ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAIT)
School of Civil and Environmental Engineering

Evaluation of the Feasibility of At-Grade Crossings and Traffic Management Strategies for The Addis Ababa Light Rail Transit Corridor

A thesis submitted to the Graduate School of the Addis Ababa Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Railway Engineering Stream)

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DECLARATION

I certify that this thesis work entitled ‘‘Evaluation of the Feasibility of At-Grade Crossings and Traffic Management Strategies for The Addis Ababa Light Rail Transit Corridor” is my original work. The work has not been presented elsewhere for assessment and award of any degree or diploma and any reference material used for its preparation is duly acknowledged. I am also responsible for the facts and accuracy of information presented herein.

Abel Girma

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ABSTRACT

Light rail transit system is being introduced in Addis Ababa. The project is a semi-exclusive alignment running along the median of roadway. It is designed to cross intersections at-grade or through grade separation facilities. Light rail generally reduce traffic congestion through the reduction of demand for vehicles, but when crossings at-grade delay is induced on the train and/or vehicles depending on factors such as: degree of priority to train, signal configuration, crossing geometry, frequency of light rail vehicles, and number of vehicles crossing. The computation of level of service of the crossing determines what kind of operation is feasible. There are three operations identified for light rail crossing: first, where light rail at-grade operation with full priority to the train is feasible; second, where light rail can operate conditionally preempted with train delays; and third, where at-grade operation is infeasible.

The study identified CMC, Salitemihiret, and Adey Abeba at-grade crossing intersections of the Addis Ababa light rail transit project for operation feasibility analysis. Geometric and traffic volume data are collected at each intersection for at-grade operation feasibility analysis. Initial screening analysis indicate that the intersections can operate at-grade with full preemption to LRT till the year 2019, 2020 and 2021 for Salitemihiret, Adey Abeba and CMC intersections respectively and each intersection may operate at-grade for additional three years with conditional priority to LRT. Geometric parameters of the sites and speed profile of the train are used as inputs for further assessments of potential impact of rail operation on the crossings. Due to long crossing distances at CMC and Salitemihiret roundabouts, the train occupies the crossing for unusually longer period, 67 and 62 seconds respectively for full priority scenario, resulting in unacceptable delay on vehicles. At Adey Abeba junction crossing occupation duration, 47 seconds, is within acceptable limit. Vehicles queue accumulated during crossing blockage is computed for all direction in order to determine the required storage area of turning movements.

The impact of train operation on the capacity of the intersection is checked for both full priority and conditional priority given to the train. The analyses are performed for existing and improved geometries. As per the detail analysis the optimized lane configurations are; for CMC 6 lanes along the North-South and 7 lanes along the East-West directions, for Salitemihiret 7 lanes in all directions, and for Adey Abeba 6 lanes along the North-South and 5 lanes along the East-West directions. In conclusion; at CMC roundabout full preemption with reduced crossing distance and conditional priority are feasible type of operations; at Salitemihiret conditional priority with train delay is feasible; and at Adey Abeba junction both full preemption and conditional type of operations are feasible. The study also presents the number of lanes and its configuration for each crossing; it also identifies improvements for pedestrian crossing facilities along the route.

Keywords: *Light rail transit, semi-exclusive alignment, at-grade crossing, priority, Level of service, operation feasibility, preemption, delay*

TABLE OF CONTENTS

LIST OF TABLES Page

LIST OF FIGURES Page

ACCRONYMS

AACRA……..Addis Ababa City Roads Authority
AALRT……..Addis Ababa Light Rail Transit
ADT…………Average Daily Traffic
EBL…………Eastbound Left
EBR…………Eastbound Right
EBS………….Eastbound Straight
HCM………...Highway Capacity Manual
ITE……….....Institute of Transportation Engineers
LOS………….Level of Service
LRT………….Light Rail Transit
LRV………….Light Rail Vehicles
NBL………….Northbound Left
NBR………….Northbound Right
NBS…………..Northbound Straight
SBL…………..Southbound Left
SBR…………..Southbound Right
SBS…………...Southbound Straight
TDM…………..Transport Demand Management
TRB…………..Transport Research Board
V/C……………Demand Volume to Capacity Ratio
WBL………….Westbound Left
WBS………….Westbound Straight
WBR………….Westbound Right

1. Introduction

1.1 Background of the Study

Addis Ababa is the administrative and commercial capital of Ethiopia. In addition, it is home to the head office of the African Union. It has an estimated urban population of 3.5 million, based on the population census of 2007 when the number has been declared 2.34 million with annual growth rate of 3.8% (CSA, 2007). The city is rapidly growing into a major urban area and lack of adequate traffic management system has created acute traffic congestion and increased accident rates. The level of air and noise pollution is also becoming critical. The movement of people and goods into and out of the city is restricted due to the deteriorating traffic condition; hence having a direct negative impact on the economic performance of the city and the nation as a whole.

The above problem has prompted the introduction of light rail transit (LRT) system in Addis Ababa. The project has planned two lines, the East-West line and the North-South line with a total length of 34 kilometers. The East-West routes with an approximate 17km stretch running between Torhayloch and Ayat roundabouts and the North-south route runs between Menelik II Square and Kality roundabout having a length 17 km. Both routes have sections where the LRT is designed to cross intersections at-grade or through provided grade separated facilities over or under the roadways.

The concept of a two-route LRT system is introduced as a possible means of improving the travel situation for mass transit passengers. LRT has been successful and very popular transit option in many cities like Frankfurt-Germany, Bordeaux-France and Portland-USA (Australian department of transport, 2013). The provision of this system will be a huge addition to the public transport but it will not be efficient unless it is supported by integrated traffic management strategies. Road ways should be utilized 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, address the safety and pollution issues efficiently.

LRT system is an alternative transportation mode and has been cited as a way to help influence development by promoting more desirable and sustainable land uses near the LRT lines. It is also generally less expensive to construct and operate than other kinds of rail transit systems. LRT is an attractive option because of its ability to be located in a variety of settings, from tracks on an exclusive right-of-way to shared lanes with vehicles in an urban street. There is a great possibility for vehicles to experience additional delays when there is interference by LRT operations, such as in the case of at-grade crossings or due to priority being given to LRT vehicles at signalized intersections at the expense of conflicting turning movements.

A concern that arises during the planning for a LRT system is that frequent light rail crossings will create unacceptable delays for regular street traffic. Traffic signals are often used with LRT systems in order to allow light rail vehicles to cross an intersection safely. 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 intersection. Each intersection might require a grade separation or not depending on the design situation and detail engineering analysis of costs and benefits.

1.2 Statement of Research Problem

The addition of LRT system in existing road corridors has the advantage of reducing the demand for vehicles; but, it will induce additional delays on vehicles due to priority given to LRT vehicles at at-grade intersections. The effect LRT operation on other traffic modes and the resulting delay needs to be evaluated to check whether it is within acceptable limit. If delays are unacceptable, traffic management strategies are required to improve the situation and make at-grade operation still feasible. Beyond certain level of delay grade-crossing solutions will not be accepted and grade separation facility will be required. A methodology has to be devised to determine whether a grade crossing along light rail lines should be grade separated or at-grade. This method can be used to evaluate existing crossings as well as to assess conditions at proposed light rail crossings.

