaledHamad, (2011) checked if changes in travel speed were statistically significant. The paired samples t-test was used to make a year-to-year comparison, i.e., comparing 1997 to 1998, 1998 to 1999, etc. The paired samples t-test was chosen to ensure that comparison was performed on a segment-by-segment basis. Benefiting from the Geographic Information System's Dynamic Segmentation tool, travel time, delay, and speed information was integrated with other relevant traffic data. The main objectives of collecting these data are to monitor the performance of individual routes and the overall network, to identify potential

problem sites in the transportation network, and to ascertain the degree to which specific planning objectives are being met.

Mohammed Abojaradeh, (2013) used SPSS (Statistical Package for Social Sciences) software in forming the Regression Models in this study. SPSS is considered one of the most frequently used program for researchers in many fields such as engineering, science, art, education, and psychology (SPSS 2009). The method of least squares that leads to the best fitting line of a postulated form to a set of data is used to form Regression Models between the dependent variable Y_i , and independent variables X_i . In this study, the dependent variable Y_i includes travel time and running time. On the other hand, the independent variable X_i includes the variables affecting the travel time such as number of stopping for pickup and discharge, bus model, bus size, number of fixed interruptions and trip direction. Regression analysis is a statistical technique for modeling and investigating the relationship between two or more variables (Montgomery, 2010).

2.6. Researches about AA-LRT

Analysis of the spatial accessibility of AA-LRT east-west corridor public transport (Aklilu and Necha, 2018), successfully applied both statistical and spatial analyses to examine the relationship between each of the service areas, population user, overlap areas, and uncovered neighborhood. The research used GIS application in transportation system, which is referred as GIS-T, as it analysis tool. In terms of spatial accessibility, most stations are well accessed, while five types of land use and road network-related causes are given as the main reasons for the least accessible stations: government and social institutions with large area compounds, low road network density, open spaces devoid of road network, natural barriers such as water courses and large area public squares. In addition, some stations were found to have large areas of overlaps, while some others with small overlap areas. Only small proportion area is found to be uncovered using the 400-m and 800-m walking distance, while the lion share of the uncovered area: 70% (19.9 km²) and 16% (4.7 km²) is found within walking distances of 1500–2000 and 1200–1500 m, respectively. Stations with large overlap of service areas have reduced number of actual users due to the fact that the accessible population is divided between the shared stations. Therefore, unnecessary large service area overlap is a wastage that does not contribute to more number of users.

On a masters research paper submitted to Addis Ababa university that studies the effects of Addis Ababa light rail transit system on pedestrians and public transport users' mobility, (Azmeraw, 2015), walking distance and time were analyzed for both scenarios i.e. before and after LRT construction. A statistical comparison was then conducted by paired t-test and p-value to determine the significance of the effect on mobility parameters. It is found that the introduction of LRT would increase walking distance and time to sampled pedestrians by 580.2m and 9min in a round trip. The increase distance and time in total O-D trips per day would be 752.2 m/day and 11.4 min/day. Overall additional average walking distance to total O-D trips per day is 752.2 m/day: the additional median walking distance is 568.5 m, with 25% of trips less than 321.5 m and 75% of walking trips less than 919.5 m.

In another paper submitted to Addis Ababa university as masters research paper that assesses the performance of AA-LRT based on sustainability variable, Mohamed,(2017), multi-criteria assessment is used in addition to Geographical Information System (GIS) to show the spatial coverage of light rail transit, stations and road networks that used by different mode transport. The analysis helped to compare transport routes alternatives of the rail and their corresponding road routes, measuring the timesaving and pollution reduction as an economic sustainability benefit. The research compared time spent by different kinds of transport modes including Addis Ababa LRT from Torhailoch to Ayat, PiassaGiorgis to Kalityboth on peak and off peak hours. Hence taking trip by Anbessa bus would take longest time compared to LRT, Midi-bus and Mini-bus both on peak hour and off peak hour. And taking trip by LRT would take smallest time compared to Anbessa, Midi-bus and Mini-bus both on peak and off peak hour. This is due to Anbessa, Midi-bus and Mini-bus take longer stoppage, access and waiting time during off peak hours and also road congestion would cause another additional time during peak hours.

For a paper that studies challenge of urban mobility taking AA-LRT as a case study, Nallet, (2018), to understand the question of tram use, short interviews were conducted with 200 passengers to collect basic data on their socio-economic profiles and types of journeys. The database is supplemented by about 20 in depth interviews with residents in the capital who do or do not use the tram. The passenger interviews were conducted at five tram stops, Megenagna and CMC on the east-west line, Gojam Berenda and Autobustera on the north-south line, and at Mexico Square where the two lines intersect. The make-up of our sample is

indicative of this: 67% of men and 33% of women, aged between 14 and 76 years (on average 30 years). 44% are under 25, 33% are between 25 and 35, 14% between 35 and 45, 9% are over 45. The different business sectors are represented at similar levels; 21% civil servants, 21% employees in the private sector and 27% self-employed, students (21%) and unemployed people (10%). The majority of passengers are part of the lower and middle segments of Addis Ababa's middle class (middle-income civil servants-employees, small traders, and small business owners), as well as more precarious socio-economic positions (low wage-earners, the unemployed and workers). The survey shows that the tram is a mobility solution for low-paid workers. In terms of place of residence, most of the passengers surveyed (65.5%) live in areas that are rather far from the capital's central districts. The passengers surveyed travel between 3 and 35 stations (on average 9.3). More than half travel between 5 and 10 stations (53.4%), 27% of them between 11 and 15 stations, 10% less than 5 stations and 9.5% more than 15 stations. Only 25% of the passengers surveyed walk to get to the tram station and to leave it. Others take a motorized mode of transport, generally the minibus-taxis to get to and/or from the tram stations. In passenger interviews, the majority (80.5%) is satisfied, 12.5% moderately satisfied and 6.5% dissatisfied with the service provided by the tram. The most common reasons for satisfaction are affordability and speed of travel over long distances covered at a "minimum price." In terms of safety, the tram is perceived as having less risk of accidents than the minibus.

Negrew et.al, (2016) studied the economic benefit and effect of AA-LRT on private business firms. The study explores the possible effects and benefits of the LRT on the private business firms' overall activity by making comparative analysis of the three periods, pre-implementation, implementation and post implementation of the project. The project has significant effect on the private business firms' profitability performance through their revenue performance over the three periods and other factors depending on the periods. Overall findings imply that the project adversely affected the firms' activity during implementation period and after the implementation, the firms feel that the business environment became less attractive as compared to the pre-implementation period. It is advisable that while implementing such bigger and multi-facial project, firms' interest should be considered in the design as well as output and also the factors that affect population mobility should be minimized as low as possible.

As political economy research paper by Kassahun et al., (2017) studied AA-LRT as the governance of Addis Ababa city turn around project along with the Integrated Housing Development Program (IHDP). The findings of this study presented the governance processes, structures, and practices in relation to Addis Ababa city turn around projects i.e. AA-LRT and housing through exploring the origins of the projects. Hence, the study fills the gap in the knowledge base by addressing urban governance issues in Ethiopia in general and the city of Addis Ababa in particular within a developmental state political economy. This paper also claims that The LRT project also induced huge traffic in all roundabouts where the LRT line is on the ground level and near all train stations. It has ignored pedestrian safety while crossing to and from the train stations.

An Economic Analysis of Addis Ababa light rail transit is a journal published by European economic commission that studied the economic viability of the project (Mohapatra, 2015). The study compared the benefits against the cost streams through an economic analysis. The net present value (NPV) of the cost stream for 32 years calculated at 12% as 699.24 million US\$. The economic internal rate of return(EIRR) on investments in the LRT is calculated as 33.63% , though the project benefits of reduction in environmental pollutions, reductions in vehicle ownership & operating costs has not been taken into consideration in the above analysis due to data lag. The costs considered are capital, maintenance and debt equity model; benefits considered are revenue, saving in fuel, time, emission and employment generation.

2.7. Basics on VISSIM Micro-Simulation and SPSS Statistical Modeling

2.7.1. VISSIM Micro-Simulation

Simulation models are mathematical/logical representations of real-world systems, which take the form of software executed on a digital computer in an experimental fashion. According to the level of detailing, simulation models can be classified into macroscopic, mesoscopic and microscopic models. A macroscopic model describes entities and their activities and interactions at a low level of detail. Traffic stream is represented in an aggregate measure in terms of characteristics like speed, flow and density. A mesoscopic model generally represents most entities at a high levels of detail but describes their activities and interactions at a much lower level of detail. A microscopic model describes both the system entities and their interactions at a high level of detail. Car following models and lane changing models are some

significant examples. The choice of a particular type of model depends on the nature of the problem of interest (Mathew, 2014).

VISSIM is a microscopic, time step and behavior based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. VISSIM can model integrated roadway networks found in a typical corridor as well as various modes consisting of general purpose traffic, buses, light rail, heavy rail, trucks, pedestrians, and bicyclists. The model was developed at the University of Karlsruhe, Germany during the early 1970s. Commercial distribution of VISSIM began in 1993 by PTV Transworld AG, who continues to distribute and maintain VISSIM today. VISSIM is a microscopic tool, since it employs individual vehicle modeling. It has many applications, but it is mainly used to analyze traffic of various alternative road designs which include both urban and highway configurations (Papageorgiou et al., 2006)

The VISSIM software is used in the analysis modeling of level crossings performance on peak hours. The VISSIM simulation software is a product of PTV Group, Gauff Consultants who have been in business for a number of decades. It has now reached version 9.0 in that many behaviors and microscopic parameters can be customized. Thus, taking this advantage, VISSIM 9.0 is ideal software for verification using software in this research. The model is based on the continued work of Wiedemann. The basic idea of the Wiedemann model is the assumption that a driver can be in one of four driving modes: Free driving, i.e. no influence of preceding vehicles observable. Approaching, i.e. the process of adapting the driver's own speed to the lower speed of a preceding vehicle. Following, i.e. the driver follows the preceding car without any conscious acceleration or deceleration. Braking, i.e. the application of medium to high deceleration rates if the distance falls below the desired safety distance (Fellendorf and Vortisch, 2001). These models can be used to analyze existing performance, based on known traffic pattern data that might otherwise be impossible to estimate via conventional data collection methods or standard traffic engineering analytical methods (Beaulieu et al., 2007).

The complexity of traffic stream behavior and the difficulties in performing experiments with real world traffic make computer simulation an important analysis tool in traffic engineering. The physical propagation of traffic flows can be specifically described using traffic flow models. By making use of different traffic simulation models, one can simulate large scale

real-world situations in great detail (Mathew, 2014).Traffic simulation can support transportation planning, and traffic management decision making, for effective corrective actions. The new solutions and techniques can efficiently be tested in a “virtual reality” environment, in the comfort of one’s office, without disrupting the road traffic or having to leave for field trials. Effective traffic management and control strategies though, require up-to-date valid simulation test results (Papageorgiou et al., 2006).

VISSIM is selected for this research because the system is the globally leading software for microscopic traffic simulation, covering all traffic modes, from motorized private transport, goods transport and public transport on rail or road right up to pedestrian and bicycle travel. Its wide range of analysis options makes VISSIM a powerful tool for planning and optimizing traffic systems – in both urban and interurban areas. In addition, the software offers flexibility in several respects, for example its easy concept of links and connectors allows users to model geometries with any level of complexity in a detailed 1/10s resolution and first of its kind to integrate microscopic simulation with strategic transport planning/travel demand modeling.

Furthermore it has an unlimited number of vehicles for traffic flow modeling, including cars, trucks, vehicles equipped with satnavs, buses, tramway and light-rail vehicles and even airplanes. In addition to motorized means of transport, the system can also cover pedestrians, cyclists and wheelchair users. It also makes possible to present the simulation and evaluation results for different scenarios and planning cases in different easy to understand and thus convincing forms such as detailed reports, various versions and impressive 3D animated graphics enabling also “non-professionals in traffic engineering” to make informed decisions.(Jones et al.,2014)

2.7.2. SPSS Statistical Modeling

SPSS means “Statistical Package for the Social Sciences” and was first launched in 1968. Since SPSS was acquired by IBM in 2009, it's officially known as IBM SPSS Statistics but most users still just refer to it as “SPSS”.SPSS is software for editing and analyzing all sorts of data. These data may come from basically any source: scientific research, a customer database, Google Analytics or even the server log files of a website. SPSS contains all basic statistical tests and multivariate analyses such as t-tests, chi-square tests, ANOVA, correlations, regression, nonparametric tests, factor analysis and cluster analysis.

SPSS offers four programs that assist researchers with their complex data analysis needs. Statistics program provides a plethora of basic statistical functions, some of which include frequencies, cross tabulation, and bivariate statistics. Modeler program enables researchers to build and validate predictive models using advanced statistical procedures. Text analytics for surveys program helps survey administrators uncover powerful insights from responses to open ended survey questions. And the visualization designer allows researchers to use their data to create a wide variety of visuals like density charts and radial box plots with ease. In addition to the four programs mentioned above, SPSS also provides solutions for data management, which allow researchers to perform case selection, create derived data, and perform file reshaping (Elliot et al., 2016).

3. MATERIALS AND METHODS

3.1. Description of Study Area

The study area is Addis Ababa, the capital of Ethiopia and Oromia regional state. The city is the country's political, economic and administrative center and headquarters of African union and United Nations economic commission for Africa and many other international and national organizations. It is found at the center of Ethiopia at geographical coordinates of 91°48' North (latitude) and 38°44'24" East (longitude) at an altitude of 2,355m. Addis Ababa has a subtropical highland climate with daily maximum temperature of 23°C and minimum temperature that can drop to freezing (Asrat, 2015).

The city is home to 25% of the urban population in Ethiopia and is one of the fastest growing cities in Africa. Addis Ababa is now urbanizing at an exponential rate. According to the forecasts, the capital is expected to double its population by 2030 and to have almost 10 million inhabitants by 2037. The city's economy is growing annually by 14% and the city alone currently contributes approximately 50% towards the national GDP, highlighting its strategic role within the overall economic development of the country (World Bank, 2015).

Population growth and Economic development create high rate of urbanization and greater demand for passenger and freight transport system; large demand is likely to produce large load of traffic on the transport infrastructure (Fekadu, 2014).

Table 3-1: Population projection values for the year 2016 and area of sub-cities and computed population density.

S.No.	Sub-City	Male	Female	Total	Area(km ²)	P.D(Peoples/Sq. km)
1	Akaki Kaliti	107,852	113907	221,759	123.4	1,796
2	Nefas Silk-Lafto	181,125	205892	387,017	58.7	6,586
3	Kolfe Keraniyo	252,436	272,293	524,729	63.4	8,266
4	Gulele	157,311	170115	327,426	31.1	10,498
5	Lideta	117,041	129764	246,805	9.1	26,885
6	Kirkos	125,828	144893	270,721	14.6	18,479
7	Arada	120,558	138250	258,808	9.5	27,243
8	Addis Ketema	151,842	160572	312,414	8.6	36,159
9	Yeka	196,452	227765	424,217	82.1	3,191
10	Bole	176,555	201549	378,104	118.5	6,452
Total		1,587,000	1765000	3,352,000	519.0	6,452

(Source: Aklilu & Necha, 2018)

3.2. Study Design

The primary interest of this study is to model travel time and delay characteristics of AA-LRT level crossing using different methods. Primarily, selected level crossings of AA-LRT are evaluated for additional delay by simulation modeling. Additionally, the travel time and delay characteristics of the light rail transit are evaluated using multiple regression modeling. The amount of effect the level crossing has on the time performance of the transit service is checked. The steps which this research has been done are shown on the flow chart below;

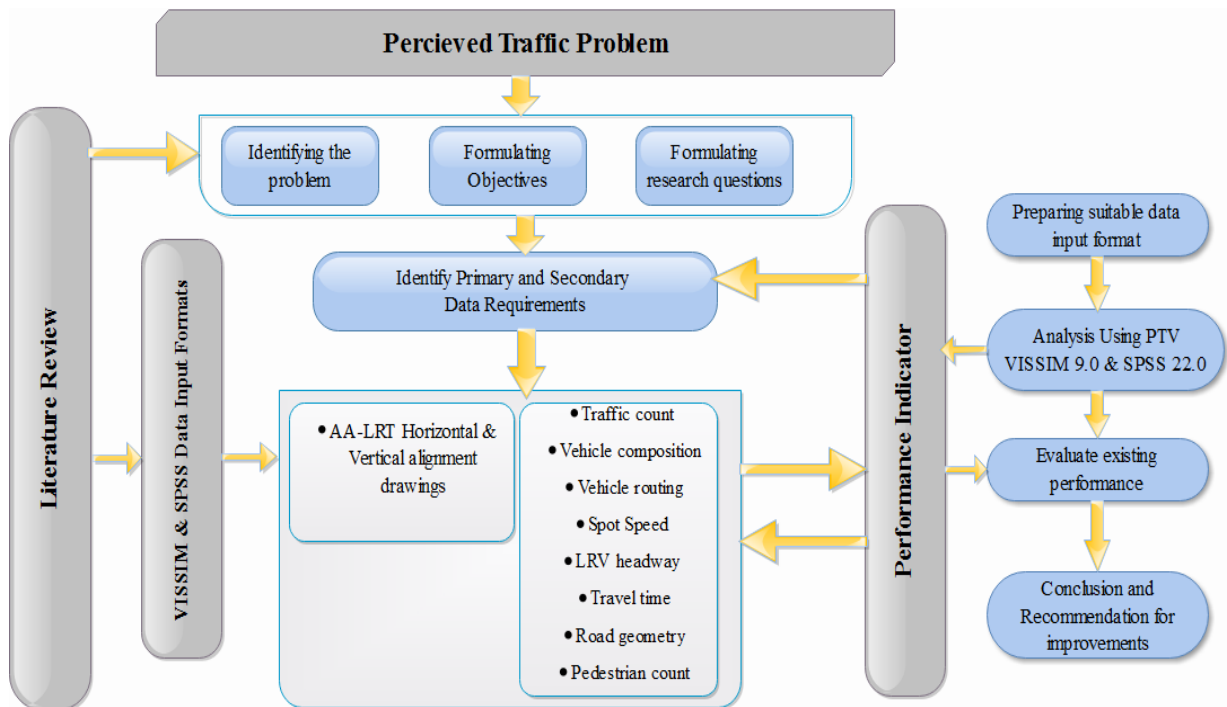


Figure 3-1: Research flow chart

3.3. AA- LRT Routes, Study Intersections and Approach Roads

3.3.1. AA-LRT Routes

A 17.4 kilometer line running from the city center to industrial areas in the south of the city (South-North) opened on 20 September 2015 and service began on 9 November 2015 for the second 16.9km line (East-West). The East-West line starts from Ayat and ends at Torhailoch. The total length is 31.6 km with a common track of about 2.7km. There are 22 stations, among which 5 are elevated stations, 1 underground station and 16 ground stations. The depots are located at the east and south ends of the project. (Amare, 2015)

From the view of safety, as an overhead contact line would be used for 1500V system, and the project contains over 20 intersections, the safety for passengers and other vehicles have to be considered. In case of an electric shock, the safety distance for 1500V electric protection is longer than that of 750V. LRT project use 6-axle double-articulated 70% low-floor Light Rail tramcar. One unit of the tramcar is formed with three modules, which are Mc, T and Mc. Under the Mc module of the tramcar body a bi-axial power bogie is installed, and a bi-axial driven bogie with independent wheel is installed under the T module (CREC, 2012).

Table 3-2: List of AA-LRT and roadway traffic level crossings

S.No	Name	Current Status	Type of intersection	Traffic condition	Remark
1	Ayat (EW)	Active (Vehicles/Pedestrians)	U-turn	Low	
2	Mikael(EW)	Active (Pedestrians only)	U-turn	Low	No roadway vehicle/Allowed only for pedestrians)
3	Sealitemihret (EW)	Active (Vehicles/Pedestrians)	Elliptical round about	High	
4	CMC(EW)	Active (Vehicles/Pedestrians)	Roundabout	High	Considered for study
5	Century mall (Kelifa)(EW)	Active (Vehicles/Pedestrians)	U-turn	Low	
6	Abo(SN)	Active (Vehicles/Pedestrians)	T-intersection	Low	Conflicting roadway is paved with cobblestones.
7	Meshualekiya (SN)	Active (Vehicles/Pedestrians)	Round about	Low	Overpass bridge for the conflicting roadway vehicle is under progress.
8	Adey Abeba (SN)	Active (Vehicles/Pedestrians)	Cross road	High	
9	Kality(SN)	Active (Vehicles/Pedestrians)	T-intersection	Low	LRT line SN LRV terminal intrance
10	Sebategna(SN)	Active (Vehicles/Pedestrians)	Cross road	High	Considered for study

(Source: Field observation of level crossings)

CMC level crossing is selected from the East-West line because all the level crossings in this line are U-turns low traffic volume. The low traffic volume on these U-turn level crossings is associated with the traffic management plan the city transport agency has implemented to use one lane of the left side of the eastern approach for vehicles towards the business district on peak hours. This measure is done to avoid vehicles using the U turn level crossings. The remaining Sealitemihret round about level crossing has the same characteristics to the CMC roundabout level crossing because both are roundabout level crossings. (Table 3-2)

Sebategna level crossing is selected from the South-North line because Abo and Meshualekia level crossings have no significant conflicting roadway traffic to the rail track because the conflicting approach is cobblestone and an overpass for these crossings respectively. Kality level crossing is an entrance to the transit depot and the trains doesn't use it except for leaving early in the morning and late at night. The rest Added Abeba level crossing has the same characteristics as Sebategna level crossing because both all way stop controlled level crossings.(Table 3-2)

The sampled intersections are comprised of 4-legged un-signalized level crossing and 4-legged roundabout level crossing. The intersections serve as links to major routes which connect different types of land use activities in the study area. All the studied intersections are non-signalized but traffic flows are controlled by traffic wardens a peak periods. At Sebategna intersection there is a presence of road-side hawkers and traders, and the location of retailing shops along the intersecting roads.