The Addis Ababa LRT corridor has at-grade crossings at a number of locations along both routes. These crossings are either intersections or U-turns. The CMC, Salitemihiret, and Ayat roundabouts and U-turns at the office of Ministry of Mines, CMC Mikael, and Ayat village are at-grade crossings along the East-West line; While Adey Abeba junction and U-turns at Meshualekia and VOLVO Company are the crossings along the North-South line.

When crossings are at-grade, delay is induced on the train and/or vehicles depending on the type of priority used at the crossing, geometrical nature of crossings, and traffic flow characteristics. According to the design of the AALRT, the project is given full priority at these locations using signalized operation with gates. This full priority scenario will impose delays on vehicular mode of transport. The magnitude of this delay, which is directly proportional to traffic volume at the crossing, is a key parameter required to check the feasibility of at-grade operation of the crossing.

Some of Addis Ababa LRT line at-grade crossings are roundabouts. This complex geometry of roundabouts will be additional influencing factor to the crossing operation. The distance the light train travels to cross is larger and crossing occupation time is higher than the usual. The vehicle crossing platforms are placed along the curve side of the roundabouts and vehicles travel very long distances to cross, making the intersection operation more sophisticated. Any operation analysis to be performed has to consider these site specific conditions.

Considering all the aforementioned factors an assessment of the feasibility of at-grade operation of these intersections is required, and traffic management measures have to be developed for the shortcomings encountered during evaluation.

1.3 Study Objectives

The main objective of this study is to evaluate the effect of LRT on the crossing operation and check the feasibility of at-grade crossing operation. It also identifies causes and quantifies delays to establish corrective traffic management strategies. The study is conducted as a case study on intersections along segments of the Addis Ababa light Rail Transit system network. The Ayat - Megenagna and Kality - Meskel Square sections of the light rail transit corridor, where the LRT crossings are at-grade and the conflicts are highly anticipated, are selected for the study.

Specific Objectives:

- Review the feasibility of at-grade operation at selected locations for short term and long term conditions
- Explore and asses factors contributing to delays and subsequent traffic congestion at selected crossings
- Asses flow characteristics of LRT and vehicular modes and establish functional classification of lanes based on vehicles occupancy, turning movement and pedestrian movement.
- Identify the means for the provision of facilities for pedestrian and turn around vehicles.
- Establish workable proposal for intersection treatment of train and vehicular modes based on priority basis
- Development of traffic management improvement plan indicating the extent, and priority of the improvement recommendation.

1.4 Thesis Organization

The study is organized in five chapters; the first chapter is a general introduction describing the background of the research, statement of the problem, and objectives of the study. A review of relevant literature is presented in Chapter 2. Chapter 3 describes a methodology used for determining additional delays caused by light rail transit crossings, including descriptions of the scenarios that were considered for the study. Results from applications of the methodology are discussed in Chapter 4, with conclusions and recommendations detailed in Chapter 5. Chapter 6 concludes the thesis by suggesting and discussing future study areas.

1.5 Scope and Limitation of the Study

The study addresses the feasibility of at-grade crossings between Light rail vehicles operating on semi-exclusive right-of-way of the Addis Ababa light rail transit. Scope of this study is limited to assessment of selected at-grade crossings; namely CMC and Salitemihiret from the East-West line and Adey Abeba junction from the North-South line. It also asses pedestrian movement across at-grade crossings along Meskel square to Kality roundabout and Megenagna to Ayat roundabout sections. The analysis is made based on data collected from design documents of the AALRT and field vehicular count. Selected at-grade crossings are currently un-signalized and the research assumed that the intersections will be signalized.

During the data collection process, there was still construction going around the study areas and this may have caused some motorists to avoid the intersections. As a result some normal traffic s may have been uncounted for due to this inconvenience. Another limitation of the study is that all computations were performed manually due to inaccessibility of simulation programming software that could have furnished better modeling and rigorous analysis.

2. Literature Review

2.1 Mass Transit Systems

2.1.1 Classification and features

Cities are centers of diverse activities which demand effective transportation systems for people and goods. High capacity transport modes such as bus and light rail are required to satisfy the need of high density movements. These mass transit systems are more economical, energy efficient and use of less space than private cars.

Urban transport systems are classified as private and mass transit (public) transport. Mass transits are defined by their right-of-way (ROW) category, technology, and types of operations as (Vuchic, 1981):

- Urban Streets with mixed traffic: Street transit modes include buses, trolleybuses, tramways and streetcars.
- Partially separated tracks/lanes: Usually street median include Light Rail Transit (LRT) and semi rapid bus. It has a higher performance than street transit.
- Paths used exclusively by transit vehicles: comprise rapid transit mode or metro system. Its electric rail vehicles are operated in trains and provide the highest performance.

2.1.1(a) Bus systems

Buses are the most common transit mode. They operate on streets and have an extensive network of lines. Buses can transport large numbers of people while occupying relatively little road-space offering a highly cost-effective use of resources. In some cities they have been upgraded by provision of exclusive bus lanes and provision of bus preferential signal. Conventional buses can be protected from the effects of traffic congestion by segregated lanes or track.

2.1.1(b) LRT and Metro Systems

Light rail transit (LRT) is the most common mode of semi rapid transit. LRT is a form of urban rail public transportation that generally has a lower capacity and lower speed than heavy rail and metro systems, but higher capacity and higher speed than traditional street-running tram systems. The term is typically used to refer to rail systems with rapid transit-style features that usually use electric rail cars operating mostly in private rights-of-way separated from other traffic but sometimes, if necessary, mixed with other traffic in city streets.

LRT are modern, high quality and environmentally–acceptable modes of transport. Essentially, LRT face the same on–street operating problems as buses but, unlike buses, LRT systems introduced into high degree of segregation and priority over other traffic can be achieved either through construction of purpose–built track and bridges or through the use of redundant railway lines in combination with preferential traffic management and control.

Metro have by far the highest performance – capacity, speed, reliability- of all transit modes. It requires very high investment, but it is essential for efficient functioning and quality of life in large cities.

2.2 Rail-roadway and Traffic Characteristics

2.2.1 Types of Light Rail Transit Alignments

LRT is a mode of urban transportation that employs light rail vehicles (LRV) on surface streets. Grade crossings of highways and light rail transit can occur at intersections or at mid-block locations. Light rail alignments can be grouped into one of the following alignment types (Korve, 1995, p 10-2).

2.2.1(a) Exclusive: LRT right-of-way without at-grade crossings that is grade separated or protected by a fence or substantial barrier, as appropriate to the location (includes subways and aerial structures). Motor vehicles and pedestrians are prohibited within the right-of-way.

2.2.1(b) Semi-Exclusive: LRT alignment that is in a separate right-of-way or in street right of-way with at-grade vehicle and/or pedestrian crossings, protected between crossings by fencing, barriers, curbs, striping, and lane designation. Motor vehicles and/or pedestrians cross at designated crossings only.

2.2.1(c) Non-Exclusive: LRT corridor where LRVs operate in mixed traffic with automobiles, trucks, buses, bicycles and pedestrians.

2.2.2 Traffic Analysis Parameters

The operation analysis of Light rail vehicles with vehicular mode at at-grade crossings is based on the duration LRVs occupy the crossing. This parameter is computed using LRT speed profile at the crossing, length of the crossing, required warning time, and gate operation time whenever the crossing is equipped with gated operation. Table 2.1 depicts typical LRT crossing time (MTA, 2003).

Table 2.1: Typical LRT At-grade Crossing Time

Description	Time (seconds)
Warning and gate closing time	20
Passage, clearance time	12
Gate up time	10
Total	42

The traffic flow analysis of light rail at-grade crossings requires the following basic analysis parameters (HCM 2000).

An intersection's overall operating conditions are typically characterized by two standard measures: the demand volume to capacity ratio (V/C) and the level of service (LOS). Taken together, they provide an indication of delay and the number of vehicles that can be accommodated through an intersection. The V/C ratio is an indication of the volume of traffic attempting to make a specific movement through an intersection, versus the theoretical capacity of that movement. The computation is based on the lane configurations, operating conditions and signal timings provided at the intersection. A V/C ratio of 1.0 represents a condition where all available capacity for a particular movement is being used.

The level of service (LOS) of the overall intersection or a particular movement is a measure of the average vehicle delay experienced by the motorists attempting to travel through the intersection. LOS is measured from “A” to “F” with peak hour LOS in the “A” to “D” range are considered acceptable by most, and a LOS of F represents an unacceptable delays. Critical movements were identified as those operating with a V/C ratio of 0.89 or higher and/or the poorest level of service.

A signalized intersection's level of service, according to the method described in Transport Research Board (TRB) Circular 212, is based on dividing the sum of the critical volumes by the intersection's capacity. This calculation yields the volume-to-capacity ratio of the intersection. Table 2.2 depicts LOS with their corresponding V/C for signalized intersections.

Table 2.2: Intersection Level of Service Definitions

LOS	Interpretation	V/C ratio
A	Uncongested operations, all queues clear in a single signal cycle	Less than 0.60
B	Very light congestion; an occasional approach phase is fully utilized	0.60 to 0.69
C	Light congestion; occasional backups on critical approaches	0.70 to 0.79
D	Significant congestion on critical approaches, but intersection functional. Cars required to wait through more than one cycle during short peaks. No long-standing queues forms	0.80 to 0.89
E	Severe congestion with some long-standing queues on critical approaches. Blockage of intersection may occur if traffic signal does not provide for protected turning movements. Traffic queue may block nearby intersection(s) upstream of critical approaches	0.90 – 0.99
F	Total breakdown, stop and go operation	1.00 and greater

Source: TRB Circular EC-212

2.3 Mass Transit and Traffic Congestion

2.3.1 Effects of LRT Lines on traffic and congestion

Light rail lines generally reduce traffic congestion by providing mass transport supply for the increased demand. However, additional delay of vehicles is induced when the implementation is at-grade and traffic signal preemption (traffic light priorities) are set in favor of the LRT. Another effect is that LRT lines may reduce available space in automobile traffic lines as they share right-of-way.

One would assume that the availability of a clean and comfortable mass transit system would decrease congestion by reducing the need to use cars. A set of factors have been identified to increase traffic congestion at LRT crossings are: number of vehicles crossing, the frequency of Light Rail car crossings, intersection geometry, signal preemption configurations, the presence of driveways or intersections near crossings, types of traffic, and degrees of priority given to LRT. When LRT crossed very often with vehicles, the delays could be significant.

2.3.2 Location and Conflict Zones and common conflicts

The common conflicts LRT has with other modes of transport are summarized in this section. These conflicts are classified as rail-vehicle and rail-pedestrian conflicts (TRB, 2007, p88).

Railway – Vehicular Conflicts

The conflict spots are at–grade rail crossing at/near cross intersection or roundabout. There are two types of problems leading to traffic congestion or safety problems:

- The traffic queue protrudes back onto the railroad crossing due to congested downstream, and
- The closing of the railroad crossing disturbs the intersection flow

The common conflicts are:

- Complex intersection geometry confusing vehicle drivers;
- Effect of priority for LRT (signal preemption);
- Left turn by motorists into the LRT right of way and right angle conflicts; and
- Illegal crossing and turns across tracks and vehicle blocking of LRT crossing.

Railway – Pedestrian Conflicts

The major causes of the conflicts between rail and pedestrian traffic are low level of pedestrian awareness, poor definition of pedestrian path, and cross-street access (inadequate storage, queuing, and refuge space)

The Common Conflicts are:

- Pedestrians trespassing to cross street and to access train;
- Overflow of pedestrian from waiting/queue area;
- Pedestrians trespassing on side-aligned LRT rights-of-way where there are no sidewalks; and
- Pedestrians jaywalking across LRT/transit mall rights-of-way after receiving unclear messages about crossing legality.

2.3.3 Conflict Mitigation Measures and Traffic Management

2.3.3(a) Geometric Improvement

Intersection designs and controls should clearly define and control conflicts between LRVs and other road users. The roadway geometry should be simple as much as possible. Strategies that increase intersection capacity can reduce delays, since intersections are often a limiting factor in roadway traffic flow. These include additional lanes at the intersection approach, left- and right-turn lanes, and improved signal synchronization. Left turns across LRV tracks pose both capacity and safety concerns. These turns should either be provided and protected or prohibited and redirected. In case of provision, it should have sufficient vehicle storage distance. Vehicles should be channelized near crossing using channelization devices like traffic dots or flexible posts (Korve, 1995, p68).

Intersection design and control

- Where possible, physical barriers should separate the LRV dynamic envelope from adjacent motor vehicle travel lanes. The LRV dynamic envelope should have a distinct and contrasting pavement texture at all crossings.
- In semi-exclusive LRT alignments, motor vehicle traffic that would cross over the median LRT alignment from across street should be prohibited except at signalized intersections.
- In semi-exclusive LRT alignments, left-turn-only lanes should be provided at signalized intersections and given a protected phase. The left-turn phase should follow the phase for the parallel through traffic and LRVs so that the LRT preemption does not shorten or eliminate the left-turn phase.
- A clearance interval should be provided for cross-street traffic to prevent any backups across the tracks.
- At stations that use side-boarding platforms, a low fence between the tracks should be provided to channel pedestrian movements to designated crossing points.
- A pedestrian refuge area should be provided between the parallel roadway lanes and the LRT tracks at crossings.