3.3.2. Description of Sebategna Intersection

Sebategna is found in one of the high business districts of Addis Ababa; Merkato. In addition the intersection is located in the second densely populated sub city of Arada sub city (Table 3-1) .Besides, one of the biggest bus stations of the country is found within 500m of the intersection location. As a result there is high number of pedestrian, minibuses and buses at the intersection location.

Highway capacity manual classifies this intersection as All Way Stop Controlled (AWSC). AWSC intersections require drivers on all approaches to stop before proceeding into the intersection. While giving priority to the driver on the right is a recognized rule in some areas, it is not a good descriptor of actual intersection operations. What in fact happens is the development of a consensus of right-of-way that alternates between the drivers on the intersection approaches, a consensus that is dependent primarily on the intersection geometry and the arrival patterns at the stop line (HCM, 2010).

Table 3-3: Sebategna level crossing four approaches basic geometric characteristics.

S/N	Intersection Approach Legs	Lane Width(m)	Median Width(m)	Number of Lanes	Walkway (cm)
1	South(Abnet) Approach	3.00	-	3	250
2	North(Awtobstera) Approach	3.00	-	3	250
3	East (Merkato) Approach	3.00	1	3	-
4	West (Amanuel) Approach	3.50	-	1	-

(Source: Field observation of level crossings)

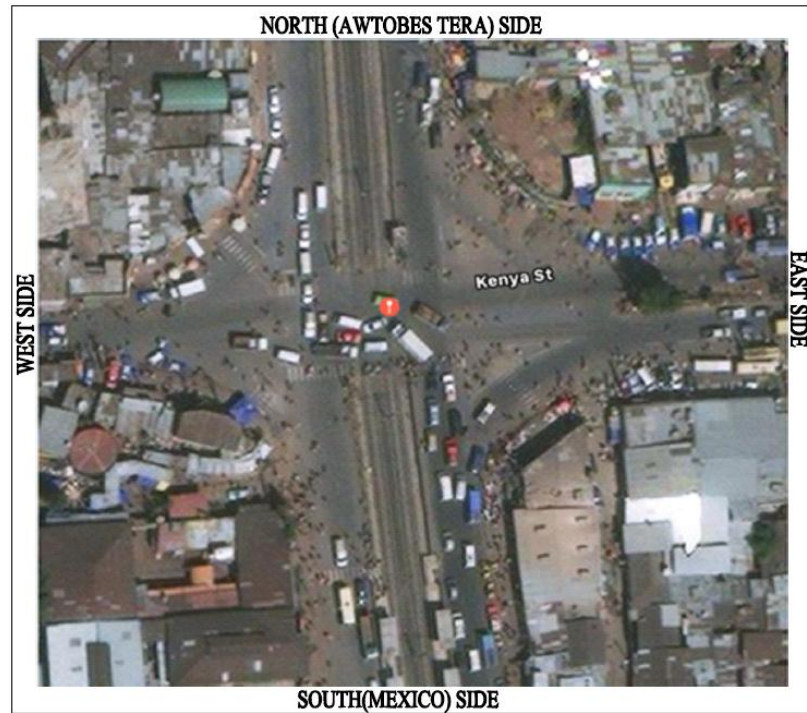


Figure 3-2: Sebategna level crossing four approaches Google earth picture with directions considered for analysis (Source : (Google Earth, 2019))

3.3.3. Description of CMC Intersection

CMC is found in one of the finest residential and relatively modern locations of the city. In addition the location is of the least population density locations of the city. Most residents of this location are characterized as living in a better economic status of the city, hence automobile ownership and use is significantly high. This high automobile ownership of the location is evidenced in the vehicle composition of the intersection traffic volume count.

This intersection is located on Ayat-Megenagna on which during peak hours, upward of 5,000 cars pass through the Ayat-Megenagna artery in an hour, according to a survey conducted in

2017 by the City's Traffic Management Agency. The Ayat-Megenagna corridor was selected as it is one of the most congested roads in the city during peak morning and evening travel times, according to AshuSintayehu, deputy director of the Agency (Minwagaw, 2019).

Table 3-4: CMC roundabout level crossing four approaches basic geometric characteristics.

S/N	Intersection Approach Legs	Lane Width(m)	Median Width(m)	Number of Lanes	Walkway (cm)
1	South approach	3.50	20	2	250
2	North approach	3.50	20	2	250
3	East approach	3.00		4	300
4	West approach	3.00	-	4	300

(Source: Field observation of level crossings)



Figure 3-3: CMC roundabout level crossing four approaches Google earth picture with directions considered for analysis (Source : (Google Earth, 2019))

3.4. Target Population

For the simulation modeling of level crossings, two representative intersections are selected from the total of initially assigned ten level crossings. Sebategna cross road and LRT line level crossing is selected from the SN (Blue) line for simulation evaluation. CMC roundabout level

crossing selected from the EW (Green) line is the other intersection considered for simulation evaluation. These two intersections are selected each from different routes and from different intersection hierarchy that represents the nature of the intersection in the specific route. As it can be referred from Table 3-2, the SN line has two high traffic activity crossroad level crossings; Adey-Abeba and Sebategnalevel crossings. The EW line as well has two high traffic activity roundabout level crossing; Sealitemihret roundabout level crossing and CMC roundabout level crossing. Therefore, besides being representatives of the intersection types and the two different routes, these two intersections are found to be convenient for video recording traffic data collection method used in this research. All the activities of the intersection and the approaches is found to be very important in the traffic volume, route decisions and vehicle composition study of the paper. Therefore, selection of the intersection with comfortable location for video recording is selected with trial and error. All of the four high traffic level crossings are checked for convenience to video recording from a high rising building at the surrounding of the intersections.

In addition, for the evaluation of travel time and delay mathematical modeling of the AA-LRT, SN route is considered for the study. Stations, level crossings, train size (single/double), direction, alignment and operating weather conditions and other important data are consider. In addition the road travel corridor adjacent to the light rail transit line is considered for the comparison evaluation of travel time. AA-LRT the South- North (S-N) routes is considered for travel time and delay calculations of the light rail transit infrastructure using SPSS mathematical modeling.

3.5. Method of Data Collection

The data required for this study include information on intersection geometric characteristics, traffic volumes, traffic directional flows, vehicle composition, vehicle speeds(both roadway light rail),traffic delay causes and land use activities. As it is not possible to study all the level crossings in the city, a sampling technique was employed as stated in Section 3.4.

The method used when collecting, processing and analyzing the required data is mainly quantitative research method. The nature of the study requires quantitative information to reach a good understanding of the travel time and delay characteristics of the municipality's light rail transit travel time patterns, delay causes, AA-LRT level crossings before and after

characteristics and improvements and applications of the process implemented. But there are a number of qualitative analysis done based on available literature on the different ideas.

Secondary data was collected from Addis Ababa Transportation Agencies, AA-LRT administration and TPMO .Different publications, researches, journals, presentations, books and manuals are used as sources of additional secondary data and are properly referenced.

3.5.1. Primary Data Collection Details

A reconnaissance survey of the study area was first carried out at the level crossings to identify the characteristics that predispose them to recurrent traffic delay. In addition, observatory survey was carried out at each of the selected level crossings.

Traffic volume studies are conducted to determine the number, movements and classifications of roadway vehicles at a given location. The length of the sampling period depends on the type of count being taken and the intended use of the data recorded. For example, an intersection count may be conducted during the peak flow period and if so manual count with 15-minute intervals could be used to obtain the traffic volume data (Mekonen, 2015).

Table 3-5: Primary Data Collection (Quick Research Facts)

Item No.	Primary Data Type	Locations	Quantity or Size	Relevance	Collection tool
1	Video recording of traffic flow data	Two level crossings: Sebategna & CMC	36.07GB/6hrs for CMC/7hrs for Sebategna	Traffic volume, vehicle composition, Routing decisions, Speed and pedestrian movement study.	Video camera
2	Train and minibus taxi travel time data	South North line	40 number of repetitions for light train; 13 number of repetitions for minibus taxi.	Travel time, running time, Stop-open door time, Open door-close door time, Close door-start movement time, Level crossing delay time, Size of train, Direction of travel	Stop watch and notebook

(Source: Field observation & desk study of level crossings)

3.5.1.1. Time of Data Collection

Globally work and school trips are important trip purposes and in Addis Ababa the “work” and “education” are also the most important trip purposes which accounted for about 32% and 46% of all trip purposes respectively (ERA, 2005). The daily temporal patterns of trips reflect the double peaking characters of school and work trips. Most offices and school open at the same time in the morning but in the afternoon schools close earlier than offices. In response, there is one major peak (6 to 9a.m.) and two minor ones (12 to 13p.m. and 16 to 18p.m.). Most of the trips or about 36 percent occur in the morning peak hours of 6 to 9 a.m. The number of

trips significantly declines to a very low level of close to zero after 8p.m (Woldetensae, 1996). Based on this information on peak period traffic data is asked from TPMO and they have assured that the morning and the second evening peaks are the highest. For Sebategna for morning (6:00 to 9:30 a.m.) and afternoon (15:00 to 18:30p.m.) and CMC (6:00 to 9:00 a.m.) and afternoon (15:00 to 18:00p.m.) are recorded and counted.

3.5.1.2. Intersection Traffic Flow Video Recording

Two methods are available for conducting traffic volume counts: manual and automatic. Manual counts are typically used to gather data for determination of vehicle classification, turning movements, direction of travel, pedestrian movements, or vehicle occupancy. Automatic counts are typically used to gather data for determination of vehicle hourly patterns, daily or seasonal variations and growth trends, or annual traffic estimates. The selection of study method should be determined using the count period (Robertson, 1994).

Video recording and manual transcription or tracing were used to collect traffic volume and travel time data. This method of data collection relies on video cameras to collect or capture the traffic flow in the field and human personnel to transcribe or trace vehicles into a data at the office after the actual time of data collection. Video capturing techniques is preferred over the manual collection (pen and paper method) because it provides a permanent, easily-review record and shows the traffic conditions at any time, and enables to capture a larger sample of the total number of vehicles. Video cameras were arranged at convenient height where maximum possible view could be captured and visibility was maximized. The locations for video capturing were the floors of high-rising buildings alongside the study sections.



Figure 3-4: Buildings Used for Video recording (Source: Taken at locations of level crossings)

3.5.1.3. Light Rail Transit Travel Time Data Collection

Travel time or the time required to traverse a route between any two points of interest, is a fundamental measure in transportation. Data was collected for South-North light line by using the light rail transit system and by using the minibus taxi. The collection of data was taken at the peak hours, the morning peak from 7:00 AM to 9:30 AM, and the afternoon peak from 3:30 PM to 6:30 PM. Data collection was on different week days. The South-North line was chosen as a representative of the two light rail transit lines because it has the longest travel distance. Besides that both lines have equal number of level crossing interruptions as can be seen in Table 3-2. Therefore the result of the impact of the level crossing on the travel time of the train using SPSS mathematical modeling will not be that much different. The trip distance for South- North line is 16.765 km. The reason for comparing the travel time with the minibus taxi is that as per a joint research by International Association of Public Transport (UITP) and African Association of Public Transport (UATP) has estimated modal share for the city of Addis Ababa. According to the transport studies by UITP and UATP (2010), walking takes a modal share of about 44% and is followed by minibus (34%). Therefore; it was intended to compare the light rail transit service with the most competent transportation mode.

Table 3-6: Mode split in Addis Ababa

Mode of Transport	Modal Share
City Bus	7%
Mini Bus Taxi	34%
Walking	44%
Private Taxi	6%
Private Car	9%

(Source: UITP /UATP, 2010)

South-North line is an interrupted line which consists of two crossroad level crossings, two T-intersection level crossings and one roundabout level crossing as detailed on Table 3-2. This line begins from Kality station and ends at Menilik square underground station. On this line there are four couple and four single trains as per the data given from Ethiopian Rail Corporation (Table 4-1). The data was collected for the two trip directions, from South to North (Kality-Menilik square) and from North to South (Menilik square –Kality). For each direction, the data of 20 trips was collected using the light rail transit system, therefore the

total number of trips was 40 trips. On the other hand, the data of seven South-North and six North-South trips was collected by using the minibus taxi; therefore the total number of trips was 13 trips.

For each trip by using the light rail transit system, the following data was collected and measured: travel time, Stop-open door time, Open door-Close door time, close door start time and the delay at level crossings. The collected data for the minibus are running time, time for pickup and discharge of passengers, traffic stop time, walking time to board minibus taxis at different stations and waiting time. These time series data is collected using smart mobile phone stop watch starting from the starting station and lapping the stop watch for the different occasions and recording a note if any additional occasion other than anticipated occurs.

3.5.1.4.Sampling Strategy

3.5.1.4.1. Traffic Volume

The major primary data of this research was collected using video cameras on the day Thursday, May 16, 2019 for Sebategna level crossing and Monday May 20,2019 for CMC level crossing .The buildings used at the vicinity location are Tsehay real state building and private building where the construction is currently halted. The videos are recorded for three hours for CMC level crossing and for three and half hours for Sebategna level crossing to catch on which hour the maximum traffic flow occurs. Therefore, for Sebategna for morning (6:00 to 9:30 a.m.) and afternoon (15:00 to 18:30p.m.) and CMC (6:00 to 9:00 a.m.) and afternoon (15:00 to 18:00p.m.) are recorded and counted.

Table 3-7: Volume of intersections used in the model

Approach direction	Sebategna	CMC
N	862	854
S	974	1469
E	295	2140
W	319	1012

(Source: Field observation & desk study of level crossings)

Table 3-8: CMC roundabout level crossing morning peak traffic volume and direction

CMC morning peak hour traffic count									
S.No.	Legs	Time				Total No. of vehicles	Directions	Percentage share	No. of vehicles
		00:00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00				
1	W _{total}	307.32	224.00	251.00	230.00	1012	W _{RT}	18.67%	189
							W _{TR}	54.90%	556
							W _{LT}	26.43%	268
2	E _{total} E _{diversion}	404.66	689.00	391.00	399.00	1884	E _{RT}	5.00%	107
		64.00	67.00	70.00	55.00	256	E _{TR}	77.02%	1648
						2140	E _{LT}	17.98%	385
3	S _{total}	448.47	472.00	253.00	296.00	1469	S _{RT}	18.70%	275
							S _{TR}	5.30%	78
							S _{LT}	76.00%	1117
4	N _{total}	190.55	208.00	192.00	263.00	854	N _{RT}	63.05%	538
							N _{TR}	18.10%	154
							N _{LT}	18.85%	161
Total		1,415	1,660	1,157	1,243	5,475.00			

(Source: Field observation & traffic counts study)

Table 3-9: CMC roundabout level crossing afternoon peak traffic volume and direction

CMC afternoon peak hour traffic count									
S.No.	Legs	Time				Total No. of vehicles	Directions	Percentage share	No. of vehicles
		00:00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00				
1	W _{total}	545.00	876.00	741.00	408.00	2570	W _{RT}	15.21%	391
							W _{TR}	73.68%	1894
							W _{LT}	11.11%	286
2	E _{total} W _{diversion}	325.00	290.00	297.00	338.00	1250	E _{RT}	10.83%	161
		55.00	70.00	51.00	63.00	239	E _{TR}	56.70%	844
						1489	E _{LT}	32.50%	484
3	S _{total}	212.00	193.00	190.00	198.00	793	S _{RT}	28.30%	224
							S _{TR}	15.00%	119
							S _{LT}	56.70%	450
4	N _{total}	188.00	146.00	105.00	100.00	539	N _{RT}	11.70%	63
							N _{TR}	35.00%	189
							N _{LT}	53.30%	287
Total		1,325	1,575	1,384	1,107	5,391			

(Source: Field observation & traffic counts study)

Table 3-10: Sebategna level crossing morning total 3hr and 30 minutes summary

S.No	Direction	Time													
		00:00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00
		00:00:00	00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00
1	M-NS	172	213	179	176	189	209	208	205	231	213	212	206	192	141
2	M-SN	234	217	213	219	227	192	203	257	257	225	249	243	131	218
3	M-EW	63	62	53	37	46	30	58	59	70	72	72	81	71	91
4	M-WE	32	57	51	66	53	63	78	68	60	73	102	84	77	75
15 minutes count		501	549	496	498	515	494	547	589	618	583	635	614	471	525
Hourly count					2,044	2,058	2,003	2,054	2,145	2,248	2,337	2,425	2,450	2,303	2,245

(Source: Field observation & traffic counts study)

Table 3-11: Sebategna level crossing afternoon total 3hr and 30 minutes summary

S.No	Direction	Time													
		00:00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00
		00:00:00	00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00
1	AF-NS	211	244	213	209	177	211	192	235	190	187	217	184	173	112
2	AF-SN	263	240	237	250	241	250	255	230	213	255	242	198	246	141
3	AF-EW	87	78	90	96	79	100	130	154	161	111	137	158	124	115
4	AF-WE	61	56	54	50	47	46	45	50	51	40	50	40	52	21
15 minutes count		622	618	594	605	544	607	622	669	615	593	646	580	595	389
Hourly count					2,439	2,361	2,350	2,378	2,442	1,906	1,877	1,854	2,434	2,414	984

(Source: Field observation & traffic counts study)

3.5.1.4.2. Vehicle Composition

In most cases extreme accuracy is not needed for classification studies. The usual procedure is to collect classification data for one session during the time period of interest e.g. peak hour. Vehicles for traffic study shall be classified into Heavy Vehicles and Passenger Cars (HCM, 2010).

Table 3-12: Vehicle composition from traffic volume study

CMC level crossing morning peak vehicle composition		Sebategna morning peak vehicle composition		
Bus	1%	Mid-bus	93	3.8%
Mid-bus	1%	Bus	74	3.0%
Mini-bus	15%	Mini-bus	970	39.6%
Automob	66%	Automob	941	38.4%
Pick-up t	11%	Pick-up t	218	8.9%
Isuzu	1%	Isuzu	116	4.7%
Bajaj	3%	Motor	31	1.3%
Motor	0%	Truck	7	0.3%
Truck	0%	Semitraile	0	0.0%
Semitraile	0%			

(Source: Field observation & traffic counts study)

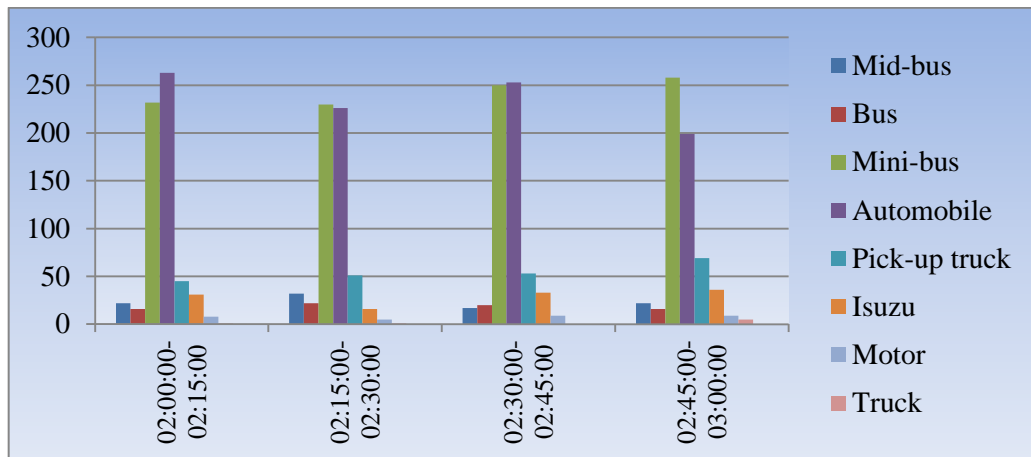


Figure 3-5: Sebategna peak hour vehicle composition (Source: Traffic counts study)

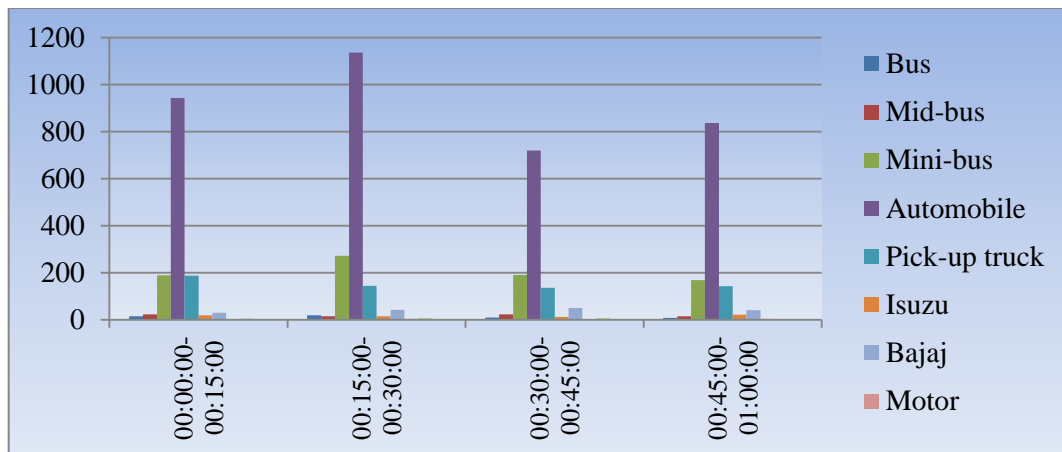


Figure 3-6: CMC intersection peak hour vehicle composition (Source: Traffic counts study)

3.5.1.4.3. Vehicle Routing Decision

For populations that are large, Cochran (1963) developed an equation to yield a representative sample for proportions; therefore, the formula used to determine the sample size was:

$$n = \frac{Z^2 pq}{\epsilon^2} \dots \dots \dots \text{Equation 3.1}$$

$$= \frac{(1.96)^2 (0.5)(0.5)}{(0.05)^2} = 385$$

Where, n = Sample size

Z = the standard normal deviation at the required confidence level.

p = the proportion in the targeted population estimated to have characteristics being measured. If there is no reasonable estimate, use of 50% (i.e. p=0.5) yields the

maximum value for ‘n’ or conservative sample size (for a large population and assuming maximum variability).

q = 1-p (proportion in the target population not having the particular characteristics)

e = the level of statistical significant set (margin of error).