2.3.3(b) Pedestrian Conflict Countermeasures

Table 2.3 shows solutions that can be used to overcome the possible pedestrian conflict with LRT and vehicular operation.

Table 2.3: Possible Pedestrian Related Conflicts and Engineering Solutions

Possible pedestrian conflict	Proposed Solution
• Pedestrians trespassing on rail tracks to cross street	• Define pedestrian pathway, channelize flows, install fence • Provide refuge areas between roadway and parallel LRT tracks
• Pedestrians crossing to access train	• Define pedestrian pathways, and channelize pedestrian flows
• Overflow of pedestrians from waiting/queue area	• Define pedestrian pathways, • Provide adequate storage/queuing space • Orient station to prevent errant and random crossing • Install safety islands • Install automatic gates, swing gates, bedstead barriers, Z-crossings
• Pedestrians trespassing side-aligned LRT right-of-way where there are no sidewalks	• Install fence/barrier between tracks, or to separate LRT right-of-way • Provide curbside landscaping, bollards, barriers
• Pedestrian jay-walking across LRT/transit mall right-of-way after receiving unclear messages about crossing legality	• Install fence/barrier between tracks, or to separate LRT right-of-way • Provide curbside landscaping, bollards, barriers

2.3.3(c) Traffic Control Systems

Traffic control devices are used at grade crossings to facilitate reasonably safe, orderly, and integrated movement of all traffic. Highway-LRT grade crossings in semi-exclusive alignments shall be equipped with a combination of automatic gates and flashing-light signals, or flashing-light signals only, or traffic control signals

2.3.3(c.1) Signaling

Signals are useful at the intersections of LRT and other modes to accomplish the following aims:

- Coordinate traffic signal phasing and timing to preclude cross-street traffic from stopping on and blocking the tracks.
- Use traffic signal turn arrows or active, internally illuminated signs to actively control motor vehicle turns that conflict with LRT operations.
- Provide separate turn signal indications to avoid conflicts.
- Use flashing, internally illuminated signs displaying the front view LRV symbol or the side view LRV symbol to warn motorists making conflicting turns of the hazards involved in violating traffic signals.

Active traffic control systems inform motorists and pedestrians of the approaching or presence of LRVs at grade-crossings. They include automatic gates, flashing lights, automobile traffic signals, and other active warning traffic control devices. LRT grade crossings with motor vehicles and pedestrians that occur along semi-exclusive right-of-way shall be controlled by automatic gates and flashing lights or traffic signals, depending upon LRV operating speeds and specific alignment features (Korve, 1995, P10-49).

I. Automatic Gates

Automatic gates with flashing lights are appropriate at grade crossings within semi-exclusive alignments where LRV speeds exceed 55km/hr, and where LRVs are permitted to operate at 15km/hr more than the legal speed of parallel traffic.

II. Traffic Signals

When LRT automatic crossing gates are located within 60m of a motor vehicle intersection that is controlled by traffic signals, the traffic signals should be coordinated with the gate control by using a railroad preemption sequence. Factors to be considered include: motor vehicle traffic volumes, approach speeds, and queue spillback; LRV headways and speeds; and gate down time.

All LRV movements in semi-exclusive, non-gated alignments shall be controlled by separate LRV signal indications at grade crossings that are controlled by traffic signals. Traffic signal strategies to control LRV and vehicle movements include signals that do not give LRV priority at crossings, signals who’s phasing is actuated by the approach of an LRV, and signals that allow LRV priority. Vehicular traffic on mixed (non-exclusive alignments shall be controlled by stop signs or traffic signals.

III. Light Rail Transit Signal Indications

Signal indications that govern only LRVs should have a format and color that are clearly different from conventional traffic signal displays. The light rail signal indication should convey the intended message to the LRV operator. It should contrast with vehicular signals in size, shape, color, aspect, and placement.

IV. Pedestrian Crossing Control Systems

Pedestrian crossing control systems should be used to channel and/or control pedestrian access to and/or across LRT tracks, supplementing with signs or signals. Common LRV/pedestrian incidents involve pedestrians crossing unimpeded across the LRT right-of-way. The at-grade crossing control systems are designed to alert the pedestrian of a situation where special attention must be given. They are designed to warn, channelize and/or block pedestrians from their desired paths of travel. These systems also channel pedestrians to specific areas of the crossings and away from vehicular traffic. Pedestrian crossing systems are listed below.

1. Signalized Pedestrian Crossing

At signalized intersections where pedestrians cross LRT tracks, the primary control device shall be the standard symbolic WALK/DON'T WALK pedestrian signal indication.

2. Un-signalized Pedestrian Crossing.

At non-gated, un-signalized (without pedestrian WALK/DON'T WALK signals), pedestrian only, LRT crossings of semi-exclusive right-of-way, the primary warning device shall be the flashing light signal assembly shown in Figure 2.1.

3. Pedestrian Automatic Gate

Pedestrian automatic gates are the same as standard automatic grade crossing gates except the gate arms are shorter as shown in Figure 2.2. They are utilized to physically prevent pedestrians from crossing the LRT tracks when the automatic gates are activated by an approaching LRV. This type of barrier method is used in areas where pedestrian risk of a collision with an LRV is high.

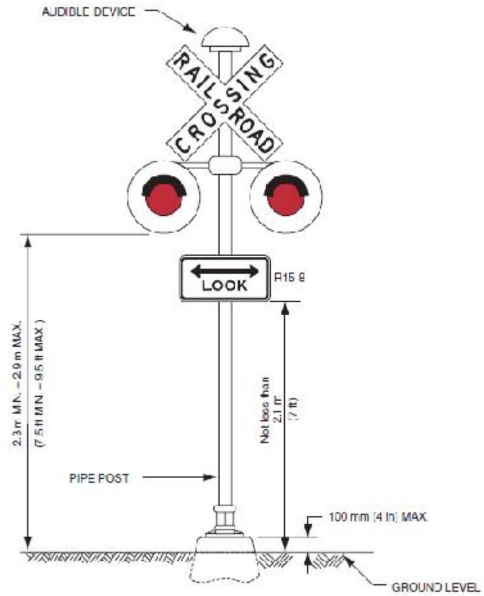
4. Swing Gate

The swing gate alerts pedestrians to the LRT tracks that are to be crossed and forces them to pause, thus acting as a deterrent to running freely across the tracks without unduly restricting exit from the LRT right-of-way. Figure 2.3 illustrates the typical swing gate configuration.

5. Curbside Pedestrian Barriers

Between LRT crossings, curbside barriers (landscaping, bedstead barriers, fences, and/or bollards and chains) should be provided alongside-running LRT alignments for contra-flow operations or two-way operations along a one-way street.

Figure 2.1, 2.2, and 2.3 show: pedestrian crossing warning devices, single unit pedestrian automatic gates, and swinging gates respectively.