Then, p = 50% =0.5 and q = 1-p = 0.5

Z statistic was 1.96 and ‘e’ desired accuracy at 0.05 levels (considering 95% confidence level and 5% error). Therefore, the sample size will be:

Therefore, 385 vehicle samples are taken at CMC roundabout level crossing to determine the routing decisions of the vehicle from the four approaches. This means 96 vehicle from approaches are taken. To take in to consideration the variability if routing throughout the peak hour 24 vehicles are sampled for each 15 minutes of the peak hour. Based on this the routing decisions of the CMC level crossing is calculated.

Vehicular Speed

In assessing vehicular speeds in this study, time mean values were assessed rather than space mean values. Therefore as discussed by Montgomery et al.,(2003), sample size can be determined as:

$$n = \frac{(Z\sigma)^2}{\epsilon^2} = \frac{(1.96 * 4.9)^2}{1.4^2} = 47 \dots\dots\dots \text{Equation 3.2}$$

Table 3-13 Recommended spot speed study lengths

Traffic Stream Average Speed	Recommended Study Lengths (meters)
Below 40km/h	27
40-64km/h	54
Above 64 km/h	81

Source: Currin (2001)

Recommended values of standard deviation for different roadway types can be used: Rural 2-lane: 5.3 mph, Rural 4-lane: 4.2 mph, Urban 2-lane: 4.8 mph, Urban 4-lane: 4.9 mph.

ε = Precision level or limit of acceptable error in the average speed estimate (mi/h) and it depends on the study. Therefore, for 95% confidence and urban 4-lane roadway at a

recommended precision level of 1.4mph for spot speed study. A sample size of 47 vehicles each is taken for minibus, automobile and pickup/Isuzu vehicles for both level crossings and is shown in appendix II.

Speed is used for validation of the simulation model. Initial sample of vehicles is taken for evaluation of the speed of vehicles in the intersection to identify which recommended study length should be taken from Table3-12. Based on this initial sample of vehicles, the speed of the vehicles in the intersection is found to be below 40km/ and a recommended study length of 27meters is taken for the speed study. This 27 meter length of the intersection is marked within the intersection prior to video recording and vehicles passing through this marked section are measured for the time it took them to pass through in the video recording. This same length is used in the simulation software data collection points distance for recording speed of vehicles in the simulation model.

3.5.1.4.4. Number of Observations for Statistical Model

The number of independent variables that should be used in your final model is limited by the number of observations. A rule of thumb used by some researchers is to limit the number of independent variables to one independent variable for every 10 observations. Thus, if you have 50 observations, this rough guide would suggest that you should limit your final regression model to a maximum of about five independent variables (Elliot et al., 2016).

As a result a total of forty runs are made by using the light rail transit for evaluation of the dependent variable travel time using the variables stop-open door time, open door-Close door time, close door start movement time and delay at level crossings time. For the case of the minibus taxi, the number of the observation runs done is thirteen because it is used mainly for evaluating travel time reliability of the transit service in comparison to this mode but additionally the variables affecting the travel time using this mode was computed.

3.5.1.4.5. Pedestrian Volume

High volume of pedestrians is available at Sebategna level crossing but is negligible at CMC roundabout level crossing. The pedestrian volume is counted at Sebategna but is not used in the VISSIM simulation because the available software license doesn't include pedestrian analysis. But count data is presented below in Table 3-13 below;

Table 3-14: Sebategna level crossing peak hour pedestrian count data

Direction	Time							
	02:00:00-02:15:00		02:15:00-02:30:00		02:30:00-02:45:00		02:45:00-03:00:00	
P _{EW}	S(straight)	N(straight)	S(straight)	N(straight)	S(straight)	N(straight)	S(straight)	N(straight)
	142		193		187		141	
	S(diagonal)	123	S(diagonal)	151	S(diagonal)	123	S(diagonal)	177
	264		302		253		281	2337
P _{WE}	S(straight)	N(straight)	S(straight)	N(straight)	S(straight)	N(straight)	S(straight)	N(straight)
	615	372	561	386	499	321	410	186
	S(diagonal)	N(diagonal)	S(diagonal)	N(diagonal)	S(diagonal)	N(diagonal)	S(diagonal)	N(diagonal)
	238	185	343	214	308	198	305	187
								5328
P _{SN}	E(straight)	W(straight)	E(straight)	W(straight)	E(straight)	W(straight)	E(straight)	W(straight)
	73	60	82	66	85	62	90	66
								584
P _{NS}	E(straight)	W(straight)	E(straight)	W(straight)	E(straight)	W(straight)	E(straight)	W(straight)
	122	112	126	131	134	122	131	116
								994
Total number of pedestrians on peak hour								9243

(Source: Traffic counts study)

3.5.2. Secondary Data Collection

The secondary data was collected from Addis Ababa Road Transport Bureau Transport Program Management Office (TPMO) and AA-LRT Operational Control Center (OCC) to obtain data like: original design drawings of AA-LRT, ridership data, intersections characteristics and other. In addition different researches, journals, publications books and manuals are browsed in detail for additional data.

3.6. Method of Data Processing and Analysis

After accumulating the collective road users, geometric and traffic data, the data were analyzed and processed using multimodal traffic simulation software tool (PTV VISSIM 9.0-07) and SPSS statistical software. The analysis steps for the VISSIM simulation model and the SPSS statistical software model are shown below.

3.6.1. Creating the Simulation Networks in VISSIM

As previously stated the CMC and Sebategna intersections are evaluated using VISSIM micro simulation software. The steps followed while

3.6.1.1.Setup the background

The first step in creating the model is finding the location of the study area in Google earth satellite imaging and taking snap shot of the intersection with visible approaches. This image is then inserted into the software using the ‘Background’ on the ‘Network Objects’ on the left side of the window. The scaling is done using the geometric of the intersection using the field geometric intersection data collected using actual field measurements of lane dimensions.

3.6.1.2.Network coding

Links should be created to represent road segments that carry the through movements and general curvature of the roadway. Links should proceed through a corridor with similar geometry and not be unnecessarily segmented. A connector is a type of link used to join two areas of a single link or to join two areas of two links. Connectors have additional characteristics that affect driver behavior, specifically lane changing, so it is important when coding to take this into consideration and eliminate the excessive use of connectors (C. Malet al., 2014).

The basic element of a road network in VSSIM is the link. A link represents the road (Urban road, Freeway, Pedestrian pathway...). Links can run in one direction over one or more lanes. You connect links via connectors; in this way, you construct the link network. The traffic can only flow via connectors from one link to another. Many network objects may lie on a link or connector, e.g. Stop signs, routing decisions, and PT lines or data collection points. Vehicle inputs may be positioned on links only. To place a link, click 'Links' on the top of the Network Editor window. The direction is set according to the start and end point of the link. To keep the traffic flow from one link to another ‘Connectors’ have to be used.

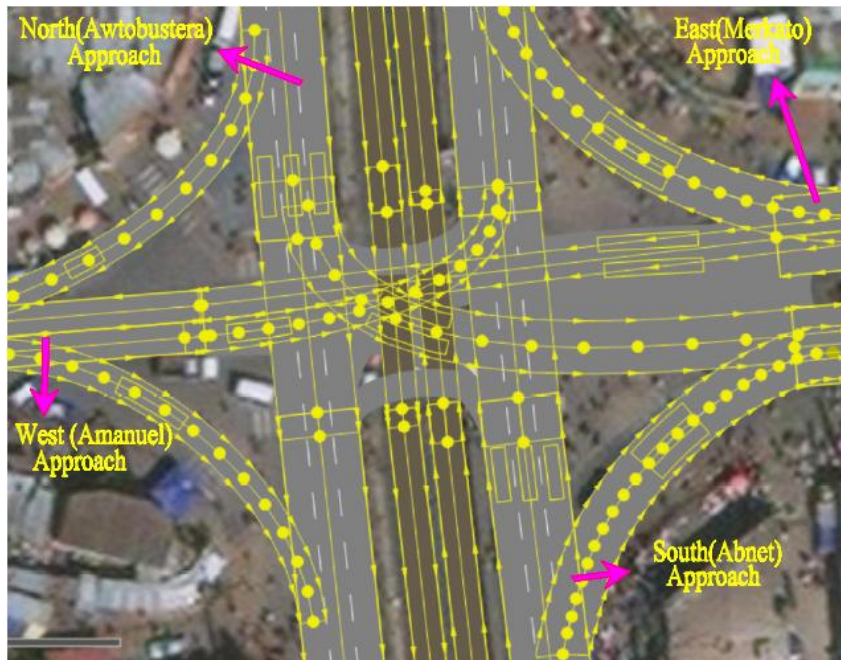


Figure 3-7: Links, connectors and reduced speed areas of Sebategna intersection

3.6.1.3. Vehicle inputs

After the links are set the volume of traffic counted on the intersections is fed into the software 'Vehicle input'. The field counted volumes of the intersection approaches are inserted into the model using this.

The basic element of a road network in Vissim is the link. Links can run in one direction over one or more lanes. Public transport line such as light rail transit is also coded in the form of link and the property is changed to rail and the whole line is lined with public transportation line from the Network objects list. The vehicle of the transit line is coded based of the frequency of arrival of the LRV in one hour per each direction and 5 vehicles per hour per each direction is used based on the frequency of the LRV arrival data (Check Appendix I).

3.6.1.4. Vehicle compositions

After the volumes are fed into the model, the vehicle compositions of each of the routes is defined and assigned to the respective approach directions. Four different vehicle compositions are created for each of the intersections four approach roads.

3.6.1.5. Speed control coding

To control the speed of vehicles in Vissim, the modeler can apply a "speed decision" or "reduced speed" on a network link. Desired speed decisions change the desired speed of

vehicles that cross it, and should be used when the free-flow speeds of an area have a significant change due to the posted speed limit, geometric changes, topography, or facility changes. Reduced speed areas are temporary zones with a reduced speed and should be used to code small sections where vehicles have a significant change in speed due to reduced speed locations in the field (e.g., ramps, turning movements). Vehicles reduce their speed to that coded prior to reaching the zone and maintain that speed through the zone, then increase to link speed after (C. Malet al., 2014).

3.6.1.6. Vehicle routing

Directional counts are counts taken of traffic movements on a roadway by direction of travel. On a segment of highway, directional counts include counts of each movement past the point at which the count is being taken. At an intersection, directional counts are made of each possible movement-through movements by direction of travel, and left and right turns by direction of travel (Traffic Engineering Manual, 2007).

In VISSIM the routes for the vehicles from the start to the end lane have to be specified as per the field data. A ‘Static’ route decision is used when defining the routes of vehicles. Use partial route decisions when you have to divide the traffic inside the static route decision. For this research static routing decision option is used.

Vehicle routes should also be coded in 15-minute demand increments. However, in some cases hour increments may be acceptable if volumes are consistent throughout the hour. There are three different methods for coding vehicle routing: static, dynamic, and origin-destination.

Static routes

The most common method is static routes, which is used for most arterial networks. Static routes can pass through one intersection, several intersections, or from one end of the network to the other. Traffic volumes in smaller networks with adequate intersection spacing can usually be coded as traditional intersection-to-intersection (point to point) turning movement routing decisions. All vehicles exiting one intersection are then assigned as left turns, through movements, or right turns at the next downstream intersection. Routing decisions should be placed as far upstream on a link as possible to allow for maximum weaving and/or merging distance (C. Malet al., 2014).

Defining vehicle routes was configured based on the actual field conditions (static vehicle route decision) considering the direction of the link flows. Then, link relative flows are entered

in each direction for each movement types of the intersection. In the routing decision, a route starting point was fixed first (red line in the VISSIM interface); then, the corresponding movements (through, left and right) were assigned accordingly. Each routing decisions show the branches of possible movements with their corresponding relative flows/traffic volumes.

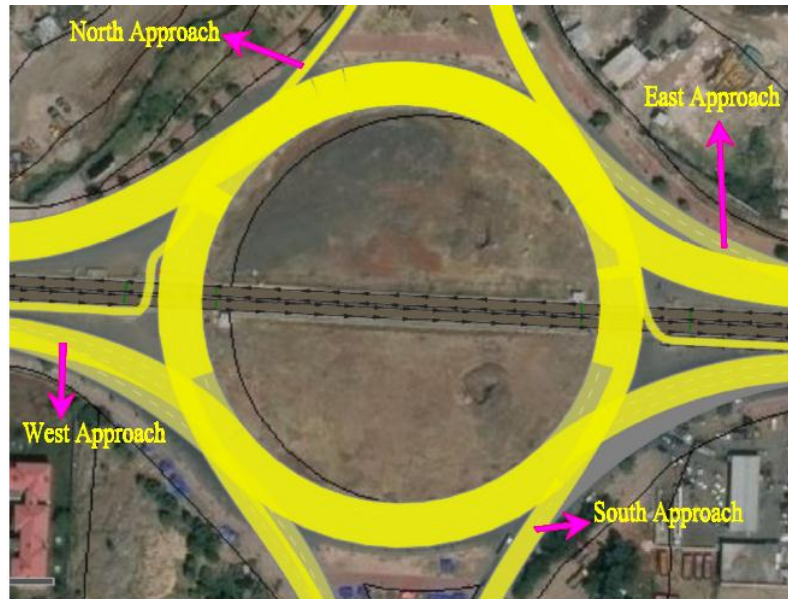


Figure 3-8: Vehicle routing decisions for CMC roundabout intersection

3.6.1.7. Priority rules and conflict areas

Conflict areas can be defined anywhere two links/connectors overlap in the network, such as at the entry point of a roundabout. Depending on the geometry of the roundabout, additional conflict areas may need to be defined. Priority is designated by the user. In the case of roundabouts, priority will be given to the circulating traffic. Entering traffic looks downstream as it approaches the conflict area. If a circulating vehicle is approaching the conflict area or is in the conflict area, the entering vehicle will slow down or stop to give way to the circulating vehicle. The entering vehicle then proceeds through the conflict area after satisfying the gap conditions (front gap, rear gap, and/or safety distance).

The benefit of the conflict area is that each vehicle determines the total gap time it requires to proceed through the conflict area, based on its own specific vehicle attributes such as acceleration and deceleration capabilities. In addition, with conflict areas, the vehicle that has the right of way is also able to see and respond to vehicles that may have entered the conflict

area aggressively and adjust speeds to avoid collisions. For Sebategna level crossing the vehicles interaction is managed by conflict areas management tool and the priority for the LRV is given using priority rules.

Priority rules do not offer the interactive driver behavior decision-making that conflict areas provide. This means that priority is given to one movement over another and only the non-priority movement sees the priority rule and is required to stop. In addition in this research the LRV is given full priority at its arrival on the intersection using priority rules.

Priority rules do, however, allow for added flexibility by defining the exact location and gap times required for vehicles to cross over the point of conflict. Typically, the gap times are based on the distance a vehicle must travel to pass through the entire point of conflict.

Roundabouts can be modeled with either conflict areas or priority rules. Both methods provide benefits. Typically, either method is acceptable for single lane roundabouts or priority rules are recommended for multi-lane roundabouts (with minimal conflict area use). Conflict areas provide more realistic and complex driver behavior and decision-making. Priority rules allow for more control over input parameters such as minimum gap times, the minimum headways, and placement of where these interactions should take place. When modeling roundabouts, priority rules are the recommended choice.

3.6.1.8. Roadside parking

On-street parking (roadside parking) is a common feature in most of the metropolitan areas around the world. On-street parking assists to improve economic viability of commercial developments along transport corridors by providing easy and convenient access for customers, delivery vehicles and employees of such developments. However, the provision of on-street parking along transport corridors could adversely impact the capacity as well as the achievable driving speeds of the adjacent road. Road safety is another key factor which needs to be considered when considering the provision of on-street parking along a transport corridor. The debate regarding the merits and drawbacks of on-street parking stem from a lack of research surrounding the subject over the last two to three decades (Marshall et al., 2008).

From the two level crossings under study Sebategna level crossing has roadside parking characteristics and it is coded in the simulation model using the parking tool at the Network objects sidebar. The locations of the roadside parking are shown in Appendix I.

3.6.1.9. Running the network simulation

After all the necessary measured inputs are fed for the three conditions, the networks were saved and ready for simulation. The simulation run takes 3600sec to complete the analysis and generate the required results for the given volume of traffic. When the simulation runs, the active flow video of traffic looks like the image displayed in Figure 3-6 below.

3.6.1.10. Evaluation

Node evaluation, data collection points and travel time are the three evaluation tools used for presentation of the analysis results and validation process.

3.6.1.10.1. Node evaluation

Node evaluation data is obtained by placing "nodes" at locations throughout the network. All study intersections, ramp terminals, and any other study locations must have nodes placed around them with Node Evaluation toggled on.

Use node evaluation for intersections, junctions, when you need quick result to have an overall view of the traffic. To record evaluation results for nodes: Evaluation menu--Evaluation menu--Configuration--Select collect data for Nodes. Travel time measurement starts upstream of the specified distance Start of delay segment before node, before node entrance. In our intersections the node evaluation is done for 50 m upstream and downstream of the node in all approaches for both the CMC and Sebategna level crossings.

Travel time measurement starts immediately after the closest node, if there are no more than four junctions between the two nodes. You can find here all the default selected attributes for Node evaluation. The node results for basic evaluation of the intersection include: various delay types, overall delays, queues lengths, LOS and many other important results. The direct results include simulation seconds, lane characteristics, delays, desired speeds, operating speed, headways, vehicle type and other result attributes based on need of the researcher.

3.6.1.10.2. Data collection points

Data collection points shall be placed at all entry and exit locations within the calibration area of a model. If archived speed or volume data is being used for calibration and evaluation of alternatives then these data collection points must be placed at the same location in the model as they had been collected in the field. Great care should be given to placing these points with an understanding that any additional points could affect the ability to auto group and will likely affect any spreadsheets set up to manage output. Be sure to name each point clearly as

this will save much confusion during spreadsheet work. Points on multilane links shall be aggregated together as one data point. If further specifics are desired near a grouping of points, for example: densities of lanes that feed turning links, then additional collection points are to be used. At a minimum, the following MOEs should be reported: number of Vehicles and mean speed.

3.6.2. Creating the Mathematical Model Using SPSS

Raw data usually need some editing before it can be properly analyzed. After collecting the travel time data using stop watch the raw data was in mm:ss.us. format. Before introducing the data to the software this data was converted to all microsecond to make it uniform unit.

Opening the software, SPSS displays data input page in a spreadsheet-like fashion. This sheet called data view always displays our data values. An SPSS data file always has a second sheet called variable view. It shows the metadata associated with the data. Metadata is information about the meaning of variables and data values. The data analysis used in this research is multiple linear regressions that uses multiple variables for modeling a dependent variable.

SPSS' output viewer window holds tables with all statistics on all variables we chose. The Output viewer window has a different layout and structure than the data Editor window. Creating output in SPSS does not change our data in any way because SPSS uses different windows for data and outcomes based on those data. SPSS Output items, typically tables and charts are easily copy and pasted into other programs. All output items can be exported easily to PDF, MS Word and many other file formats.

The method of least squares that leads to the best fitting line of a postulated form to a set of data is used to form Regression Models between the dependent variable Y_i , and independent variables X_i . In this study, the dependent variable Y_i includes travel time and running time. On the other hand the independent variable X_i includes the variables affecting the travel time. A relationship between the dependent and the independent variables of the form;

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$$

The selections of explanatory variables follow the following four guidelines to decide which explanatory (independent) variables to include in the linear regression model. The selected independent variable has to follow the following four rules:

- i. Must be linearly related to the dependent variable.
- ii. Must be highly correlated with the dependent variable.
- iii. Must not be highly correlated between themselves.
- iv. Must lend them-selves to relatively easy projection.

The selected regression model has to have a maximum of 3 to 4 variables in order to have an easy projection and application, and in order to have a lower cost. Also, the selected regression model should have strong coefficient of determination R^2 value (Montgomery, 2010).