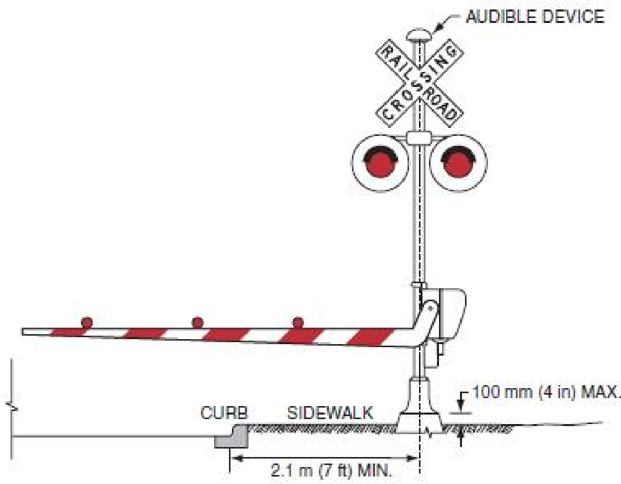


Figure 2.1: Pedestrian Crossing Warning Devices Figure 2.2: Single Unit Pedestrian Automatic Gates

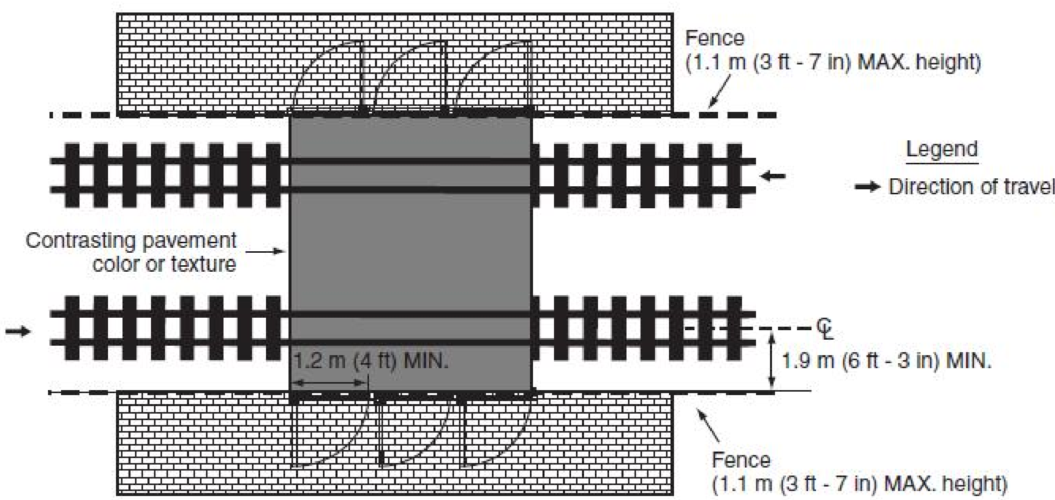


Figure 2.3: Swing Gates

6. Bedstead Barrier

The bedstead is used in tight urban spaces where there is no fenced-in right-of-way, such as a pedestrian grade crossing at a street intersection. The barricades are placed in a maze-like manner. They should be designed and installed to turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs. The barriers should be also used to delineate the pedestrian queuing area on both sides of the track area. Figure 2.4 illustrates a possible application of bedstead barriers.

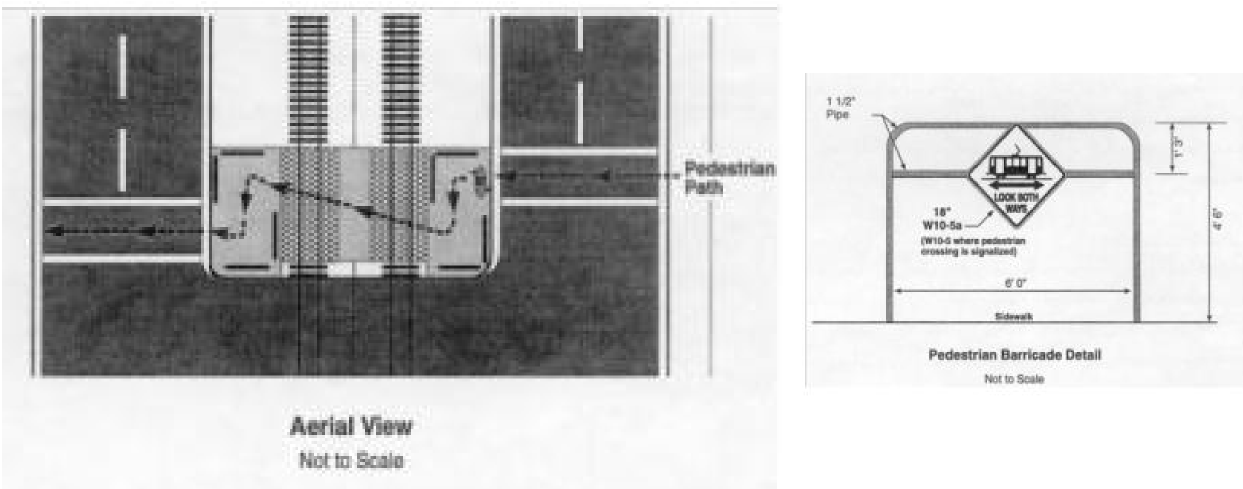


Figure 2.4: Bedstead Barriers at LRT Crossing

7. Z-Crossing Channelization

The Z-Crossing controls movements of pedestrians approaching LRT tracks. Its design and installation turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs. Figure 2.5 illustrates the Z-Crossing configuration.

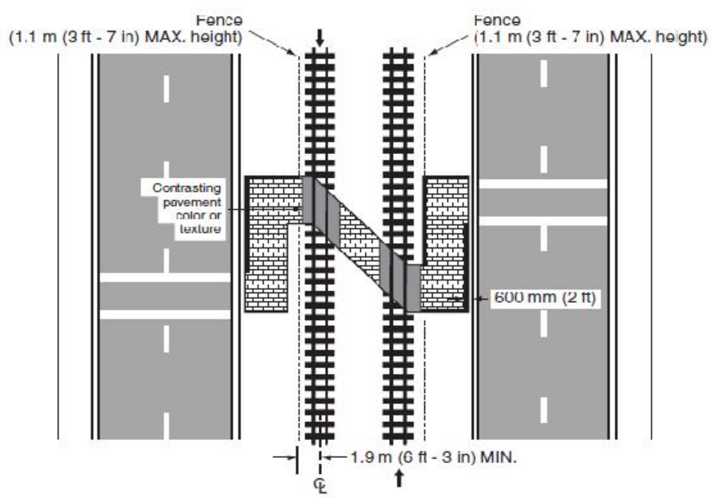


Figure 2.5: Z-Crossing Channelization

2.3.3(c2) Signage and Marking

Signs and markings are provided for the purpose of identifying and directing attention to specific situations/locations so that LRT operators, motorists, and pedestrians may take appropriate action. The different types of signage and markings used for the safe and facilitated operation of intersections are indicated in this section (Korve, 1995, P10-7).