The coefficient of determination R^2 , quantifies the fact that the goodness of fit of a regression line increases with the proportion of the total variation that is explained by the regression line. R^2 ranges from zero, when none of the total variation is explained by the regression line, to unity when all of the variation is explained by the line. It is denoted as a squared quantity to capture the fact that it is always non negative. The square root of R^2 is the Coefficient of determination, and it is called the coefficient of correlation (r or R). Its value can range from -1 to 1. In the case of linear regression, the sign of R is the same as the sign of the slope of the regression line. When R is near 1, there is a high positive correlation between x and y . when R is near -1, there is high negative correlation. If R is around zero, then there is no correlation between x and y (Papacostas 2008).

4. RESULTS AND DISCUSSIONS

4.1. Introduction

The simulation results were extracted in various forms like node evaluation for collecting selected basic outputs and data collection for various overall results used in validation and evaluation of performance indicators. The analysis results are stored in the results directory in text format and the comma delimited text files are imported to excel for further analysis. Prior to discussion of the results, the simulated VISSIM model was asserted for validated for further analysis.

4.2. Simulation Model Validation

Validation is the process to determine whether the simulation model is an accurate representation of the system under study. This establishes that the model behavior accurately and reliably represents the real-world system being simulated, over the range of conditions anticipated and it involves the following major steps (Mathew, 2014).

The simulated VISSIM model is validated based on Washington State Department of Transportation WSDOT VISSIM protocol validation criteria. Therefore according to WSDOT protocol for VISSIM simulation the following steps should be met for validation;

4.2.1. Confidence

Confidence, as outlined in this section, is intended to demonstrate that the micro-simulation runs that have been conducted have an average that is representative of the true average of the model. To determine the level of confidence in the reported results, an initial sampling of the model outputs is required. The initial sample will consist of the results of several simulation runs. The number of simulation runs must be large enough to reduce the impact that a typical run will have on the sample average. Each run must use different random number seeds starting at one and advancing sequentially. If vary the random seed, the stochastic functions in Vissim are assigned a different value sequence and the traffic flow changes. This, e.g., allows you to simulate stochastic variations of vehicle arrivals in the network.

In order to ensure that the results reported are representative of the unknown model average, the following formula for a 95 percent confidence level shall be applied:

$$N = \left(2 * t_{0.025, N-1} \frac{s}{R} \right)^2$$

R= Confidence Interval for the true mean

$t_{0.025, N-1}$ = Student's t-statistic for two-sided error of 2.5 percent (totals 5 percent) with N-1 degrees of freedom (this is related to a 95% Confidence Level)

s = Standard Deviation about the mean for selected MOE

N = Number of required simulation runs

The value of the student-t statistic can be found in any statistics manual, but based on the data set of 11 runs, $t = 2.228$. A confidence level of 95% must be used unless specified otherwise.

The goal of this effort is to determine if the number of runs conducted is sufficient enough to produce an average result that falls within a certain range of values (confidence interval) which the confidence level the unknown true mean of the model lies.

This statistical process requires the generation of an initial data set, which in this case will be the aforementioned 11 runs. In most cases, these 11 runs will generate a large enough sample size to meet our desired confidence criteria.

Table 4-1: Sebategna Level Crossing average volume of Simulation runs

No. of Simulations	Without LRT	Actual LRT arrival	Twice Arrival	Signalized actual arrival	Signalized twice arrival
1	2429	2431	2459	2219	2221
2	2417	2423	2431	2277	2242
3	2422	2441	2435	2219	2193
4	2450	2455	2464	2310	2223
5	2442	2463	2473	2353	2199
6	2431	2453	2439	2321	2207
7	2426	2436	2429	2313	2205
8	2432	2473	2438	2303	2209
9	2459	2469	2483	2331	2253
10	2465	2477	2441	2297	2190
11	2480	2495	2491	2324	2179
Average	2441	2456	2453	2297	2211

Table 4-2: CMC roundabout Level Crossing average volume of Simulation runs

No. of Simulations	Without LRT	Actual LRT arrival	Twice Arrival	Signalized actual arrival	Signalized twice arrival
1	5610	5220	5182	5616	5605
2	5621	5228	5207	5627	5597
3	5631	5237	5215	5632	5664
4	5638	5248	5229	5610	5601
5	5622	5265	5246	5665	5642
6	5617	5281	5253	5676	5741
7	5602	5290	5251	5683	5733
8	5611	5311	5262	5695	5712
9	5622	5292	5258	5693	5703
10	5722	5215	5199	5716	5726
11	5731	5229	5217	5724	5734
Average	5639	5256	5229	5667	5678

4.2.2. Calibration

Calibration is the process used to achieve adequate reliability or validity of the model by establishing suitable parameter values so that the model replicates local traffic conditions as closely as possible. The goal of performing calibration is to create a model that replicates real world conditions. The calibrated model can then be used with confidence to evaluate potential changes in the transportation network. These changes could be in geometry, traffic demand, driver behavior, signal timing, etc. Since the calibration process requires real world data to be thoroughly performed, it is typically only conducted for the existing conditions scenario(s).

4.2.2.1. Minimum Requirements

In order for the calibration process to be effective, there needs to be at least two calibration goals focusing on two different measures of effectiveness (MOE). At a minimum, it is strongly recommended that the following MOEs be used as calibration goals for all traffic models:

- Traffic Volumes
- Speed/Travel Times

These MOEs are suggested to be prioritized, given their influence on the many other operational characteristics of the transportation network, such as density and delay. Field data for these MOEs are also relatively quick to obtain. For projects that require a multi-hour analysis, the calibration criteria provided should only be applied to the peak hour.

4.2.2.1.1. Throughput Volumes

The first measure of proof of calibration is how closely throughput volumes from the field match simulation output volumes.

A simple percentage difference is not a fair comparison of the wide range of mainline segment or turning movement throughput volumes possible in the model. The best universal measure to compare field data and simulation outputs is the GEH formula. This continuous volume tolerance formula was developed to overcome the wide range in volume data described in the previous paragraph. GEH statistics shall be calculated for all mainline segments and ramps identified in the scope of work.

For hourly throughput volumes, the GEH formula is:

$$GEH = \sqrt{\frac{2(m-c)^2}{m+c}}$$

Notes:

Calibration of the model should use the GEH formula, calculated to a value of 3 or lower

m= output traffic throughput volumes from the simulation model (veh/h)

c = traffic throughput volumes based on field data (veh/h)

The GEH formula above was originally intended to evaluate total hourly volumes (vph), Utilizing hourly lane volumes makes it easier to target areas of congestion, regardless of the facility type.

Table 4-3 provides guidance on interpreting the calculated GEH statistic. The throughput traffic volume calibration criteria are listed in Table 4-4.

Table 4-3: GEH Statistics Guidelines

GEH Statistic	Guidance
<3.0	Acceptable Fit
3.0-5.0	Acceptable for Local Roadway Facilities
>5.0	Unacceptable

(Source: C. Mai et al., 2014)

Table 4-4: Through Traffic Volume (veh/hr.) calibration criteria

Criteria	Acceptable Targets
GEH <3.0	All state facility segments within the calibration area
GEH <3.0	All entry and exit locations within the calibration area
GEH <3.0	All entrance and exit ramps within the calibration area
GEH <5.0	At least 85% of applicable local roadway segments.
Sum of all segment flows within the calibration area	Within 5%

(Source: C. Mai et al., 2014)

In addition, increasing the GEH threshold from 3.0 to 5.0 may be acceptable for certain projects. A higher GEH could be acceptable on facilities where a higher variation in volume is expected.

Table 4-5: Sebategna Level Crossing volume calibration results

Equation	Without LRT	Actual LRT arrival	Twice Arrival	Signalized actual arrival	Signalized twice arrival
m	2441	2456	2453	2297	2211
c	2450	2450	2450	2450	2450
m-c	-8.82	6.00	3.00	-153.00	-239.00
(m-c) ²	77.76	36.00	9.00	23409.00	57121.00
2(m-c) ²	155.52	72.00	18.00	46818.00	114242.00
m+c	4891	4906	4903	4747	4661
$\frac{2(m-c)^2}{(m+c)}$	0.03	0.01	0.00	9.86	24.51
GEH	0.18	0.12	0.06	3.14	4.95

(Source: Validation analysis based on GEH formula)

Table 4-6: CMC roundabout Level Crossing volume calibration results

Equation	Without LRT	Actual LRT arrival	Twice Arrival	Signalized actual arrival	Signalized twice arrival
m	5639	5256	5229	5667	5678
c	5475	5475	5475	5475	5475
m-c	163.82	-219.00	-246.00	192.00	203.00
$(m-c)^2$	26836.40	47961.00	60516.00	36864.00	41209.00
$2(m-c)^2$	53672.79	95922.00	121032.00	73728.00	82418.00
m+c	11114	10731	10704	11142	11153
$\frac{(2(m-c)^2)}{(m+c)}$	4.83	8.94	11.31	6.62	7.39
GEH	2.20	2.99	3.36	2.57	2.72

(Source: Validation analysis based on GEH formula)

4.2.2.1.2. Speed

After the throughput volume outputs are calibrated in the model, replication of driver behavior is needed. One method is to match spot speeds. This usually pertains to freeway segments because it is difficult to measure accurate speed data on arterials due to the influence of signalized intersections.

The method used to collect field measured speed data should be considered when trying to replicate speeds in the model. For example, if spot speeds are collected in the field via a radar gun at a specific location, then a data collection point should be used to obtain similar model speed data at the same location. The speed data can also be measured and compared at various time intervals. This will most likely be dictated by the available field data.

Interrupted flow speeds

Spot speeds in the model for local roadways with interrupted flow can be allowed to vary by 10 percent of the base free-flow speed when compared to the observed real-world spot speed data. This calibration threshold was selected using information provided in the Highway Capacity Manual 2010. For a typical urban segment, the difference in speed between the LOS D and E thresholds is approximately 10 percent of the Free-Flow Speed. Using this threshold (+/- 10 percent of the Free-Flow Speed) as a calibration target will allow us to accurately match the model speeds and LOS to real world operations.

For example, an interrupted flow facility has a free-flow speed of 40 mph. The allowable variation for this facility will be +/- 4 mph (10% of the free-flow speed). Since this range is based on free-flow speed of the facility, it will remain constant regardless of the observed speeds collected in the field during congested periods. This means that if the facility operates at 20 mph during peak congestion, the allowable variation when comparing field data to the model outputs will still remain +/- 4 mph.

Table 4-7: Highway capacity manual 2010: LOS Criteria

Transverse speed as a percentage of base Free flow speed	LOS by Critical Volume-to-Capacity Ratio	
	≤ 1.0	≥ 1.0
>85	A	F
>67-85	B	F
>50-67	C	F
>40-50	D	F
>30-40	E	F
≤ 30	F	F

(Source: C. Mai et al., 2014)

Table 4-8: CMC roundabout Level Crossing Speed variation table

Vehicle types	VISSIM vehicle code	VISSIM Speed(km/h)	Field measured speed (Time mean speed, U_t (km/hr))	Speed Variation (%)
Mini/SUV	630	24.19	22.32	-8%
Yaris	640	27.35	25.94	-5%
Executive	650			
Pickup/Isuzu	660	23.44	21.84	-7%

(Source: Analysis based on speed validation criteria)

Table 4-9: Sebategna Level Crossing Speed variation table

Vehicle types	VISSIM vehicle code	VISSIM Speed(km/h)	Field measured speed (Time mean speed, U_t (km/hr))	Speed Variation (%)
Toyota yaris	630	17.58	16.63	-6%
Toyota execu	640			
Pickup/Isuzu	650	18.14	17.09	-6%
Mini/SUV	670	17.89	16.71	-7%

(Source: Analysis based on speed validation criteria)

The actual average travel time over the study segment is done for three vehicle classes at both of the intersections. For CMC level crossing 93% of the vehicle and for Sebategna level crossing 87 % are composed of these vehicles; as a result the speed represents most part of the vehicle classes. The compared average speeds of field data and VISSIM output are under 10%, which shows the model is acceptable representation of the real traffic behavior.

4.3. Operational Characteristics Based On Delay Results

Each of the intersections in this project was tested without LRT crossings to obtain a baseline average total delay. Average total delays were then obtained for each scenario including a range of LRT headways. As improvements signals are designed to check if delay improvements can be attained. The difference between the average total delays with two LRT headways, baseline average total delay, signalized level crossing total delays are compared. The LOS in Vissim is comparable to the LOS defined in the American Highway Capacity Manual of 2010 (Vissim 11 Manual, 2019).

Table 4-10: VISSIM LOS and delay criteria

	Signalized intersection	Non-signalized intersection
LOS _A	Loss time <10 s or no volume, as no vehicle is moving,also due to traffic jam	
LOS _B	>10 s to 20 s	>10 s to 15 s
LOS _C	>20 sto35 s	>15 sto25 s
LOS _D	>35 sto55 s	>25 sto35 s
LOS _E	>55 sto80 s	>35 sto50 s
LOS _F	>80 s	>50 s

(Source: Vissim 11 Manual, 2019)

4.3.1.1. CMC Roundabout Level Crossing Results

Table 4-11: CMC roundabout level crossing simulation results

Parameters	Without LRT			Actual LRV arrival			Twice actual LRV arrival			Signalized actual LRV arrival			Signalized twice actual LRV		
	VEHS	LOS	VEHDELAY	VEHS	LOS	VEHDELAY	VEHS	LOS	VEHDELAY	VEHS	LOS	VEHDELAY	VEHS	LOS	VEHDELAY
VEHS (ALL)	5639	E 47%		5256	E 53%		5229	E 47%		5667	E 29%		5678	E 28%	
LOS (ALL)	LOS_F W 5%			LOS_F W 2%			LOS_F W 5%			LOS_F W 2%			LOS_F W 2%		
VEHDELAY (ALL)	134.6	S 32% N 16%		135.2	S 29% N 16%		136.2	S 31% N 18%		124.0	S 24% N 45%		120.1	S 26% N 44%	

(Source: Vissim result output summary)



Figure 4-1: Snapshot display of the CMC level crossing during simulation run

Pattern of traffic flow and delay at CMC roundabout level crossing

According to O’flaherty , the delay which an individual vehicle experiences at a roundabout can be regarded as consisting of two components; “*moving delay*”, caused by the vehicle having to slow down, travel extra distance about a roundabout and then accelerate to the normal speed of the road and the “*obvious delay*”, caused by the vehicle having to queue in order to get into the roundabout and by obstruction from other vehicles while in the roundabout.

The average traffic delay in seconds at CMC level crossing during the peak period is shown on Table 4-11. The analysis reveals that CMC roundabout level crossing recorded the highest volume of traffic and delay than Sebategna level crossing.

In the without scenario the average delay of traffic is 134.62s/veh in which 47 % of this delay is experienced by East approach and West approach 5% South-32% and N-16%.This scenario is used as the base condition for comparison.

In the actual scenario the average delay of traffic is 135.2 s/veh .The average headway of the LRV at this level crossing is 00:10:42 (hh:mm:ss) for the WE direction and 00:11:56 for the EW direction and alternatively (what actually happens on the intersection) is 00:05:41.The average delay increased by 0.43% as compared to the base without LRT scenario. The increase in the average total delay is minimal because on the morning peak traffic volume distribution among the four approaches, i.e. the West approach contributes 18% of traffic, East approach contributes 39%, South approach contributes 27% and the North approach 16%.Because the east approach is parallel to the rail line (not in conflicting direction) the increase in average delay is not that much significance. In this scenario 53 % of this average delay is absorbed by the vehicles on the East approach, 2% is absorbed by the vehicles on the West approach, 29% is absorbed by the vehicles on the South approach and 16% by is absorbed by the vehicles on the North approach. The south approach is second in the average vehicular delay share. This is because 76% of the vehicles arriving in this approach turn left after crossing the rail line; therefore the movement direction is in direct conflict with the transit line. The North approach is the third in the share of the average vehicular delay. This is because 63.05% of the vehicles on this approach turn right without entering the roundabout and crossing the rail line. Only 18.10% percent of the through and 18.85% of the left turning vehicles of North approach is affected by the transit line. The west approach is the last in absorbing this average vehicular delay, and this is because 54.95% of the vehicles are through movement which is parallel to the rail line and 18.67% right without entering the roundabout with a total of 73.57% not substantially affected by the by the transit line.

In the twice arrival frequency scenario is when the headway of the LRT is reduced by half and the volume of the LRVs on the rail route are twice the actual condition. The average vehicular delay of the intersection is 136.22s/veh. The increase in delay is 0.76% from the actual conditions. From this average vehicular delay 47 % absorbed by vehicles on East approach, 5% by West approach, 31% by South and 18% by North approach vehicles. The pattern of traffic flow and traffic delay is same as the actual conditions scenario. The increase in average vehicular delay is not significant because of traffic volume routing that most flows on this

intersection with high volume are not in conflict with the transit line. The West, North and South approaches average vehicular delay has increased and the East approach delay has decreased from the actual conditions. This is mainly because the decrease in headway has affected 26.43%, 36.95% and 81.3% of vehicles movement in conflict with the transit line and 77.02% through movement not affected on the approaches respectively.

Signalized improvement proposed at CMC roundabout level crossing

Although yield control of entries is the default at roundabouts, when necessary, traffic circles and roundabouts have been signalized by metering one or more entries, or signalizing the circulatory roadway at each entry. Roundabouts should never be planned for metering or signalization. However, unexpected demand may dictate the need after installation. Each of these will be discussed in turn. In the first case, entrance metering can be implemented at the entrance or some distance upstream. Roundabouts operate effectively only when there are sufficient longer and acceptable gaps between vehicles in the circulatory lanes. If there is a heavy movement of circulating drivers, then entering drivers at the next downstream entry may not be able to enter. This situation occurs most commonly during the peak periods, and the performance of the roundabout can be greatly improved with entrance metering. A focus on maximizing intersection capacity rather than widening streets may therefore be appropriate (FHWA, 2000).

There are several advantages with signal control of roundabout. With the aid of the signals the delay can be more balanced in the roundabout and to decrease the delay in coordinated networks through balancing flows and give the possibility for transit priority. By using signals for metering, the queues can be handled and prevent that they block for example nearby intersections (Inman et al., 2007). When not active, the signals are unlit (off) at the roundabout entrance, this avoids the confusion drivers might experience, if they received a green signal only a few meters upstream of the yield control (Baranowski, 2004).

Detailed design of signalized roundabout should focus on the situation of the most important (high traffic volume) and vulnerable road users for maximum delay, for example, in the peak hour studied the most important (high traffic volume) are vehicle from the East, South, West and North approaches at CMC level crossing based on their contributions to the peak hour traffic flow.

For signal coordination the signal times were adjusted by optimizing the simulation results of the VISSIM through many trials (trial and error). The cycle time was 79 s, and green time for the East approach road with the highest traffic volume is give 40s and 13s each for the rest of the other approaches. From the 40sgiven for the East approach 37s is green time and 3s is amber time. For the rest of the approaches 10s each is given for the green and 3s each for the amber.

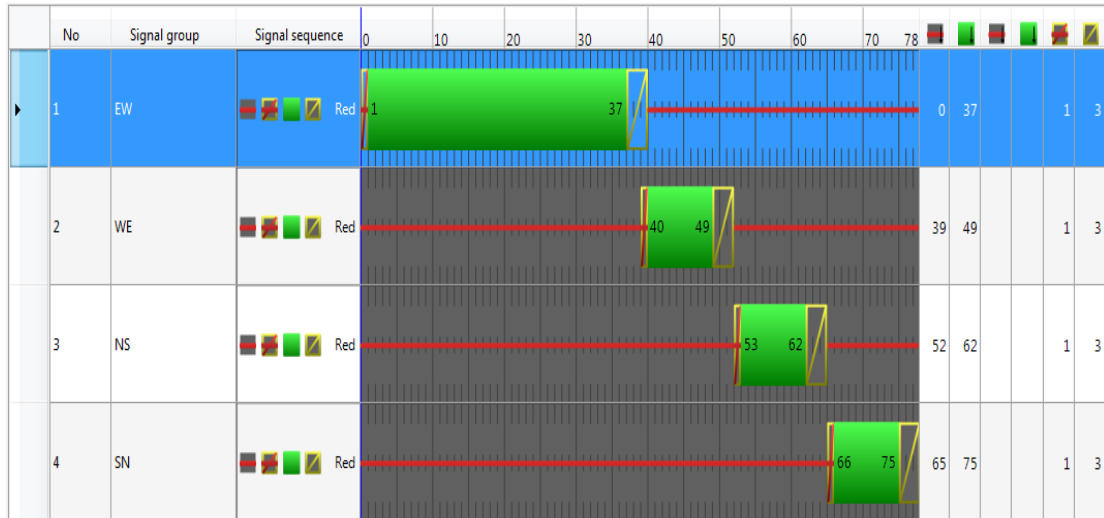


Figure 4-2: Proposed Signal program and signal group of the CMC level crossing

The signal is applied to the two LRV headway scenarios (actual and twice actual) to evaluate its effect on the average vehicular delay of the level crossings. In the signalized actual arrival frequency scenario the delay of the average delay of traffic is 124.01 s/veh. The signalized level crossing proposed has reduced the average vehicular delay by 8.29% from the actual unsignalized scenario. This is done by redistributing the actually existing delays for the less important approaches (less traffic volume). East approach vehicles absorb 29%, West approach vehicles absorb 2%, South approach vehicles absorb 24% and North approach vehicles absorb 45% of the delay. With this arrangement the North approach which is the least contributor to the peak hour traffic volume is given most of the delay taken from the East approach which has the highest traffic volume contribution for the peak hour. In this scenario 29 % of average vehicular delay is experienced by East approach, 2% average vehicular delay by the West approach, 24% average vehicular delay by the South approach and 45% average vehicular delay by the North approach.

In the signalized twice arrival frequency scenario the delay of the average delay of traffic is 120.13s/veh. The signalized level crossing proposed has reduced the average vehicular delay by 11.81% from the twice arrival un-signalized scenario. The patter of average vehicular delay distribution among the four approaches is not that much different from the preceding scenario but there is slight increase to the South approach (26%) and decrease of the East (28%) and North (44%) approaches. In all of the scenarios when a specific direction is affected it doesn't mean that the other direction movements are not affected , because vehicles will be queuing behind the affected direction vehicles and the effect is transferred; what it meant to show is the movements in direct conflict with transit line.

In general adding the LRT crossing changes the flow from uninterrupted to signalize. As traffic volumes increase, the capacity of the roadway decreases and total delays go up in an uninterrupted flow situation; however, in a signalized intersection, the total flow remains constant at the level of the saturation flow rate when demand exceeds capacity, so the increase in total delay is not as great. The increase in delay that happens when the roadway without LRT is over capacity makes the average total delay closer to that found with LRT crossings, therefore making the average additional delay smaller, since it is the difference between the two delay values (Chandler et al., 2004).

4.3.1.2. Sebategna Level Crossing Results

Table 4-12: Sebategna level crossing simulation results

Parameters	Without LRT			Actual LRV arrival			Twice actual LRV arrival			Signalized actual LRV arrival			Signalized twice actual LRV arrival		
VEHS(ALL)	2441	E	2%	2456	E	21%	2453	E	30%	2297	E	5%	2211	E	36%
LOS(ALL)	LOS_C	W	50%	LOS_C	W	70%	LOS_D	W	64%	LOS_E	W	44%	LOS_F	W	39%
VEHDELAY (ALL)	22.3	S	3%	23.5	S	4%	33.1	S	3%	67.3	S	25%	98.5	S	11%
		N	45%		N	5%		N	3%		N	27%		N	13%

(Source: Vissim result output summary)

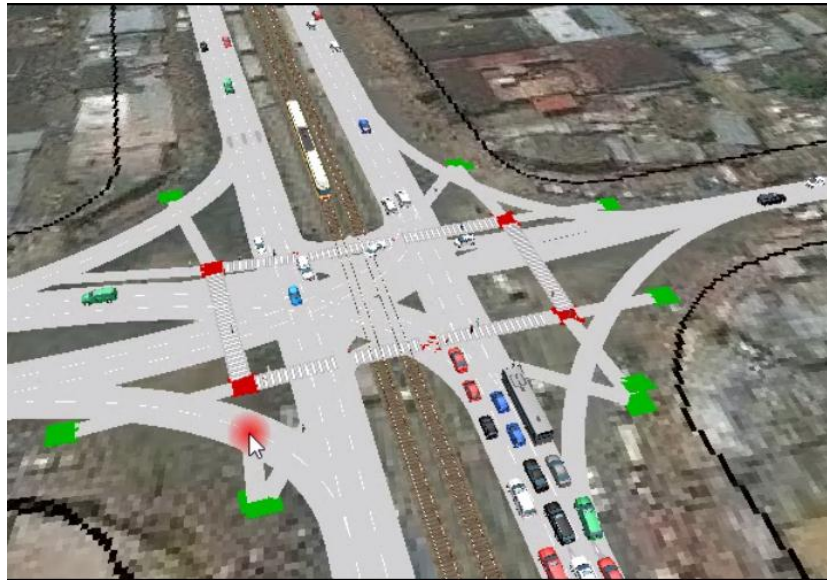


Figure 4-3: Snapshot display of the Sebategna level crossing during simulation run

Pattern of traffic flow and delay at Sebategna level crossing

The average traffic delay in seconds at Sebategna level crossing during the peak period is shown on Table 4-12.

In the without scenario the average delay of traffic is 22.31s/veh which 2 % of this delay is experienced by East approach and West approach 50% South-3% and N-45%. This scenario is used as the base condition for comparison.

In the actual scenario the delay of the average delay of traffic is 23.53 s/veh . The average headway of the LRV at this level crossing is 00:12:37 (hh:mm:ss) for the NS direction and 00:11:52for the SN direction and alternatively (what actually happens on the intersection) is 00:06:30. The average delay increased by 5.47% as compared to the base without LRT scenario. The delay absorbed by the East approach increased because the left turn (56.61%) and the through (16.61%) which comprise 73.22% in total are affected by the transit line. The delay absorbed by the West approach increased because 73% of the vehicles (29% left turn &44% through) are affected by the transit line. But in general this approach absorbed most of the delay experienced at this intersection and this is mainly because of three reasons; this approach has only one lane per each direction, there is on-street parking of minibus taxis just at the entrance of the approach throughout the peak analysis period and the introduction of the transit line has added upon these two. The delay absorbed by the South approach increased but not significantly because only 13.55 %(9.14% U turn and 4.41% left turn) vehicles are

affected by the introduction of the transit line. The North approach absorbed delay doesn't increase because 76% of the vehicles on this approach are through vehicles and their movement is parallel to the transit movement. In general on this scenario 21 % of the delay is absorbed by East approach and West approach 70% South 4% and North 5%.

In the twice arrival frequency scenario is when the headway of the LRT is reduced by half and the volume of the LRVs on the rail route are twice the actual condition. The average vehicular delay of the intersection is 33.11s/veh. The increase in delay is 40.7% from the actual conditions. From this average vehicular delay 30% absorbed by vehicles on East approach, 64% by West approach, 3% by South and 3% by North approach vehicles. The pattern of traffic flow and delay is almost same as the actual conditions scenario but there is a slight increase on the East approach and decrease on the rest approaches. This is mainly because 73.22% of vehicles on the east approach are affected on this approach which is relatively higher as compared to the rest approaches.

Signalized improvement proposed at Sebategna level crossing

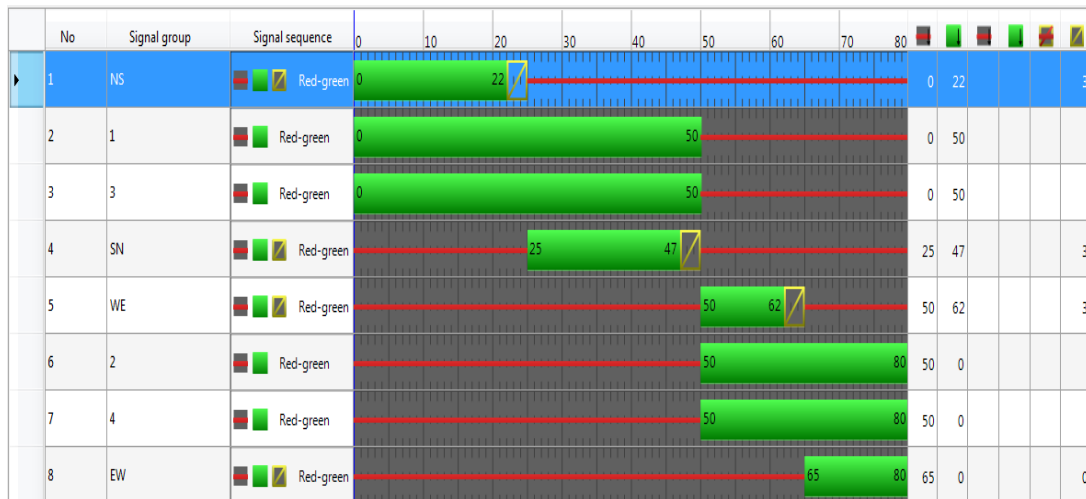


Figure 4-4: Proposed Signal program and signal group of the Sebategna level crossing

For signal coordination the signal times were adjusted by optimizing the simulation results of the VISSIM through many trials (trial and error). The cycle time was 80 s, and green time for the East is give 15s ,West is given 12s green and 3s amber and North and South approaches are given 22s each green time and 3s amber. In this signal time is given for pedestrians' movement too with overlapping (non-conflicting) movement of the vehicle to check the effect what will happen if pedestrians are included in the intersection. The movement of pedestrians

crossing the west approach in SN/NS directions (represented by 1) and the movement of pedestrians crossing the East approach in SN/NS directions (represented by 3) are given 50s each. The movement of pedestrians crossing the South approach in EW/WE directions (represented by 2) and the movement of pedestrians crossing the North approach in EW/WE directions (represented by 4) are given 30s each

The signal is applied to the two LRV headway scenarios (actual and twice actual) to evaluate its effect on the average vehicular delay of the level crossings. In the signalized actual arrival frequency scenario the delay of the average delay of traffic is 67.32 s/veh which 5 % of this delay is experienced by East approach and West approach 44% South 25% and N 27%.the installation of signal at the intersection didn't improve the delay at the intersection because the signal increased the stopped time delay of the intersection. Signal with priority to north and South approach redistributed the delay from the East and West approaches to the North and South approaches in the form of stop time delay. Because the vehicle volume on the South(40%) and North(35%) approaches is very high at peak hour the stop time delay redistributed increased the delay of the signalized intersection drastically. In addition the high on-street parking, complex geometry, high pedestrian volume, high bus volume and high volume of U-turn and left turn vehicles of the intersection has created a very complex relationship to create such a delay value.

In the signalized twice arrival frequency scenario the delay of the average delay of traffic is 98.47 s/veh which 36 % of this delay is experienced by East approach and West approach 39% South 11% and North 13%. The signalized level crossing proposed has increased the average vehicular delay by 197.4% from the twice arrival un-signalized scenario. The twice arrival of frequency (reduced headway) has increased the delay of the level crossing.

Chandler et al., (2004) found that on a two-lane isolated intersection, there was an average of 3.6 seconds of additional delay per vehicle with approximately 250 vehicles crossing and almost 32 seconds/vehicle of additional delay with 1700 vehicles crossing the light rail tracks. As light rail crossing frequencies decreased from 5 to 10 minutes, the average additional delays decreased by close to half, to a maximum of 14.9 seconds/vehicle. At the 15 minute crossing frequency, there was a maximum of 9.4 seconds/vehicle of average additional delay, and it was at 7.1 seconds/vehicle with crossings every 20 minutes and a traffic volume of 1700 vehicles/hour. The four-lane isolated intersection case showed that average additional delays

are lower than those for the two-lane case. For lower traffic volumes, between 500 and 3000 vehicles/hour in each direction, the average additional delays range from 2.1 sec./vehicle to 6.9 sec./vehicle at the 5 minute crossing frequency. There is a sharp increase in the total delay to 31 seconds/vehicle at 3250 vehicles/hour, then a slight decrease to around 21 seconds per vehicle as the roadway becomes over saturated. When the light rail frequencies decrease, there is a corresponding decrease in additional delays. At the 20 minute frequency, for example, the maximum additional delay is 8.3 seconds/vehicle. The average additional delays for crossing traffic volumes below 3000 vehicles/hour in each direction were all under 2 seconds.

4.4. Mathematical Multiple Regression Results

Statistical Models Results

Also, by using the selection of variables in multiple regressions to find the best variables to enter the model, Stepwise Regression Procedure was used for this purpose and standardized coefficients are used for the model equation. Summary for the best multiple regression models are as follows:

Train travel time correlation with the variables

$$Y = -2.311E-6 + 0.699X_1 + 0.079X_2 + 0.311X_3 + 0.142X_4 + 0.556X_5 \quad R^2 = 0.993$$

Y1- Travel time	X4- Close door start movement time
X1- Running time	X5- Grade intersection delay time
X2- Stop-open door time	X6- Size of train (Short-1; Long-0)
X3- Open door-Close door time	X7-Direction of travel(SN-1;NS-0)

Minibus taxi travel time correlation with the variables

$$Y = -12564 + 0.454X_1 + 0.274X_2 + 0.440X_3 + 0.234X_4 + 0.597X_5 \quad R^2 = 0.915$$

Y1- Total travel time	X3 - Traffic stop
X1- Running time	X4 - Walking
X2 - Boarding stop	X5 - Waiting

From the correlation between the variables, the following results are obtained:

Train travel time is most highly correlated with the running time (X_1), and then with the grade intersection delay time X_5 , open door-close door time X_3 , close door-movement time X_4 and stop-open door time X_2 . On the other hand, the travel time is not correlated with the size of the train X_6 and the trip direction X_7 , which means the size of the train and trip direction has no

effect on travel time of the rail transit. The average travel time using the taxi transportation is 50.72 minutes.

Minibus taxi travel time is most highly correlated with the waiting time X_5 , and then with running time X_1 , time associated with traffic congestion and stop at signals X_3 , pickup and discharge of passengers' time X_2 and walking time between some stations X_4 . The average travel time using the taxi transportation is 1 hour and 45.7 minutes.

4.5. Modal Shift Character Based On Reliability Variables

Reliability of travel time is increasingly being regarded as an important component in an individual's decision making concerning route choice or mode choice (Small et al., 2007). Reliable transit service is essential to attracting and retaining riders, particularly in modern times when many transportation options are available (Levinson 2005).

The added travel cost of unreliable service eventually influences mode choice decisions, resulting in patronage declines over time and an increase in the amount of public funds required to support public transit services. To improve service quality from the customer's viewpoint, transit agencies should focus their efforts on reducing the inconsistency in transit performance over time (Kimpel, 2001). Travel time, waiting time, and the uncertainties associated with both have been shown to affect customer perceptions of transit service quality (Reed, 1995).

In essence, travel time reliability is the certainty or stability of travel time of any particular trip under repetition, and as such, it is related to the statistical concept of variability. Variability in travel times introduces uncertainty for travelers in that they do not know exactly when they will arrive at their destinations (Bates et al., 2001).

The first type of measure includes the standard deviation of travel time (Jackson and Jucker, 1981; Senna, 1994), percentile difference of the travel time distribution (Lam and Small, 2001; Small et al., (2005); the coefficient of variation (Small et al., 1995), and the width of uncertain travel time distribution (Hensher, 2001), etc., all of which consider the dispersion of travel time distribution, but with different statistical viewpoints on describing the variation in travel times.

The standard deviation of travel time measures how wide the spread of travel times is about the mean, and both the right- and left-hand sides of travel time distribution are considered in this case. The travel time reliability can be expressed in terms of standard deviation, maximum delay, and relative delay. Absolute value of standard deviation is inversely proportional with

reliability. If the travel time is high variability, the reliability is low; if variability is low, the reliability is high. Since travelers generally are very serious in case of arriving at destination later than their expectation, thus maximum delay of travel time can be used to indicate the reliability of transportation system (Doohee Nam et al., 2005).

Table 4-13: Standard deviations of light train and minibus taxi travel time

	Minibus Taxi		Light rail transit	
	Total travel time	Total travel time(Including waiting time)	Total travel time	Total travel time(Including waiting time)
	5,087,240,000	6,896,030,000	2,937,050,000	3,740,050,000
	5,635,850,000	6,401,460,000	2,911,070,000	3,714,070,000
	6,140,150,000	7,616,910,000	2,925,240,000	3,728,240,000
	4,341,820,000	6,528,210,000	3,116,000,000	3,919,000,000
	5,774,350,000	7,278,370,000	3,040,450,000	3,843,450,000
	4,979,570,000	6,161,400,000	3,017,610,000	3,820,610,000
	5,001,140,000	6,466,540,000	3,218,480,000	4,021,480,000
	4,747,090,000	5,546,720,000	3,064,160,000	3,867,160,000
	5,259,500,000	6,805,130,000	3,028,040,000	3,831,040,000
	4,529,300,000	5,420,750,000	2,946,540,000	3,749,540,000
	4,336,840,000	5,372,530,000	2,854,490,000	3,657,490,000
	5,183,260,000	6,260,800,000	3,524,580,000	4,327,580,000
	4,687,290,000	5,697,050,000	2,922,600,000	3,725,600,000
Standard deviation(μsec)	550,079,645.5	704,364,627.2	175,827,976.7	175,827,976.70
Standard deviation(minutes)	9.168	11.739	2.930	2.930

(Source: variability analysis summary)

As per Doohee Nam et al., (2005) absolute value of standard deviation is inversely proportional with reliability. This means if the value of the standard deviation of the travel time is higher its reliability is considered low. Based on this the reliability of the light rail transit is much better than the reliability of minibus taxi transportation along the South-North light rail transit line. Besides there is significant difference between the travel times using the rail transit and the minibus taxi.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This research examined the impacts of level crossings on the change in average total delay experienced by vehicles. It presented a methodology to estimate the average additional delay created by level crossings using VISSIM computer simulation software.

The study of traffic delay problems at sampled level crossings in Addis Ababa revealed that there are significant variations in traffic flows and delay times at the studied intersections during peak period.

Based on the results from the five scenarios that were tested, it appears that light rail vehicle arriving frequency (headway), number of vehicles at the crossing and the geometry of the intersection have a great effect on the average increase in delays experienced by the vehicles. In addition the prevalence of on street parking (on the East, West and South approaches) and very high number of pedestrians on the Sebategna intersection had a great effect on the delay caused. When the roadway is in an over saturated condition, the total delay continues to increase with increasing volumes and transit headway frequencies. Left and U turns on the main approaches and approaches that were perpendicular to the tracks that were in conflict with the light rail experienced significant delays and also had an effect on the other movements because vehicles are queued behind vehicles that are in direct conflict.

Moreover, the proportion of traffic delay times was found to be related to the proportion of vehicle volume the approaches' contribute to the studied level crossing and also the movement the different routes each approach is consisted of whether it is conflicting with the transit line or not. In addition the composition of the traffic itself (for example, the number of buses), and the difference in the types of intersection considered for the study have shown a significance difference in the amount of delay experienced.

With a complex roadway and crossing geometry, such as the case when the LRT is located within a street median or as part of a larger network, the change in delay is also dependent on the degree of coordination and preemption of traffic signals within the network. If traffic signals are set to allow non-conflicting phases to proceed during LRT crossings, an average travel time savings could result. Travel time savings may result on some approaches if additional green time is given to non-conflicting phases during a light rail crossing. Individual results are likely more dependent on the traffic volume and capacity of a given location.

In contrast, the impact of LRT on reducing traffic congestion in middle of Addis Ababa is more significant. This is due to the fact that if the LRT was not available as a mode choice for passengers that are mostly from the lower and middle income population of the city, the alternative modes that are available are higher buses, medium buses and mostly minibuses. And these modes would have highly contributed to the prevailing traffic problem of the city. As introducing transit service of any form (bus/rail) into the existing traffic infrastructure is going to be the future of public transportation the analysis methods need to provide accurate impact measures of effectiveness. The LOS impacts of introducing median running LRT appear to have no effect on the LOS of the peak hour, but with respect to delay there is a marked difference. Of course, inputs such as signal timing, traffic volumes, and LRT headways will have a major impact on the results of any particular analysis.

With respect to the mathematical modeling of the travel time of the South-North transit line, there is a significant difference between travel time by using the light rail transit and by using the minibus taxi. The travel time by using the light rail transit system depends mainly on the running time, delay time at grade intersections, and open door close door time and to a lesser extent on stop-open door time and close door start movement time. The level crossings interrupt the transit priority 27.5% of the peak studied hours. It is clear that the impacts of the level crossings on the travel time characteristics of the train are mainly on peak periods.

If improvements on the travel time of the light rail transit are required the main variables that should be taken are identified in this result. The trip direction and the train size have no significant impact on the travel time. Increasing the train speed, adding more locomotives to the network, and creating awareness on travel time effects of alighting and boarding time to passengers will have a positive effect on the travel time. In addition, the drivers of the trains check at every stations if all passengers are inside and doors are closed standing from their sits and getting out of the trains. If this activity is avoided there will be an improvement in the open door close door time (X_3). Full priority for the transit line at level crossings also will have an impact on the travel time of the facility. The waiting time for the light rail transit system on both East-West and South-North directions is not high (as witnessed by the headway data) as compared to the minibus taxi and it has improved after this data has been collected as per the report by Ethiopia Railway Corporation.

As it can be seen from the reliability the variation on the travel time of the train is lesser than by using the minibus taxi on the South-North transit line. Therefore its attractiveness to passengers is clearly high, beside the average travel time using the light rail transit is 47.98% lesser than the minibus taxi travel time. In addition the cost of travel using the transit line is 69% less than the cost using the minibus taxi. Even though the transit line is very highly better than the minibus taxi transportation, further improvement of the light rail transit is very essential to attract more passengers to use the facility. Improvements can be attained by increasing the number of LRVs' or by decreasing the headway mainly at peak hours instead of constant headway throughout the day.

5.2. Recommendations

Intersections should not be designed with railroad tracks passing through the center of it and locating level crossing near intersections is generally discouraged. And if such a condition occurs different options should be checked based on the tradeoff between the operational cost of the level crossing and the cost incurred if it is grade separated.

On level crossings, there are many variables that influence a motorist's ability to react appropriately. These include information available at the approaches of the crossing and human factors such as competing decisions, distractions, and impaired driving. Therefore due attention should be given to the amount of information provided to the motorists using the level crossings. Besides, rough crossing surfaces impact the motoring public far more than the railroad. Therefore, when a highway project passes through a railroad level crossing, the highway traffic should dictate the type of crossing surface and due consideration should be given to the comfort of the crossing surface for motorized vehicles.