I. Regulatory Signs

1. Stop Sign at LRT Grade Crossings

All LRT crossings shall be equipped with stop signs, traffic signals, or gates, depending upon the type of alignment, LRV and traffic operating speeds, sight distances, and cross street traffic volumes. No LRT grade crossing should be without a regulatory traffic control device. A STOP sign should be the minimum traffic control device.

2. Turn Restrictions Signs

At signalized intersections, left and right turns by parallel traffic in front of an LRV present potential conflicts, which may require prohibition of left/right turns at certain intersections at all times or for specified periods of time.

3. Do Not Pass Stopped LRV Sign

To emphasize that motor vehicles are required to stop behind an LRV that is receiving or discharging passengers in the street in a non-exclusive type right-of-way where there is no safety zone or island, a DO NOT PASS STOPPED LRV sign, as shown in Figure 2.6, may be located immediately upstream of an LRV boarding and alighting street stop.

4. Do Not Stop on Tracks Sign

Whenever there is the potential for vehicles stopping on the tracks is high, a DO NOT STOP ON TRACKS sign should be used. This is often the case if the crossing involves multiple stops for the motor vehicle or there is a possibility of queue spillback onto the LRV's dynamic envelope.

5. Stop Here Sign

The STOP HERE sign may be needed at certain locations to define the stop line as shown in Figure 2.6. It should be used to define and facilitate observance of the stop lines (or limit lines) in conjunction with traffic signals and railroad gates. It should be used as a means of emphasizing the dynamic envelope of LRVs.

Figure 2.6: No Turn Sign, Do Not Pass Sign, No Vehicles On Tracks Sign, and Stop Here Sign

II. Warning Signs

LRT warning signs are used when it is necessary to warn traffic of the presence of LRVs on or adjacent to a highway or street.

1. Light Rail Transit Crossing Sign

A LIGHT RAIL TRANSIT CROSSING sign may be installed in advance of LRT non-gated, signalized crossings of semi-exclusive right-of-way on streets approaching the crossing. The primary warning sign for signalized pedestrian crossings of LRT tracks shall be the LIGHT RAIL TRANSIT CROSSING sign. (Fig 2.7)

Figure 2.7: Light Rail Transit Crossing Signs

2. Train Approaching Sign

A flashing internally illuminated warning sign displaying the front view LRV symbol and the legend TRAIN or the side view LRV symbol and the legend TRAIN , as shown in Figure 2.8 should be used at street crossings on semi exclusive, non-gated LRT alignments where left or right-turning parallel traffic is controlled by arrow indications. This advisory sign would alert and warn traffic turning left and/or right across the tracks of a parallel, approaching LRV.

Figure 2.8: Train Approaching Warning Signs

III. Pavement Markings - Motor Vehicles

1. Dynamic Envelope of a Light Rail Vehicle

The dynamic envelope of a light rail vehicle is the clearance on either side of a moving LRV such that no contact can take place. The dynamic envelope of an LRV should be delineated on semi-exclusive type rights-of-way. The preferred method of delineating the dynamic envelope is by differential pavement or contrasting pavement texture, which may be supplemented by 10cm solid yellow striping.

2. Separation between Track way and Roadway

To discourage vehicular encroachment onto the track way, low-profile pavement bars, rumble strips, or rough textured pavement may be used.

IV. Pavement Markings – Pedestrians

1. Crosswalks

Pedestrian crossings of LRT tracks in street-running rights-of-way should be defined by two continuous, parallel lines and/or contrasting pavement texture across the entire length of the crossing. A LOOK LEFT or LOOK RIGHT legend may be painted in the crosswalk.

2. Dynamic Envelope of a Light Rail Vehicle

The LRV's dynamic envelope shall be delineated in semi-exclusive and nonexclusive corridors at pedestrian crossings. Contrasting pavement texture should be used to identify an LRV's dynamic envelope.

2.3.3(d) Demand Management Strategies

Transport Demand Management (TDM) has a significant impact on congestion and selective strategies are efficient in alleviating traffic congestion through reduction of peak hour travel demand. A study conducted in the US (INBRX Corporation, 2009) to evaluate highway traffic congestion indicates that congestion reduced by 30% from 2007-2008 due to a 4% reduction in total traffic volume. Traffic incidents caused by disabled cars, accidents and dangerous driving induce series impacts on operation of LRT incorporated corridors such as the Addis Ababa LRT system, where the size old cars population is high. These vehicles tend to require more road space and are slower to accelerate. This section describes relevant strategies applicable to LRT-Highway right of way (Victoria Transport Policy Institute, 2014).

I. Intelligent Transport Systems

An intelligence transport system is the application of new technologies such as driver information, vehicle control and tracking system, and transit improvement. It includes message signs, radio reports and internet information about traffic condition. These techniques improve driver anticipation to condition ahead, reduce delay and improve safety.

II. Incident Detection and Management

Traffic management centers need to be organized to prevent, identify and respond to incidents caused by disabled cars, accidents and dangerous driving. These centers have to be equipped with video surveillance systems, emergency response teams with vehicle moving equipments.

III. Reversible Lanes and One Way Streets

In some situations, it is possible to have a reversed lane to carry traffic in the direction of maximum flow, for example, into a city center during the morning rush hour and outward during the evening rush hour. In other cases, converting from two-way to one-way streets can increase traffic flows and simplify intersections.

IV. Trip Reduction Programs

Trip reduction programs encourage travelers to use alternative mode of transport and in some situations, avoid trips. Some of these programs are shown herein below:

- Flexible working time: employees are allowed some flexibility in their daily work schedules. This allows to rush hour traffic to disperse to a wider period of time.
- Transit Improvements: Public transit service should attract sufficient travelers who would otherwise drive on congested roads. Transit services must serve a major share of urban corridors and destinations; offer high quality service interims of convenient, speed, and frequency; be attractive to peak hour travelers;
- Restrict freight trucks during rush hours and shift freight to less congested routes; and
- Improve telecommunication systems: This involves provision of efficient and reliable telecommunication systems to substitute for physical travel. Sales and field workers who rely heavily on telecommunication and self-employed people are able to work from a home office due to efficient communications. This gives people a way to avoid traveling under congested conditions.

2.3.4 At-Grade LRT Crossings Operational Feasibility Analysis

There are three circumstances identified concerning light rail crossing operations: first, where light rail can operate at-grade with full preemption; second, where light rail might be operable only with conditional preemption with LRT delays; and third, where LRT at-grade operation is infeasible. (ITE, 1992)

If cross-street volumes are lower than the 15,000 to 20,000 ADT range, at-grade light rail operations are feasible. For the second category in many cases, light rail should be grade separated from crossing arterials with volumes greater than 30,000 to 40,000 ADT, for LRT headways of three to six minutes, respectively. For relatively low frequency operation involving relatively short trains, for cases where future funding sources will be called upon to construct future grade separations, and for times when some delay to LRT can be accepted and traffic-signal progression or conditional preemption schemes are feasible. Beyond a certain volume, even the more restrictive LRT grade-crossing solutions will not be feasible, or accepted. ADT thresholds for this limit are in the vicinity of 50,000 to 55,000. Grade separation can significantly increase roadway capacity. A typical grade separated freeway can carry more than twice vehicles per hour than arterial lane.