Coordination of highway traffic signal operations with level crossing active warning devices ("railroad preemption") when signalized intersections are located near level crossings is an important measure that will greatly increase the efficiency of a level crossing. In such instances, railroad preemption is designed to clear the tracks of any vehicles that may be stopped as a result of the highway traffic signal when a train is approaching the level crossing. Left turns and U-turns across LRV tracks pose both capacity and safety concerns. These turns should either be provided and protected or prohibited and redirected (if motorist expectancy is not violated). Traffic signal controls should always be carefully coordinated with the roadway geometry. Motor vehicles that make illegal turns in front of approaching LRVs account for the

greatest percentage of total delay for most LRT systems. Thus, traffic control devices that regulate turns are critical to LRT and general traffic safety.

The parking problems experienced at Sebategna level crossing include on-street parking, double parking, and parking to load and off-load which reduce the road space thereby impeding the free movement of vehicles. The parking problems found can be attributed to narrowness of the intersecting roads which do not give room for side-curbed parking. In addition, there is no provision for off-street parking in the city and as such vehicles have no alternative than to use the roads as parking space. This therefore gives room for indiscriminate on-street parking and parking to load and off-load. There is the need for provision of off-street parking spaces along the intersecting roads. This can be done by installing NO PARKING and NO WAITING signs at the intersections to discourage arbitrary parking. Many of the problems identified at the studied junctions are common to other road intersections in the city. The recommendations made are therefore useful for solving traffic congestion problems at road intersections generally in the city.

The provision of Addis Ababa light rail transit system is a huge addition to the public transport, but it will not be efficient unless it is supported by integrated transport and traffic management strategies. Road ways should be used efficiently and harmonically by the different modes of transport, namely train, vehicles and pedestrian; this harmony will help in order to reduce travel time, congestion and accidents. Policies need to be drafted in such a way that preferred mode of transport system is favored

During the initial planning for a light rail line if phase II of the AA-LRT project, if planned to be implemented, special consideration should be given to the traffic volumes at the proposed level crossings as well as the proposed LRV service frequency during the peak periods. If the level of service is expected to include smaller arriving interval or if level crossings are proposed for streets that are near capacity, measures such as widening roads at crossings, providing extra space for turning vehicles, or constructing a grade-separated crossing should be considered. A preliminary, planning level assessment of the roadway crossings based upon readily-available, planning-level data for roadway volumes and train frequencies should be taken in to consideration whether at grade or possible grade separations are required based on current and future traffic and passengers volume anticipated.

5.3. Suggestions for Future Research

- The VISSIM 9.0 computer simulation model is an acceptable tool to determine the impacts of LRT crossings on street traffic. The model allows for a wide range of conditions to be considered, which is useful because there is a great amount of design flexibility within light rail systems. VISSIM 9.0 has the capability to model transit operations explicitly, so it can be used to evaluate simple designs as well as more complex scenarios that might involve transit, street traffic, and pedestrians. But the model has no flexible lane management system when dealing with roadways with one lane per direction and roadside parking on one of the lanes.
- Further investigation of light rail crossings near signalized intersections is important for determining their effects. The effects of other variables on average total delay with the presence of light rail should also be studied. Various degrees of preemption signal recovery algorithms, vehicle compositions and so on should be examined for coordinated signal systems.
- Future studies should be made for several cases, particularly with regard to:
 - Varying flows for pedestrians;
 - Different flow distribution;
 - Compare with the traffic signal at the intersection;
 - Different signal diagrams and cycle times;
 - Different geometry and number of lanes.

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APPENDICES

Appendix I- Traffic Counts, composition, LRV frequency

Sebategna Level Crossing

Direction	Lane Code	Vehicle class	Time														
			00:00:00- 00:15:00- 00:30:00- 00:45:00-				01:00:00- 01:15:00- 01:30:00- 01:45:00-				02:00:00- 02:15:00- 02:30:00- 02:45:00-				03:00:00- 03:15:00-		
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00	
NS	N-S1 (U)	Mid-bus			1	1	1				1	3		2	2	1	1
		Bus											1	1			
		Mini-bus	14	17	15	15	6	11	16	16	17	13	13	9	15	4	
		Automobile	2	1	3	3	7	5	4	5	13	8	12	4	8		
		Pick-up	1	2	1	1	1		2	1	2	6	1	3	2		
		Isuzu		1			1		2		1		2	1	1		
		Motor															
		Truck															
		Semitrailer															
	N-S 1 (Left)	Mid-bus	1								2	1	1	2	1		
		Bus							1			1					
		Mini-bus	5	6	4	3	4	4	7	6	11	10	6	7	8	3	
		Automobile	2	6	2	4	8	3	8	11	9	13	10	8	9	6	
		Pick-up					5	2		1	4	2		2	1		
		Isuzu			1	2	2	2		1	4	1	5	3	1	3	
		Motor			1			1									
		Truck															
		Semitrailer															
	N-S 1	Mid-bus	1	4	2	6	4	2	2			1		2			
		Bus	5	2	4	4	1		2	2		2	1	1	1		
		Mini-bus	30	29	22	15	7	7	5	9	3	6	6	8	5	13	
		Automobile	18	12	8	9	18	27	7	15	10	7	10	12	10	15	
		Pick-up	3	3		4	5		4	2	1	1	2	5	2	4	
		Isuzu	1	3		1	2	5	2	1	1	2		3		2	
		Motor		1								1		1			
		Truck	1														
		Semitrailer															
	N-S 2	Mid-bus	1	7	5	6	5	1	3	2	1	1		3	2	1	
		Bus	2	9	2	4	3	3	2	3	8	7	10	6	3	5	
		Mini-bus	54	60	46	38	25	37	34	34	29	39	31	35	33	16	
Automobile		9	11	23	27	30	39	43	41	49	30	36	35	24	14		
Pick-up		3	5	7	11	5	5	8	10	8	8	14	10	4	5		
Isuzu			3		1	5	4	2	3	1	3	1	1	4	3		
Motor							1		3	2	1	2	1	2	1		
Truck		2	1	2										1			
Semitrailer															1		
N-S 3	Mid-bus						1			1	2			1			
	Bus						1			1					1		
	Mini-bus	2	18	13	12	28	18	20	7	21	16	22	19	18	17		
	Automobile			4	4	11	17	16	12	14	14	10	7	16	12		
	Pick-up		1		1	1	2	1		1	2	3	5		3		
	Isuzu					1	2			1	1				1		
	Motor			1			2	3	2	2	1	1	1	7	3		
	Truck																
	Semitrailer																
N-S3 (R.T)	Mid-bus		1	1	1		1	2	4		1						
	Bus	1		1			1										
	Mini-bus	12	8	6	1		3	3	7	3	6	1	2	7	1		
	Automobile	1	1	3	2	2	3	5	4	4	4	3	5	3	7		
	Pick-up	1							1		1	4	1	1			
	Isuzu		1					2		2					1		
	Motor			1				2		2		1	1	1			
Truck																	
Semitrailer																	

Sebategna morning North-South direction traffic count data

Direction	Lane Code	Vehicle class	Time													
			00:00:00- 00:15:00- 00:30:00- 00:45:00				01:00:00- 01:15:00- 01:30:00- 01:45:00				02:00:00- 02:15:00- 02:30:00- 02:45:00				03:00:00- 03:15:00	
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	
NS	S-N1 (U)	Mid-bus			12			1	1					1		
		Bus			10									1		
		Mini-bus	3	13		13	10	13	10	17	4	10	6	15	11	10
		Automobile	5	6		10	9	5	11	13	7	16	8	10	8	13
		Pick-up	2			2	1	1		1		1	2	4	1	2
		Isuzu	1				5	2	1	2	2		1	1	1	1
		Motor			1			2								
		Truck	1	1												
		Semitrailer														
	S-N1 (Left)	Mid-bus				1										
		Bus														1
		Mini-bus	2	3	8	6	4	3	3	3	3	5				
		Automobile	3	5	5	5	6	7	3	2	6	5	5	4	4	7
		Pick-up		1			1	1			4			7	2	3
		Isuzu				2		2	2		1			3	1	1
		Motor														
		Truck														
		Semitrailer														
	S-N1	Mid-bus						1								
		Bus	1			2	2		1	1						
		Mini-bus	4	3	1	10	8	7	8	6	10	4	11	4	2	2
		Automobile	4	1	1	10	11	14	11	10	12	8	18	14	6	10
		Pick-up		2			1		1	1	2	3				
		Isuzu	2				2	1	1	1	2					2
		Motor	1													
		Truck														
		Semitrailer														
	S-N2	Mid-bus		1	3	1	1	1		2	2					1
Bus		1		1	1	2				4	2	1	3	4	3	
Mini-bus		50	34	32	28	32	24	24	20	26	16	24	33	18	13	
Automobile		19	23	17	32	38	21	26	41	38	30	33	23	22	25	
Pick-up		11	2	6	2	2	7	3	9	6	3	5	6	4	7	
Isuzu		5	3	1	2		2	1	1	1	2	1	3	2	2	
Motor				1	1		1			1					2	
Truck													2	1	1	
Semitrailer																
S-N3	Mid-bus	2	1	2				1				1	1		1	
	Bus	1	4	2		1	1	2	2				1			
	Mini-bus	38	40	36	19	17	15	26	23	29	30	39	34	24	30	
	Automobile	5	10	15	14	14	14	9	18	19	12	18	9	11	14	
	Pick-up	4	2	1	3	3	2	2	6	4	2	4	4	3	4	
	Isuzu	1	1		1	1		1	2		1		1	1	2	
	Motor		1	2			1				1		3	2	2	
	Truck															
	Semitrailer															
S-N3(RT)	Mid-bus	9	10	4	7	4		7	16	9	15	4	7		10	
	Bus	1	6	1	1	2		1	5	2	3	4	2		1	
	Mini-bus	33	22	30	26	23	26	22	16	20	20	22	21		17	
	Automobile	18	13	14	18	19	16	20	33	36	30	34	16		24	
	Pick-up	1	7	3	1	3	1	1	3	4	5	7	6		5	
	Isuzu	6	2	2	1	3	1	3	2	3	1	1	4		5	
	Motor			1					1							
	Truck			1			1	1								
	Semitrailer															

Sebategna morning SN count data

Direction	Lane Code	Vehicle class	Time													
			00:00:00- 00:15:00- 00:30:00- 00:45:00-				01:00:00- 01:15:00- 01:30:00- 01:45:00-				02:00:00- 02:15:00- 02:30:00- 02:45:00-				03:00:00- 03:15:00-	
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00
EW	E-W1 (LT)	Mid-bus	5	5	3	4	3	3	5	4	2	6	5	3	5	3
		Bus	2	2	2	3	1	4	2	1	1	4	2	1	1	4
		Mimi-bus	17	16	14	8	15	14	13	10	19	22	16	16	10	16
		Automobile	1	7	3		2	7	4	6	17	7	12	11	21	16
		Pick-up		1	1	1	1	2	3		1	2		4	2	6
		Isuzu	1		2				2	1	1	1	7	5	4	3
		Motor								1						
		Truck			1					1	1				1	1
		Semitrailer														
	E-W 1	Mid-bus														
		Bus														
		Mimi-bus	2	2	2	4					1				9	
		Automobile			2							1				
		Pick-up	1		1				11							
		Isuzu		1							1			1		
		Motor							1							
		Truck														
		Semitrailer														
	E-W 2	Mid-bus	2	1						1		2	1		1	
		Bus											1		1	
		Mimi-bus	11	6	8	4	8		4	9	5	3	8	6	4	6
		Automobile		1	2	1	2		2	1		1		3	3	1
		Pick-up	1						2	2	1				2	6
		Isuzu	1	1		2			1		2	2	3	5	2	6
		Motor														
		Truck										1		1		
		Semitrailer														
	E-W 3(RT)	Mid-bus	1	3			1		2		1		1		4	1
Bus			3	3	1	4		3		1			1			
Mimi-bus		10	9	6	5	2		6	5	6	6	3	10		7	
Automobile		3	2	1	2	4		3	3	6	7	7	5		6	
Pick-up		1		1				1	2		2		3	1	3	
Isuzu		3	1		1	2		4		2	1	3	4		7	
Motor													1			
Truck																
Semitrailer																
E-W U	Mid-bus	1								1	3	1				
	Bus										1					
	Mimi-bus				1							1				
	Automobile					1										
	Pick-up		1					1								
	Isuzu				1					1		1				
	Motor															
	Truck															
	Semitrailer															

Sebategna morning EW count data

Direction	Lane Code	Vehicle class	Time														
			00:00:00- 00:15:00- 00:30:00- 00:45:00-				01:00:00- 01:15:00- 01:30:00- 01:45:00-				02:00:00- 02:15:00- 02:30:00- 02:45:00-				03:00:00- 03:15:00-		
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00	
WE	W-E 1 (LT)	Mid-bus												1		1	1
		Bus															
		Mini-bus	4	13	3	4	3	11	7	13	7	10	10	7	7	7	6
		Automobile	2	3	7	11	12	3	9	10	9	8	13	11	9	10	
		Pick-up	1		1	1		4	2		3	5	2	4	2	3	
		Isuzu	1	1	1					1	1		1		2	1	
		Motor					1		1				2				
		Truck						1									
	Semitrailer																
	W-E 1	Mid-bus					1										
		Bus															
		Mini-bus	10	12	11	12	6	12	19	10	9	9	27	17	9	15	
		Automobile	2	8	6	7	10	12	9	12	10	19	10	12	13	16	
		Pick-up	3	2	4	2	3	2	10	5	3	5	5	5	7	3	
		Isuzu		1	2	4	1	2		1	2		4	1	1	2	
		Motor								1				1			
		Truck								1							
	Semitrailer																
	W-E 3(RT)	Mid-bus	1														
		Bus		1													
		Mini-bus	3	6	5	13	3	2	2	2	9	5	4	15	4		
		Automobile		5	9	8	11	9	11	7	4	6	13	10	14	11	
		Pick-up	1	3		3	2	5	6	1	1	3	4		5	5	
		Isuzu	4	2	1				1	2	2	1	3		2		
		Motor								1		2	2	1		2	
		Truck			1				1	1					1		
	Semitrailer																
	W-E U	Mid-bus															
Bus																	
Mini-bus					1												
Automobile												1					
Pick-up																	
Isuzu																	
Motor																	
Truck																	
Semitrailer																	

Sebategna morning WE count data

Direction	Lane Code	Vehicle class	Time													
			00:00:00- 00:15:00-		00:30:00- 00:45:00-		01:00:00- 01:15:00-		01:30:00- 01:45:00-		02:00:00- 02:15:00-		02:30:00- 02:45:00-		03:00:00- 03:15:00-	
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00
NS	N-S 1 (U)	Mid-bus	2		1	1	1	2	2	1		2		1		
		Bus														
		Mini-bus	7	11	11	14	13	16	22	14	4	8	17	5	5	4
		Automobile	1	7	2	2		5	2	4	4	5	1	4	2	2
		Pick-up	3	3	3	2	1	2	2	1	1	1			1	
		Isuzu		1					1				1		2	
		Motor				2										
		Truck														
		Semitrailer														
	N-S 1 (Left)	Mid-bus				1	1		1		1				1	
		Bus										1				
		Mini-bus	6	2	6	5	4	8	4	2	2	2	1	1		1
		Automobile	6	7	6	9	9	2	3	5	10	2	5	2	1	
		Pick-up	2	1	4	5	1	2	3	5	1	4	1	1		
		Isuzu	1	3	1	1	1	3	1	1	1		1	2		
		Motor		3		2										
		Truck							1						2	
		Semitrailer														
	N-S 1	Mid-bus	1	1		1		1						1	2	
		Bus	2	1	1			1	2	2	2	2	1	3	1	1
		Mini-bus	10	21	13	11	11	9	9	5	10	7	8	13	13	8
		Automobile	21	15	17	18	20	16	11	15	16	15	17	14	20	13
		Pick-up	7	3	8	3	5	5	1	5	4	6	3	6	4	3
		Isuzu	3	4	4	2	2	3		3	1	2	2	1		
		Motor		3	1	3					1					
		Truck				2	1							1		
		Semitrailer									1				1	
	N-S 2	Mid-bus	2	2	1	4	1	1	1		3	1	1	2	2	1
		Bus	1	2	1	1	1		3	2	1	2	3	5		
		Mini-bus	32	44	38	39	33	33	16	24	26	21	28	25	26	24
		Automobile	43	49	29	33	31	42	33	44	26	25	37	26	29	11
		Pick-up	6	7	7	4	3	9	9	11	1	5	5	3	4	3
		Isuzu	3	4	4	2	2	4	2	1	2		1	1	2	1
		Motor	6	11	8	3	7	5	1	2	2		3		3	
		Truck					1			3			1			
		Semitrailer			1											
N-S 3	Mid-bus		1					1	1		1			1		
	Bus				1					2		2	1			
	Mini-bus	12	13	15	11	10	21	25	32	11	11	15	17	7	13	
	Automobile	13	9	10	7	5	10	15	23	21	20	27	13	16	14	
	Pick-up	2	1	1	6	1	5	3	6	3	1	2	6		1	
	Isuzu	1			2					2						
	Motor	3	1	4	1	1	1	4	7	4	3	1	2	3	2	
	Truck									1						
	Semitrailer															
N-S 3(RT)	Mid-bus		1	2				1								
	Bus															
	Mini-bus	4		6	2	3	2	7	5	4	7	8	8	7	2	
	Automobile	8	8	3	3	4	2	3	10	14	27	19	15	11	7	
	Pick-up		4	2	2	1	1	4	2	3	3	1	5	3	1	
	Isuzu	1	1	2	2	2	2					1				
	Motor	2			2	1			1	1	5	1		3		
	Truck			1						1						
	Semitrailer															

Sebategna afternoon NS count data

Direction	Lane Code	Vehicle class	Time													
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00		
SN	S-N 1 (U)	Mid-bus	1								1					
		Bus														
		Mini-bus	8	3	8	17	13	12	15	15	24	25	26	16	20	22
		Automobile	14	13	9	16	9	16	12	11	11	9	16	14	15	13
		Pick-up	2	3	1	1	1	4	2	2	6	2	5	4	2	3
		Isuzu	1		1	1		1	1	3	1	1		1		
		Motor														
		Truck						1			1					
		Semitrailer								1						
	S-N 1 (Left)	Mid-bus													1	
		Bus											1		1	
		Mini-bus	5	3	1	6	4	7	3		3	2	2	4	2	3
		Automobile	8	8	9	9	10	10	10	13	12	16	18	14	20	13
		Pick-up	1	1	1	1	1	3	3		3	4	4	5	3	
		Isuzu		1	1	1	1	1	2	2			1		1	1
		Motor							1							
		Truck		1		1			1							
		Semitrailer														
	S-N 1	Mid-bus			1			1							2	
		Bus					4		2	1	1	1				
		Mini-bus	7	8	10	3	9	8	1	5	2	3	2	1	3	2
		Automobile	14	14	19	9	12	13	8	10	4	9	5	4	12	
		Pick-up	3	3	3		2	4	2	2		2	1			
		Isuzu	1	2	1		3	1					1	1		
		Motor	1			1	1	2				1				
		Truck														
		Semitrailer														
	S-N 2	Mid-bus	6	1	2	3	4	1	2	2		2		2	3	1
		Bus	2	4	1	3	3	1	1	1	1	4		4	5	3
		Mini-bus	28	27	26	29	36	33	23	25	20	32	21	23	32	16
		Automobile	28	34	34	31	27	31	31	23	25	33	26	21	31	13
		Pick-up	11	9	6	7	5	4	7	7	4	10	9	7	7	2
		Isuzu	3	3	2	3	2	3	2	2	3	1	5	2	2	1
		Motor	2	9	2		3	2		2	1	3	3	1	2	1
		Truck									1	1			1	
		Semitrailer														
	S-N 3	Mid-bus	2		1			1	1			3	2	2		1
		Bus	3				1		2	1		1	1	2	1	1
		Mini-bus	21	15	17	22	23	20	34	25	21	22	35	25	30	11
		Automobile	13	7	12	12	4	8	16	13	13	11	19	9	13	6
		Pick-up	8	3	4	4		5	3	4	4	2	3	1	3	5
		Isuzu	1			4		1	3	1	2	2		1	1	1
Motor		2	5	2	4				1	1	1	2	1	1	1	
Truck																
Semitrailer																
S-N 3(RI)	Mid-bus	5	1	4	4	5	3	6	3	3	2	3	2	2	1	
	Bus	5	2	1	2	3	3	1	2	2		1	2	3	4	
	Mini-bus	30	24	18	22	22	29	35	32	21	30	16	17	16	8	
	Automobile	15	25	23	22	16	13	18	14	16	12	8	4	10	7	
	Pick-up	7	5	8	6	11	6	3	3	5	3	1	3		1	
	Isuzu	3	1	4	3	1	1	2	3		2	4	1	3		
	Motor	2	5	5	2	5	1	2	1		2		1			
	Truck				1						1	1	1	1		
	Semitrailer															

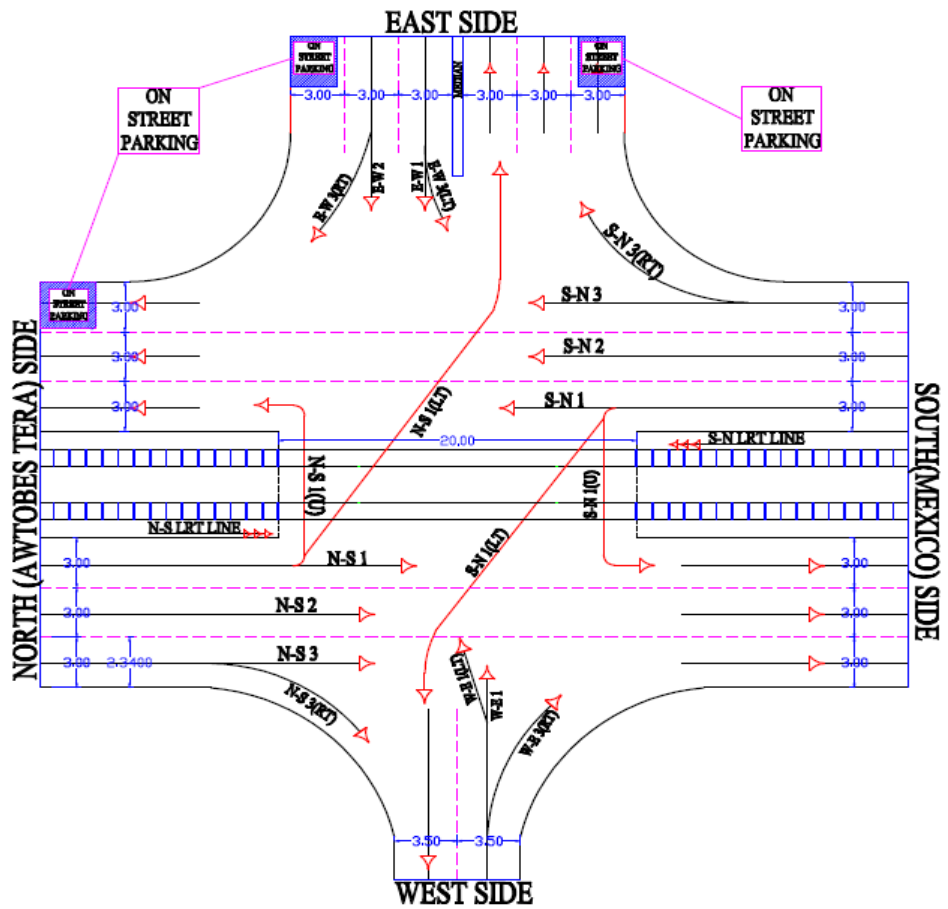
Sebategna afternoon SN count data

Direction	Lane Code	Vehicle class	Time														
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00	
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00	
EW	E-W1 (LT)	Mid-bus	3	1	3	3	1	8	2	2				1	1		
		Bus	2	6	2	4	1		2	2						1	
		Mini-bus	11	12	15	13	7	20	14	12		18	11	13	14	8	10
		Automobile	18	15	25	22	16	18	28	31		34	17	31	31	34	24
		Pick-up	3	1	4	9	3	5	6	5		4	3	6	4	3	2
		Isuzu	7	1	7	1	2	1	1	4		2	1		6	2	2
		Motor			1	2	1			1						1	
		Truck															
		Semitrailer															
	E-W 2	Mid-bus		2	2	2	3	1	6	3		4	3	2	2	2	2
		Bus			9	12							32				2
		Mini-bus	9	7	6	6	9	14	23	22		34	18	22	18	27	18
		Automobile	3	5	1	2	9	5	13	32		19	3	32	44	23	35
		Pick-up	2	3		3	3		7	7		5	3	7	6	5	5
		Isuzu	5	3			3	6	2	3		6		2	3	1	3
		Motor	1	1								1				1	
		Truck			1												1
		Semitrailer															
	E-W 3(RT)	Mid-bus		2	1		2	2	3	2							
		Bus		2		2	1		2			1		3	1		
Mini-bus		8	6	3	4	4	6	3	5		12	8	5	7	6	4	
Automobile		9	5	3	3	7	11	6	11		14	6	11	17	10	7	
Pick-up		2	1	3	4	2		7	7			2			1		
Isuzu		4	1	3	3	4	1	3	2		1	1	2	1			
Motor			1								2	1					
Truck								1	1	1	1						
Semitrailer																	
E-W U	Mid-bus																
	Bus																
	Mini-bus								1								
	Automobile		2		2			1									
	Pick-up					1	1										
	Isuzu									1							
	Motor																
	Truck																
	Semitrailer																

Sebategna afternoon EW count data

Direction	Lane Code	Vehicle class	Time													
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	03:00:00-03:15:00	03:15:00-03:30:00
			00:15:00	00:30:00	00:45:00	01:00:00	01:15:00	01:30:00	01:45:00	02:00:00	02:15:00	02:30:00	02:45:00	03:00:00	03:15:00	03:30:00
WE	W-E 1 (LT)	Mid-bus						1			2	1				
		Bus														
		Mini-bus	4	2	3	1	2	1	1	3	3	3	2	1	1	2
		Automobile	8	8	6	5	6	7	4	2	5	2	7	2	4	
		Pick-up truck			1		1			1	1	1	1		1	
		Isuzu			2	1		1	1	3	1				2	
		Motor		1	1											
		Truck					1									
		Semitrailer														
	W-E 1	Mid-bus			1		1				1		1			
		Bus														
		Mini-bus	6	4	5	5	8	5	13	9	5	2	2	4	2	
		Automobile	4	7	4	5	4	4	5	5	9	3	4	1	6	2
		Pick-up truck	2	1	4	3	2	4			1	2	1	3		
		Isuzu	2		3	2			1	1	3	1	2		1	
		Motor	2		1			1		1		1			1	
		Truck														
		Semitrailer														
	W-E 3(RT)	Mid-bus				1				1						
		Bus								8						
Mini-bus		7	10	4	8	6	5	8	14	6	10	11	9	11	7	
Automobile		18	16	8	11	9	12	10		8	10	8	10	20	9	
Pick-up truck		2	3	4	3	3	2			1	2	2	1	2		
Isuzu		2	1	3	1	2		1		1		3				
Motor		4	2	2	4					1		1				
Truck										1				1		
Semitrailer																
W-E U	Mid-bus															
	Bus															
	Mini-bus		1				1		1	1	1	3	1	1		
	Automobile			2		2	1	1	1	1	1	2	5	2	1	
	Pick-up truck															
	Isuzu						1									
	Motor															
	Truck															
	Semitrailer															

Sebategna afternoon WE count data



Sebategna level crossing layout and on-street parking locations

Approach direction	Approach Contribution to peak hour flow	Roting decision	Percentage of the routing decision
North approach	35%	U-turn	13.23%
		Left turn	11.83%
		Through	70.19%
		Right turn	4.76%
South approach	40%	U-turn	9.14%
		Left turn	4.41%
		Through	58.11%
		Right turn	28.34%
East approach	12%	U-turn	3.05%
		Left turn	56.61%
		Through	16.61%
		Right turn	23.73%
West approach	13%	U-turn	0%
		Left turn	29%
		Through	44%
		Right turn	27%

Sebategna level crossing peak hour routing decisions

Sebategna LRV data									
Morning					Afternoon				
Video No.	Arriving times	Direction	Interval	Waiting time of vehicles LRV pass	Video No.	Arriving times	Direction	Interval	Waiting time of vehicles LRV pass
1st video	0:00:23	NS		22.57	2nd video	0:02:03	SN		21.83
	0:09:14	SN	0:08:51	14.62		0:07:27	NS	0:05:24	52.63
	0:13:09	NS	0:03:55	39.3		0:14:59	SN	0:07:32	16.57
2nd video	0:07:18	SN	0:09:27	13.79		0:19:12	NS	0:04:13	26.52
	0:11:12	NS	0:03:54	43.95		0:25:11	SN	0:05:59	20.28
	0:20:59	SN	0:09:47	23.23		0:31:17	NS	0:06:06	20.95
	0:21:25	NS	0:00:26	20.77		0:37:56	SN	0:06:39	36.25
	0:32:09	SN	0:10:44	22.57		0:43:19	NS	0:05:23	20.31
	0:34:30	NS	0:02:21	33.36		0:49:26	SN	0:06:07	18.78
	0:43:30	SN	0:09:00	15.69		0:54:59	NS	0:05:33	33.23
	0:45:03	NS	0:01:33	21.75		1:06:43	SN	0:11:44	23.15
	0:57:25	NS	0:12:22	24.48		1:08:02	NS	0:01:19	40.28
	1:02:18	SN	0:04:53	17.6		1:16:40	SN	0:08:38	25.94
	1:09:19	NS	0:07:01	28.73		1:23:55	NS	0:07:15	38.28
	1:18:59	SN	0:09:40	55.32		1:31:26	SN	0:07:31	29.54
	1:23:45	SN&NS	0:04:46	56.42	1:44:10	NS	0:12:44	68.03	
	1:33:59	SN	0:10:14	29.41	1:47:32	SN	0:03:22	54.57	
	1:39:28	NS	0:05:29	38.24	2:04:52	SN & NS	0:17:20	57.09	
1:43:07	SN	0:03:39	34.07	2:22:06	NS	0:17:14	34.57		
3rd video	0:06:23	SN & NS	0:11:52	35.29	2:26:31	SN	0:04:25	23.72	
	0:16:55	SN	0:10:32	29.58	2:30:15	NS	0:03:44	44.51	
	0:18:46	NS	0:01:51	32.79	2:42:22	NS	0:12:07	58.07	
	0:30:30	NS	0:11:44	34.57	2:44:40	SN	0:02:18	28.49	
	0:32:20	SN	0:01:50	22.17	3rd video	0:00:36	SN	0:07:24	25.23
	0:38:21	SN	0:06:01	24.03		0:01:42	NS	0:01:06	42.5
	0:42:13	NS	0:03:52	41.07	4th video	0:10:51	NS	0:20:00	81.93
	0:50:59	SN	0:08:46	17.45					
	0:53:59	NS	0:03:00	22.04					
	1:01:45	SN	0:07:46	27.4					
	1:08:38	NS	0:06:53	90.39					
	1:15:10	SN	0:06:32	41.16					
1:18:14	NS	0:03:04	26.04						
<i>Average</i>			<i>0:06:30</i>	<i>31.25</i>	<i>Average</i>			<i>0:07:39</i>	<i>36.28</i>

Sebategna LRV data

CMC roundabout Level Crossing

Direction	Lane Code	Vehicle class	Time														
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00	Total	01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00	Total	02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	Total
Morning	W _{total}	Bus	5	10	4	3	22	4	4	1	3	12	4	2	3	1	10
		Mid-bus	8	5	10	5	28	2	5	3	5	15	3	1	4	2	10
		Mini-bus	55	76	49	49	229	52	46	38	44	180	43	60	50	63	216
		Automobile	212	110	150	133	605	139	137	159	146	581	150	154	164	164	632
		Pick-up	21	14	24	26	85	30	40	25	26	121	42	40	42	32	156
		Isuzu	5	5	4	8	22	7	14	6	8	35	8	11	13	10	42
		Bajaj	2	2	7	5	16	4	2	4	8	18	5	1	8	1	15
		Motor			1	1	2			3		3	2		3	5	10
		Truck		2	1		3	2	2	1	1	6	3	4	5	3	15
		Semitrailer			1		1					-					-
	Total	307	224	251	230	1,012	240	250	240	241	971	260	273	292	281	1,106	
	E _{total}	Bus	3	1	5	4	13	4	4	4	3	15	3	3	2	5	13
		Mid-bus	5	6	7	8	26	8	8	10	9	35	4	12	7	6	29
		Mini-bus	55	98	77	51	281	59	67	58	52	236	54	44	63	58	219
		Automobile	258	471	236	278	1,243	306	347	251	220	1,124	215	208	202	190	815
		Pick-up truck	65	80	46	41	232	36	40	48	28	152	37	27	28	30	122
		Isuzu	7	5	2	7	21	3	6	4	10	23	13	4	10	10	37
		Bajaj	11	20	17	10	58	25	22	18	12	77	12	18	28	11	69
		Motor	-	4			4					-		1	1		2
		Truck	-	4	1		5		3	5	5	13	7	9	3	12	31
		Semitrailer	-	-			-			1		1	2				2
	Total	405	689	391	399	1,884	441	497	399	339	1,676	347	326	344	322	1,339	
	S _{total}	Bus	5	7	1	2	15	1	-	1	1	3	1	3	1	-	5
		Mid-bus	3	2	3	2	10	2	-	1		3				-	-
		Mini-bus	51	28	30	42	151	36	43	30	21	130	21	29	31	27	108
		Automobile	306	390	172	209	1,077	168	159	183	130	640	129	134	132	140	535
		Pick-up truck	73	28	31	26	158	30	26	24	26	106	16	19	18	19	72
		Isuzu	4	3	1	3	11	1		2	4	7	3	5	6	7	21
		Bajaj	4	13	9	11	37	15	14	14	12	55	16	14	14	18	62
		Motor					-			4		4	1	1	2		4
		Truck	3	1	6	1	11		4	2	8	14	1	2	3	6	12
		Semitrailer	1				1				1	1			1		1
	Total	448	472	253	296	1,480	253	246	261	203	963	188	207	208	217	820	
N _{total}	Bus	2	2	-	-	4	-	-	-	-	-	-	1	-	-	1	
	Mid-bus	8	2	3	-	13	-	2	1	-	3	-	2	-	-	2	
	Mini-bus	23	63	27	27	140	15	15	12	6	48	10	5	4	6	25	
	Automobile	116	112	116	175	519	169	126	101	89	485	58	71	58	46	233	
	Pick-up truck	24	18	26	45	113	29	19	28	23	99	20	13	13	19	65	
	Isuzu	3	3	6	4	16	4	10	8	4	26	7	2	4	6	19	
	Bajaj	12	7	13	8	40	10	16	7	12	45	11	14	10	12	47	
	Motor				3	3	2	1		1	4	7	2	1	5	15	
	Truck	3	1	1	1	6	2	1	4	5	12	1	3	3	3	10	
	Semitrailer					-		-	1		1					-	
Total	191	208	192	263	854	231	190	162	140	723	114	113	93	97	417		

5475

4,333

3,682

CMC vehicle count data

Direction	Lane Code	Vehicle class	Time														
			00:00-00:15:00-00:15:00-00:30:00-00:45:00-01:00:00				Total	01:00:00-01:15:00-01:30:00-01:45:00-02:00:00				Total	02:00:00-02:15:00-02:30:00-02:45:00-03:00:00				Total
			00:00-00:15:00	00:15:00-00:30:00	00:30:00-00:45:00	00:45:00-01:00:00		01:00:00-01:15:00	01:15:00-01:30:00	01:30:00-01:45:00	01:45:00-02:00:00		02:00:00-02:15:00	02:15:00-02:30:00	02:30:00-02:45:00	02:45:00-03:00:00	
Afternoon	W _{total}	Bus	3	6	7	6	22	5	4	5	5	19	4	6	7	6	23
		Mid-bus	3	7	5	4	19	2	5	6	3	16	4	5	8	5	22
		Mini-bus	84	84	72	72	312	73	91	53	66	283	59	51	75	75	260
		Automobile	384	694	581	263	1,922	321	298	337	267	1,223	324	343	378	431	1,476
		Pick-up	45	57	57	35	194	58	41	51	47	197	62	43	59	54	218
		Isuzu	9	14	7	7	37	17	8	12	5	42	8	8	2	5	23
		Bajaj	4	6	4	6	20	1	5	5	3	14	3	2	2	3	10
		Motor	7	6	4	14	31	4	9	14	4	31	6	7	6		19
		Truck	6	2	2		10	1	1		3	5	2	1		2	5
		Semitrailer			2	1	3				1	1				1	1
	Total	545	876	741	408	2,570	482	462	483	404	1,831	472	466	537	582	2,057	
	E _{total}	Bus	2	2	2	3	9	7	5	2	6	20	5	4	5	6	20
		Mid-bus	2	4	1	9	16	8	13	4	3	28	9	7	2	3	21
		Mini-bus	44	79	51	49	223	66	87	84	56	293	57	60	49	49	215
		Automobile	247	152	196	221	816	176	175	121	146	618	140	147	125	120	532
		Pick-up	7	15	22	23	67	21	32	10	17	80	14	6	15	9	44
		Isuzu	6	13	7	13	39	9	11	6	9	35	5	5	2	6	18
		Bajaj	14	19	14	15	62	11	6	15	14	46	10	10	15	9	44
		Motor	1	3	1	1	6	1	1	3	1	6	2	3	4	2	11
		Truck	1	2	3	3	9	1	1	1	2	5	1	1	2	3	7
		Semitrailer	1	1		1	3					-					-
	Total	325	290	297	338	1,250	300	331	246	254	1,131	243	243	219	207	912	
	S _{total}	Bus	1	2	1	2	6	7	19	3	7	36	5	2	1	3	11
		Mid-bus	1		1	4	6	2	9	2	4	17	4	7	1	-	12
		Mini-bus	41	36	35	33	145	37	39	39	40	155	20	23	33	35	111
		Automobile	114	117	110	110	451	121	124	104	120	469	141	82	90	148	461
		Pick-up	19	22	20	28	89	30	23	28	31	112	15	17	17	12	61
		Isuzu	10	4	10	4	28	5	5	5	4	19	3	5	7	8	23
		Bajaj	22	9	7	13	51	8	13	18	15	54	10	8	16	8	42
		Motor			2		2	4	2	1	4	11	2	1		3	6
		Truck	4	3	3	4	14	5	4	4	4	17	2	3	2	1	8
		Semitrailer			1		1					-			1		1
	Total	212	193	190	198	793	219	238	204	229	890	202	149	167	218	736	
	N _{total}	Bus	-	1	-	1	2	-	1	2	1	4	2	-	-	-	2
		Mid-bus	-	4	2	1	7	-	2	-	1	3	-	-	-	-	-
		Mini-bus	34	14	11	9	68	6	16	13	20	55	20	11	9	20	60
Automobile		113	87	63	61	324	65	68	90	64	287	88	43	83	61	275	
Pick-up		20	21	13	17	71	22	15	34	17	88	13	10	15	19	57	
Isuzu		5	4	4	3	16	7	3	3	1	14	5	2	2	4	13	
Bajaj		12	9	9	5	35	7	15	10	6	38	5	7	6	5	23	
Motor		2	4		3	9			2	2	4	1	1			2	
Truck		1	2	3		6	2	3	3	1	9	3				3	
Semitrailer		1				1					-					-	
Total	188	146	105	100	539	109	123	157	113	502	137	74	115	109	435		

5.391

5326

5246

Afternoon total outlets from each legs count data

Composition on peak hour			
CMC		Sebategna	
Vehicle type	Composition(%)	Vehicle type	Composition(%)
Bus	1%	Mid-bus	4%
Mid-bus	1%	Bus	3%
Mini-bus	15%	Mini-bus	40%
Automobile	66%	Automobile	38%
Pick-up truck	11%	Pick-up truck	9%
Isuzu	1%	Isuzu	5%
Bajaj	3%	Motor	1%
Total	99%	Total	100%

Peak hour composition table

CMC											
Moming					Afternoon						
Video No.	Arriving times	Direction	Interval	Waiting time of vehicles LRV pass	Video No.	Arriving times	Direction	Interval	Waiting time of vehicles LRV pass		
2nd video	0:04:04	WE		13.31	1st video				24.13		
				43.04						19.77	
				52.44						14.98	
	0:09:16	EW	0:05:12	34.93			0:20:21	EW		20.17	
				13.01			0:23:15	WE	0:02:54		22.03
	0:15:20	WE	0:06:04	41.24			0:24:20	EW	0:01:05		18.2
				49.45			0:28:49	WE	0:04:29		20.27
	0:20:55	EW	0:05:35	18.95			0:33:27	WE	0:04:38		22.37
				36.24							12.84
	0:33:29	EW	0:12:34	25.54							27.51
				28.53			0:37:14	EW	0:03:47		17.04
	0:34:00	WE	0:00:31								14.11
				18.28							23.2
	0:47:57	WE	0:13:57	38.28			0:43:30	EW	0:06:16		22.78
				19.41							18.46
	0:48:53	EW	0:00:56	12.83			0:51:17	WE	0:07:47		23.59
				11.55							25.39
	0:50:45	WE	0:01:52	17.44			0:54:11	EW	0:02:54		30.41
				19.97							29.87
	1:01:42	EW	0:10:57	29.1			1:06:53	EW	0:12:42		25.61
				17.81							25.86
	1:05:12	WE	0:03:30	29.16			1:51:27	WE	0:44:34		41.98
				23.97							19.81
	1:07:56	EW	0:02:44	16.87			1:54:20	WE	0:02:53		12.39
				24.19							15.29
	1:15:35	WE	0:07:39	33.37			1:58:13	WE	0:03:53		20.84
				23.99							20.41
	1:21:15	EW	0:05:40	17.91			2:08:56	EW	0:10:43		21.85
				18.54							20.07
	1:24:29	WE	0:03:14	32.67			2:14:02	EW	0:05:06		18.91
				24.31							17.43
	1:32:42	EW	0:08:13	16.31			2:17:57	EW	0:03:55		23.87
			29.34						15.4		
1:44:27	EW	0:11:45	18.68		2:18:48	WE	0:00:51		26.82		
			13.94						15.88		
2:00:09	WE	0:15:42	19.22		2:21:52	WE	0:03:04		16.63		
			13.4						17.45		
2:05:36	WE	0:05:27	29.93		2:36:48	EW	0:14:56		15.92		
			14.06						15.61		
2:08:19	WE	0:02:43	34.05		2:42:44	WE	0:05:56		14.99		
			31.64						21.85		
2:11:41	EW	0:03:22	18.73		2:50:35	EW	0:07:51		33.77		
			29.29	2nd video					19.89		
2:21:27	EW	0:09:46	28.95		0:07:31	WE			27.56		
			21.77								
2:25:40	EW	0:04:13	28.49								
			18.87								
2:29:07	WE	0:03:27	31.9								
			17.94								
2:31:37	WE	0:02:30	24.17								
			14.12								
2:35:24	WE	0:03:47	26.89								
			20.97								
2:40:50	EW	0:05:26	9.92								
			33.79								
2:45:02	EW	0:04:12	23.31								
			7.77								
3rd video	0:04:15	WE		46.96							
	0:04:52	EW	0:00:37	18.04							
			18.74								
0:08:20	WE	0:03:28	23.66								

CMC LRV data

Appendix II- Speed and travel time field data collected.