2.3.4(a) Initial Screening for At–Grade Operation Feasibility

The chart developed by the Institute of Transportation Engineers (ITE) based on plots of crossing-traffic volumes (measured in terms of hourly traffic volume per lane) as a function of light rail train frequency (Measured in trains per hour per direction would be useful as screening criteria in the determination of at-grade operational feasibility.

A grade crossing that lies below Threshold Lines1 or 2 should be feasible at grade. If the crossing lies beyond Threshold Line 2 and below Threshold Line 3, at-grade operation is also feasible if the LRT operator is willing to accept some delays for the LRV at the grade crossing to accommodate cross street traffic. If the grade crossing lies beyond Threshold Line 3, then at-grade operation is not feasible without significant delays to LRV's and/or cross street traffic.

Thresholds 1 and 2 are based upon granting unconditional preemption to light rail trains at normal operating speed, with railroad-type protection features (e.g., automatic crossing gates with flashing lights and bells), For all points to the left of Threshold 3, alternative solutions might be possible when local conditions permit. When the full preemption treatment is feasible, it is generally a preferred solution, because it involves no delay to the light rail operation. In cases where full preemption is not feasible, but grade separation is not appropriate for cost or other reasons, conditional preemption or traffic-signal solutions might be appropriate. Solutions in this category would eliminate the time required for advance-warning devices and gate operation by using traffic signals or similar indications. These typically are accompanied by LRT delays, speed restrictions, and other compromises.

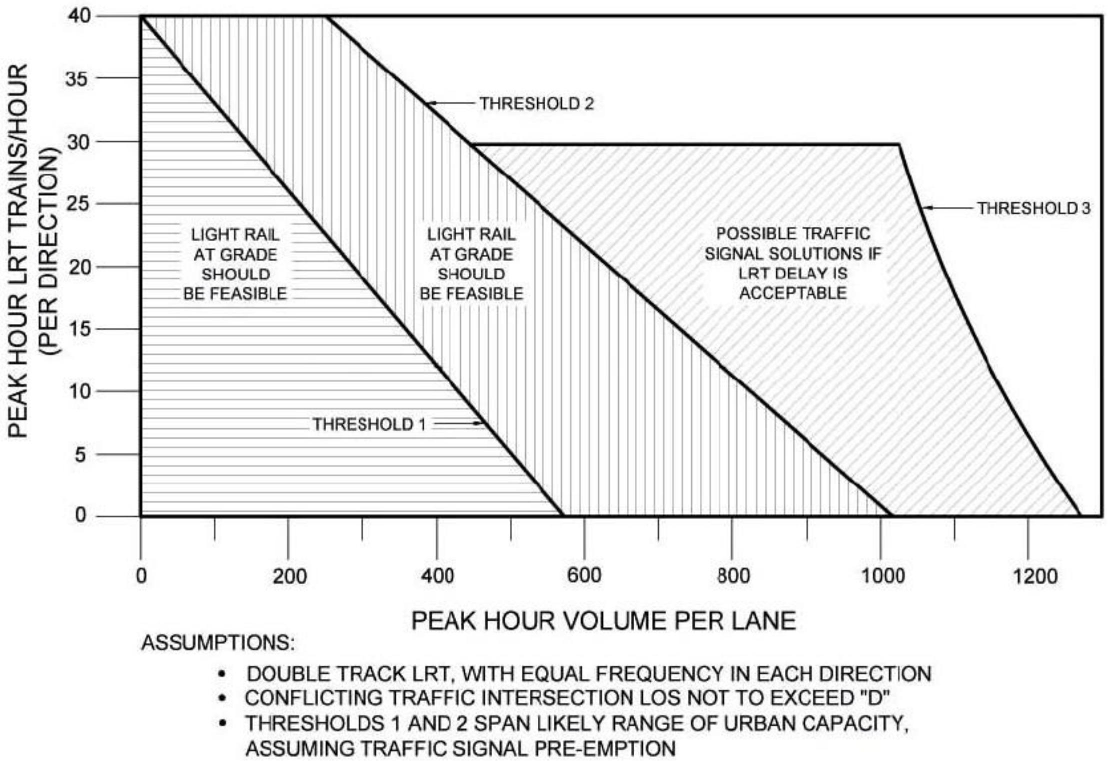


Figure 2.9: Potential Threshold Levels for At-Grade Operation (ITE, 1992)

It is understood that many factors enter into the analysis of at-grade operations, these factors include: physical configuration, intersection traffic-control characteristics, traffic-flow conditions, pedestrian-flow conditions, and LRT operational characteristics. Thus, the final decision on whether to grade separate is one that must be made on a site-specific, crossing-by-crossing basis. Therefore, these general threshold ADT values should be used only as initial guidelines for determining surface operational feasibility. The Initial Screening is accomplished using available traffic volume data. The analysis method specifies that the highest per lane flow rate should be used in applying the method.

2.3.4(b) Detail Analysis for At–Grade Operation Feasibility

The detail operational analysis is a multi-step evaluation of the Level of Service of adjacent or co-incident traffic signal controlled intersections, queuing and other safety factors along with identification of impacts to rail operations including delays (Timothy, 1995).

The steps followed in the analysis are addressed as follows:

- Traffic Volumes Used for Analysis
- Intersection Level of Service
- Queuing Analysis
- Evaluation of Impact of Pre-Emption on Progressive Traffic Movements

I. Traffic Volumes Used for Analysis

The grade crossings would typically be checked for opening year traffic levels, during the AM and PM peak periods or the period of highest traffic under the typical day. For the operational analysis in the detailed analysis phase, the traffic volume assumptions should be reviewed and adjustments made if appropriate.

II. Intersection Level of Service

The controlling intersection is the signalized intersection at the grade crossing or along the cross street within the influence zone which is the most congested during the peak period. The Level of Service of the controlling intersection provides an indication of the feasibility of transit priority solutions with traffic signal control at the grade crossing and whether the impact of operation as a gated crossing is feasible.

III. Queuing Analysis

The extent of queuing along the cross street should be compared to the roadway geometry to determine whether either the crossing spillback queue is impacting an adjacent major intersection or if an adjacent major intersection is generating an influence zone queue which would impact the grade crossing. In the event crossing queues are spilling back, mitigation measures may be appropriate. Some of the solutions are like provision of turn bays for movements approaching the grade crossing to allow parallel through traffic to continue unimpeded by traffic backing up from the grade crossing. In the event the crossing is in the influence zone, queuing mitigation measures such as warning signs, pre-signals or signal progressions should be considered and, if the crossing is gated, the adjacent traffic signal should be pre-empted. Typical crossing gate blockage time will be 34 to 45 seconds.