CMC												
Mini/SUV				Automobile				Pickup/Isuzu				
S.No.	Time	Base length (m)	Speed (km/hr)	S.No.	Time	Base length (m)	Speed (km/hr)	S.No.	Time	Base length (m)	Speed (km/hr)	
1	3.34	27	29.11	1	3.19	27	30.42	1	4.62	27	21.06	
2	3.45	27	28.14	2	3.67	27	26.48	2	4.73	27	20.54	
3	3.57	27	27.26	3	4.61	27	21.08	3	4.04	27	24.04	
4	3.67	27	26.48	4	4.19	27	23.21	4	4.23	27	22.98	
5	3.77	27	25.77	5	5.04	27	19.27	5	4.03	27	24.11	
6	3.87	27	25.14	6	4.32	27	22.50	6	4.52	27	21.52	
7	3.96	27	24.56	7	4.00	27	24.27	7	4.60	27	21.13	
8	4.04	27	24.05	8	2.93	27	33.17	8	4.42	27	21.97	
9	4.12	27	23.58	9	3.34	27	29.08	9	3.87	27	25.10	
10	4.20	27	23.16	10	3.21	27	30.28	10	4.58	27	21.20	
11	4.27	27	22.78	11	3.08	27	31.58	11	4.52	27	21.49	
12	4.33	27	22.44	12	3.45	27	28.14	12	3.19	27	30.50	
13	4.39	27	22.13	13	2.68	27	36.26	13	3.64	27	26.69	
14	4.45	27	21.86	14	5.72	27	16.99	14	3.79	27	25.67	
15	4.50	27	21.62	15	4.50	27	21.62	15	3.99	27	24.38	
16	4.50	27	21.59	16	4.50	27	21.59	16	4.23	27	23.00	
17	4.70	27	20.70	17	4.70	27	20.70	17	4.43	27	21.96	
18	4.83	27	20.13	18	4.83	27	20.13	18	4.48	27	21.69	
19	4.96	27	19.59	19	4.96	27	19.59	19	4.04	27	24.08	
20	5.09	27	19.08	20	2.55	27	38.14	20	4.97	27	19.57	
21	5.23	27	18.60	21	2.81	27	34.55	21	6.13	27	15.85	
22	5.36	27	18.14	22	3.57	27	27.26	22	5.60	27	17.34	
23	3.57	27	27.26	23	4.39	27	22.13	23	4.85	27	20.04	
24	5.62	27	17.29	24	4.27	27	22.78	24	5.77	27	16.84	
25	5.75	27	16.89	25	4.20	27	23.16	25	5.89	27	16.49	
26	5.89	27	16.51	26	3.57	27	27.26	26	5.99	27	16.22	
27	3.57	27	27.26	27	4.88	27	19.92	27	4.10	27	23.73	
28	6.15	27	15.80	28	3.74	27	25.99	28	6.15	27	15.80	
29	6.28	27	15.47	29	3.57	27	27.26	29	6.28	27	15.47	
30	3.57	27	27.26	30	4.12	27	23.58	30	4.72	27	20.57	
31	6.55	27	14.84	31	3.57	27	27.26	31	5.24	27	18.53	
32	3.57	27	27.26	32	3.77	27	25.77	32	4.84	27	20.09	
33	6.73	27	14.44	33	3.96	27	24.56	33	6.84	27	14.20	
34	6.86	27	14.16	34	4.45	27	21.83	34	2.98	27	32.60	
35	7.00	27	13.89	35	4.33	27	22.44	35	5.71	27	17.03	
36	5.09	27	19.08	36	3.83	27	25.40	36	4.98	27	19.52	
37	5.23	27	18.60	37	3.67	27	26.48	37	4.87	27	19.96	
38	3.34	27	29.11	38	3.45	27	28.14	38	3.78	27	25.70	
39	3.45	27	28.14	39	3.57	27	27.26	39	3.60	27	27.03	
40	3.57	27	27.26	40	4.04	27	24.05	40	3.72	27	26.13	
41	3.67	27	26.48	41	3.87	27	25.14	41	3.80	27	25.61	
42	3.77	27	25.77	42	3.61	27	26.91	42	4.43	27	21.96	
43	3.87	27	25.14	43	2.77	27	35.09	43	4.01	27	24.26	
44	3.96	27	24.56	44	3.49	27	27.86	44	3.65	27	26.65	
45	4.04	27	24.05	45	3.34	27	29.11	45	4.54	27	21.41	
46	4.12	27	23.58	46	3.57	27	27.26	46	4.23	27	23.00	
47	4.20	27	23.16	47	3.73	27	26.05	47	4.44	27	21.90	
1406.8			945	134.335			918	166.035			945	1026.61
Parameters to be determined are:				Parameters to be determined are:				Parameters to be determined are:				
1. Time mean speed, U_t (km/h) 22.32				1. Time mean speed, U_t (km/h) 25.94				1. Time mean speed, U_t (km/h) 21.84				
2. Standard deviation(km/hr) 4.47				2. Standard deviation(km/hr) 4.66				2. Standard deviation(km/hr) 3.92				

CMC roundabout level crossing field data collected speed for validation

Mini/SUV				Sebategna Automobile				Pickup/Isuzu			
S.No.	Time	Base length (m)	Speed (km/hr)	S.No.	Time	Base length (m)	Speed (km/hr)	S.No.	Time	Base length (m)	Speed (km/hr)
1	5.05	27	19.25	1	5.98	27	16.25	1	6.51	27	14.92
2	5.37	27	18.11	2	7.17	27	13.56	2	5.34	27	18.21
3	5.67	27	17.14	3	7.09	27	13.72	3	6.97	27	13.94
4	5.80	27	16.75	4	5.77	27	16.84	4	5.67	27	17.14
5	6.03	27	16.12	5	6.47	27	15.02	5	5.15	27	18.86
6	6.29	27	15.46	6	6.62	27	14.68	6	4.88	27	19.92
7	6.51	27	14.92	7	4.87	27	19.97	7	5.57	27	17.44
8	6.78	27	14.33	8	5.09	27	19.08	8	6.78	27	14.33
9	6.97	27	13.94	9	6.01	27	16.17	9	5.80	27	16.75
10	4.88	27	19.92	10	5.31	27	18.30	10	6.52	27	14.91
11	5.18	27	18.76	11	6.02	27	16.16	11	7.25	27	13.41
12	5.34	27	18.21	12	6.30	27	15.43	12	7.17	27	13.56
13	5.62	27	17.30	13	6.95	27	13.98	13	6.34	27	15.33
14	7.80	27	12.46	14	5.21	27	18.67	14	7.80	27	12.46
15	7.25	27	13.41	15	5.61	27	17.32	15	5.18	27	18.76
16	6.34	27	15.33	16	7.48	27	12.99	16	6.03	27	16.12
17	6.52	27	14.91	17	5.67	27	17.14	17	6.29	27	15.46
18	6.82	27	14.25	18	6.12	27	15.88	18	6.82	27	14.25
19	7.17	27	13.56	19	7.25	27	13.40	19	5.62	27	17.30
20	4.88	27	19.91	20	6.53	27	14.89	20	6.13	27	15.86
21	5.07	27	19.16	21	5.56	27	17.47	21	5.07	27	19.16
22	5.34	27	18.21	22	7.08	27	13.72	22	5.02	27	19.34
23	5.55	27	17.53	23	5.56	27	17.47	23	5.78	27	16.82
24	5.91	27	16.46	24	6.74	27	14.42	24	4.81	27	20.23
25	6.13	27	15.86	25	5.21	27	18.67	25	4.88	27	19.91
26	5.60	27	17.35	26	7.13	27	13.62	26	5.31	27	18.29
27	5.02	27	19.34	27	5.65	27	17.19	27	5.17	27	18.80
28	5.78	27	16.82	28	5.12	27	19.00	28	4.36	27	22.30
29	6.51	27	14.93	29	5.34	27	18.20	29	5.55	27	17.53
30	4.81	27	20.23	30	4.61	27	21.10	30	5.60	27	17.35
31	5.20	27	18.69	31	6.46	27	15.05	31	4.47	27	21.73
32	5.31	27	18.29	32	6.26	27	15.54	32	5.34	27	18.21
33	5.66	27	17.17	33	6.24	27	15.58	33	4.85	27	20.06
34	5.89	27	16.50	34	7.04	27	13.80	34	5.89	27	16.50
35	6.03	27	16.13	35	4.98	27	19.52	35	4.72	27	20.59
36	4.89	27	19.87	36	6.94	27	14.01	36	4.89	27	19.87
37	5.17	27	18.80	37	6.44	27	15.10	37	6.91	27	14.07
38	5.35	27	18.18	38	7.06	27	13.77	38	5.66	27	17.17
39	7.94	27	12.25	39	4.62	27	21.03	39	5.35	27	18.18
40	5.82	27	16.70	40	5.36	27	18.14	40	4.74	27	20.52
41	5.98	27	16.25	41	4.86	27	20.00	41	7.22	27	13.46
42	6.40	27	15.18	42	4.81	27	20.20	42	6.51	27	14.92
43	6.51	27	14.92	43	5.76	27	16.87	43	6.03	27	16.13
44	6.91	27	14.07	44	5.10	27	19.07	44	5.92	27	16.41
45	7.03	27	13.82	45	4.59	27	21.17	45	5.82	27	16.70
46	4.85	27	20.06	46	6.29	27	15.44	46	7.03	27	13.82
47	5.21	27	18.64	47	5.72	27	16.99	47	5.98	27	16.25
	206.07	945	785.48		0	945	781.61		0	945	803.27
Parameters to be determined are: 1. Time mean speed, U_t (km/h) 16.71 2. Standard deviation(km/hr) 2.17				Parameters to be determined are: 1. Time mean speed, U_t (km/hr) 16.63 2. Standard deviation(km/hr) 2.35				Parameters to be determined are: 1. Time mean speed, U_t (km/hr) 17.09 2. Standard deviation(km/hr) 2.42			

Sebategna level crossing field data collected speed for validation

Appendix III- Images of Addis Ababa light rail transit level crossings



Ayat grade intersection
No significant traffic at peak hours



Mikael level crossing
Currently closed for vehicle, only open for pedestrians.



Sealitemihret level crossing
Building for video recording not available at the vicinity of the intersection and the elliptical shape of the roundabout make it very difficult for recording.



CMC roundabout level crossing
Study location of this project



Century-mall level crossing
No significant traffic at peak hours



Cobblestone road
Less attractive for vehicles



Meshualekiya level crossing
This intersection has no any approach road that conflicts with the LRT line. Only vehicles that use the roundabout for changing directions. Most vehicles doesn't use the roundabout for changing directions at peak hours.



Adey abeba grade crossing
Building for video recording not available at the vicinity of the intersection



Kality LRT terminal entrance level crossing
No significant traffic at peak hours



Sebategna grade crossing
Study location of this research paper.

Appendix IV- HCM roundabout evaluation criteria

ROUNDBABOUTS - UNSIGNALIZED INTERSECTIONS WORKSHEET					
General Information			Site Information		
Analyst : Daric Tesfaye			Intersection _____		
Agency or Company _____			Jurisdiction _____		
Date Performed _____			Analysis Year _____		
Analysis Time Period _____					
Volume Adjustments					
		EB	WB	NB	SB
LT Traffic	Movement	v1	v4	v7	v10
	Volume, veh/h	136	59	39	359
	PHF	1	1	1	1
	Flow rate, veh/h	136	59	39	359
TH Traffic	Movement	v2	v5	v8	v11
	Volume, veh/h	582	123	38	25
	PHF	1	1	1	1
	Flow rate, veh/h	582	123	38	25
RT Traffic	Movement	v3	v6	v9	v12
	Volume, veh/h	38	42	131	88
	PHF	1	1	1	1
	Flow rate, veh/h	38	42	131	88
Approach Flow Computation					
Approach Flow (veh/h)			va (veh/h)		
va,E = v1 + v2 + v3			756		
va,W = v4 + v5 + v6			224		
va,N = v7 + v8 + v9			208		
va,S = v10 + v11 + v12			472		
Circulating Flow Computation					
Approach Flow (veh/h)			vc (veh/h)		
vc,E = v4 + v10 + v11			443		
vc,W = v1 + v7 + v8			213		
vc,N = v1 + v2 + v10			1077		
vc,S = v4 + v5 + v7			221		
Capacity Computation					
		EB	WB	NB	SB
Capacity	Upperbound	976.88	1172.07	584.31	1164.71
	Lowerbound	793.07	968.19	450.00	961.54
v/c Ratio	Upperbound	0.77	0.19	0.36	0.41
	Lowerbound	0.95	0.23	0.46	0.49

Appendix V- SPSS input and output data

S.No.	Y1	X1	X2	X3	X4	X5	X6	X7
	Travel time	Running time	Stop-open door	Open door-Close door	Close door start movement	Grade intersection	Size of train Short-1 Long-0	Direction SN-1 NS-0
1	2,937,050,000	2,237,760,000	92,880,000	433,200,000	173,210,000	-	1	1
2	2,911,070,000	2,268,300,000	103,210,000	372,160,000	167,400,000	-	1	1
3	2,925,240,000	2,227,730,000	119,660,000	435,120,000	142,730,000	-	1	1
4	3,116,000,000	2,209,620,000	124,720,000	434,080,000	161,960,000	185,620,000	1	1
5	3,040,450,000	2,268,300,000	100,610,000	497,450,000	174,090,000	-	1	1
6	3,017,610,000	2,187,270,000	95,220,000	436,410,000	175,130,000	123,580,000	1	1
7	3,218,480,000	2,486,850,000	91,610,000	495,370,000	144,650,000	-	1	1
8	3,064,160,000	2,237,760,000	87,770,000	409,010,000	159,880,000	169,740,000	1	1
9	3,028,040,000	2,227,730,000	102,270,000	535,120,000	162,920,000	-	0	1
10	2,946,540,000	2,217,240,000	109,610,000	474,080,000	145,610,000	-	0	1
11	2,854,490,000	2,187,270,000	107,270,000	387,440,000	172,510,000	-	0	1
12	3,524,580,000	2,486,850,000	115,200,000	536,000,000	166,360,000	220,170,000	0	1
13	2,922,600,000	2,209,620,000	140,570,000	407,090,000	165,320,000	-	0	1
14	3,328,390,000	2,486,850,000	116,290,000	408,050,000	164,280,000	152,920,000	0	1
15	3,022,170,000	2,331,760,000	109,230,000	409,010,000	172,170,000	-	0	1
16	2,916,520,000	2,217,240,000	145,620,000	409,970,000	143,690,000	-	0	1
17	2,881,140,000	2,187,270,000	100,170,000	420,230,000	173,470,000	-	0	1
18	2,992,110,000	2,316,850,000	95,230,000	421,190,000	158,840,000	-	0	1
19	3,216,070,000	2,237,760,000	100,170,000	418,150,000	172,590,000	287,400,000	0	1
20	3,174,960,000	2,486,850,000	99,450,000	417,110,000	171,550,000	-	0	1
21	2,938,380,000	2,316,850,000	100,260,000	381,460,000	139,810,000	-	1	0
22	3,259,930,000	2,453,060,000	106,570,000	500,420,000	199,880,000	-	1	0
23	3,119,340,000	2,271,150,000	103,450,000	383,380,000	207,630,000	153,730,000	1	0
24	2,927,440,000	2,217,240,000	110,590,000	422,260,000	177,350,000	-	1	0
25	3,183,900,000	2,453,060,000	107,920,000	422,080,000	200,840,000	-	1	0
26	3,119,060,000	2,227,730,000	102,660,000	408,050,000	174,230,000	206,390,000	1	0
27	2,965,000,000	2,271,150,000	97,880,000	420,000,000	175,970,000	-	1	0
28	2,859,560,000	2,209,620,000	92,210,000	418,960,000	138,770,000	-	1	0
29	2,995,010,000	2,271,150,000	96,600,000	485,530,000	141,730,000	-	0	0
30	2,779,820,000	2,187,270,000	101,630,000	364,490,000	126,430,000	-	0	0
31	3,132,820,000	2,217,240,000	106,600,000	485,450,000	176,050,000	147,480,000	0	0
32	2,973,750,000	2,209,620,000	102,710,000	486,410,000	175,010,000	-	0	0
33	2,872,520,000	2,217,240,000	111,660,000	367,310,000	176,310,000	-	0	0
34	3,051,360,000	2,237,760,000	113,770,000	368,270,000	175,270,000	156,290,000	0	0
35	3,218,110,000	2,486,850,000	104,230,000	429,230,000	197,800,000	-	0	0
36	2,966,830,000	2,187,270,000	92,610,000	490,190,000	196,760,000	-	0	0
37	3,135,470,000	2,486,850,000	111,360,000	360,330,000	176,930,000	-	0	0
38	3,000,650,000	2,268,300,000	102,470,000	421,290,000	208,590,000	-	0	0
39	3,162,950,000	2,316,850,000	100,410,000	418,250,000	209,550,000	117,890,000	0	0
40	3,027,840,000	2,237,760,000	102,360,000	477,210,000	210,510,000	-	0	0

SPSS time series train input data for analysis (μsec)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	589158828.553	350856356.414		1.679	.101
	X1	1.073	.153	.751	7.001	.000
2	(Constant)	524424743.127	182527506.391		2.873	.007
	X1	1.080	.080	.755	13.552	.000
	X5	1.020	.100	.567	10.177	.000
3	(Constant)	206749284.462	86869363.312		2.380	.023
	X1	1.034	.036	.723	28.453	.000
	X5	1.031	.045	.574	22.694	.000
	X3	.980	.082	.305	12.003	.000
4	(Constant)	129896239.429	45865841.891		2.832	.008
	X1	1.001	.019	.700	52.181	.000
	X5	1.006	.024	.560	42.319	.000
	X3	.961	.043	.299	22.602	.000
	X4	.936	.095	.133	9.897	.000
5	(Constant)	-2.310E-6	.000		.	.
	X1	1.000	.000	.699	.	.
	X5	1.000	.000	.556	.	.
	X3	1.000	.000	.311	.	.
	X4	1.000	.000	.142	.	.
	X2	1.000	.000	.079	.	.

SPSS coefficients output table for train travel time.

Y1	X1	X2	X3	X4	X5
Total travel time(Including waiting time)	Running time	Boarding stop	Traffic stop	Walking	Waiting
6,896,030,000	2,706,140,000	1,204,850,000	424,450,000	751,800,000	1,808,790,000
6,401,460,000	3,134,360,000	981,160,000	768,530,000	751,800,000	765,610,000
7,616,910,000	3,233,890,000	1,121,860,000	1,032,590,000	751,800,000	1,476,760,000
6,528,210,000	2,568,650,000	945,100,000	452,170,000	375,900,000	2,186,390,000
7,278,370,000	2,652,910,000	1,047,620,000	1,322,030,000	751,800,000	1,504,020,000
6,161,400,000	2,496,150,000	829,660,000	901,950,000	751,800,000	1,181,830,000
6,466,540,000	2,413,460,000	697,270,000	1,138,610,000	751,800,000	1,465,400,000
5,546,720,000	2,543,750,000	920,180,000	531,360,000	751,800,000	799,630,000
6,805,130,000	3,031,650,000	540,180,000	935,870,000	751,800,000	1,545,630,000
5,420,750,000	2,922,620,000	773,820,000	456,970,000	375,900,000	891,450,000
5,372,530,000	2,346,160,000	843,140,000	771,640,000	375,900,000	1,035,690,000
6,260,800,000	2,428,500,000	797,770,000	1,205,200,000	751,800,000	1,077,540,000
5,697,050,000	2,207,900,000	614,920,000	1,112,670,000	751,800,000	1,009,760,000

SPSS time series minibus taxi input data for analysis (μsec)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4993824199.973	531993895.633		9.387	.000
	X5	1.047	.394	.625	2.657	.022
2	(Constant)	3337270737.405	691342394.765		4.827	.001
	X5	1.148	.303	.686	3.783	.004
	X4	2.295	.774	.537	2.964	.014
3	(Constant)	959028421.403	822384976.416		1.166	.274
	X5	1.104	.207	.660	5.324	.000
	X4	2.098	.531	.491	3.947	.003
	X1	.962	.272	.437	3.531	.006
4	(Constant)	348095861.799	590953329.309		.589	.572
	X5	1.117	.142	.667	7.875	.000
	X4	1.277	.438	.299	2.917	.019
	X1	1.138	.193	.517	5.882	.000
	X3	.788	.235	.347	3.355	.010
5	(Constant)	-12564.896	22865.700		-.550	.600
	X5	1.000	.000	.597	178646.849	.000
	X4	1.000	.000	.234	58830.784	.000
	X1	1.000	.000	.454	132336.381	.000
	X3	1.000	.000	.440	107112.641	.000
	X2	1.000	.000	.274	74667.868	.000

SPSS coefficients output table for minibus taxi travel time.