IV. Evaluation of Impact of Pre-Emption

When an LRT-highway grade crossing is on at-grade intersection, right-of-way can be allocated by either of the following methods:

- Transit pre-empt operation: with this approach, the crossing operates as a traditional rail-highway grade crossing, with the LRT line always receiving the right-of-way upon demand.
- Normal roadway operation: with this approach, the LRT line is treated like just another roadway. In theory, the intersection could be stop-controlled or signal-controlled. In most circumstances, however, the crossing is likely to be signalized.

1. Transit Pre-Emption Operation

For transit pre-empt operation, traditional queuing theory was utilized in **order** to estimate vehicular delays. As shown in Figure 2.10, this approach is based on the premise that roadway vehicles arrive at the crossing at a constant rate of ‘A’ vehicles per hour. When an LRT approaches tie crossing (at time X), vehicles begin to queue. At time Y, the LRT clears the crossing, and normal roadway operations are resumed. At this point, tie queue is dissipated at a saturation flow rate of ‘S’ vehicles per hour, until queue is completely dissipated (at time C). Total delay to roadway vehicles is the area of triangle XYZ.

In attempting to apply this approach to field conditions, a number of factors must be taken into account. These factors include the amount of time, prior to the arrival of the LRT at the crossing, during which the crossing is closed to roadway traffic. At a crossing with automatic gates, this would be the period during which the gates are dropping and flashing light signals are active. Similarly, the time required for automatic gates to return to the upright position and for flashing light signals to stop operating once the LRT has cleared the crossing need to be considered as well. The directional distribution of roadway traffic, and the number of travel lanes available, also needs to be considered.

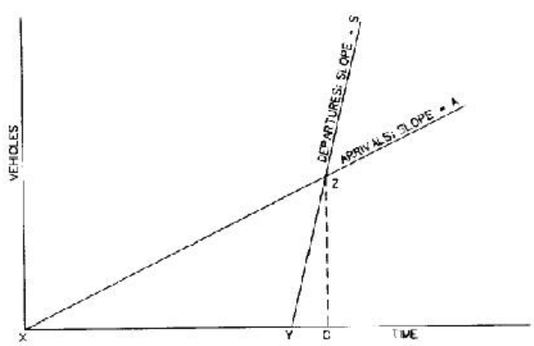


Figure 2.10: Roadway Delay

2. Conditional Roadway Operation

Under the normal roadway operation scenario, the LRT line is assumed to be treated like "just another roadway", with the at-grade crossing being signalized with a traditional traffic control signal. As noted previously, use of the HCM to analyze conditions of this sort was found to be inappropriate, due to operational differences between LRTs and roadway vehicles. As a result, two variations on the HCM procedures were utilized and the results being compared. In the first version, the LRT-highway grade crossing was treated as a two-phase signalized intersection. The roadway movement was given an actuated phase; the LRT was given a fixed pedestrian phase, with the length of this phase being equal to the time required by an LRT to cross the roadway. The lengths of the intervals at the conclusion of the LRT phase were set specifically to account for the unusually long start-up/clearance times required for the LRT. In the second analysis, the fixed pedestrian phase for the LRT was adjusted such that the cumulative time for the LRT phase during the peak hour equaled the demand time for the LRT (based on the estimated number of crossings during the peak hour).

Traditional capacity analysis procedures, such as those found in the Highway Capacity Manual (HCM) are not adequate for LRT-highway grade crossings, for the reasons that automatic assignment of right-of-way to the LRT under transit pre-empt operation is not addressed by the procedures, and LRT lines typically have low volumes, when compared to normal roadways which have signalized intersections. In addition, LRTs have acceleration/clearance time requirements which are substantially different from highway vehicles. Since impact on traffic operations is often a topic of concern when an LRT line is proposed, it was felt that capacity analysis procedures, dealing specifically with this type of at grade crossing, are needed.

3. Research Methodology

3.1 Introduction

This research performs traffic assessment of the Light Rail Transit (LRT) operation of the Addis Ababa LRT along the Megenagna roundabout to Ayat roundabout and Meskel square to Kality roundabout sections as illustrated in Figure 3.1. The study focuses on the analysis of the LRT-vehicle interaction and pedestrian movement at at-grae intersections.

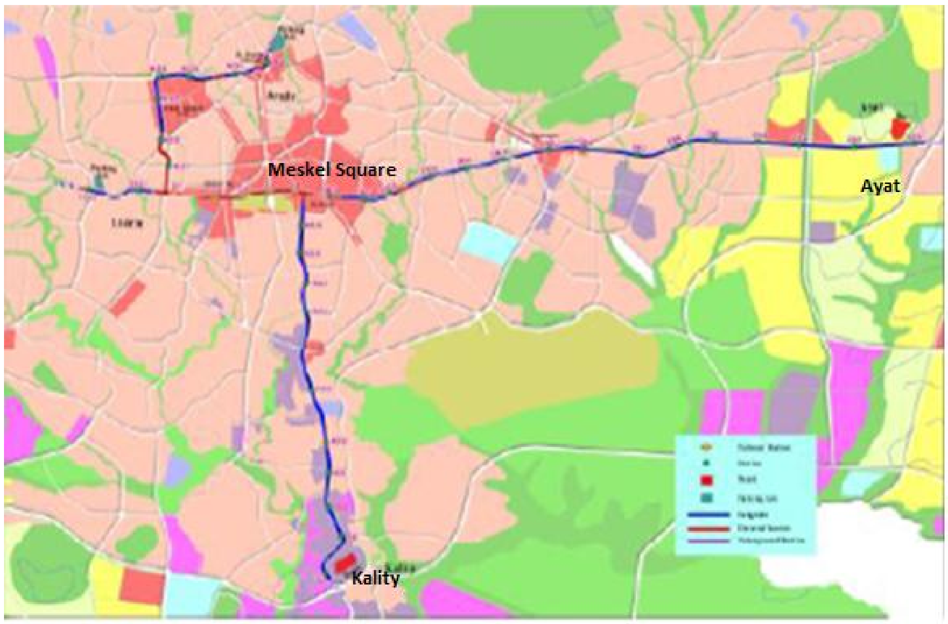


Figure 3.1: Partial North-South and East-West Routes of the Addis Ababa LRT (CREC, 2012)

The overall traffic analysis covers the LRT alignment along the two routes where the light rail vehicles, vehicles and pedestrians share at-grade crossings. The initial feasibility analysis is conducted for existing and future conditions with LRT implementation using a grade separation policy methodologies developed by the Institute of Transportation Engineers (ITE, 1992). Then the traffic analysis consisted of two steps: an analysis of existing and future conditions to assess critical crossings, followed by a detailed analysis assuming the crossings shall be converted into signalized intersections.

3.2 Study area

3.2.1 Project description

The LRT alignment the research assess runs from Station 14+540 (Megenagna roundabout) to the east end of the project (21+950) in the East-West direction and from Meskel Square (9+670) to the south end of the project (18+180), where the vehicular crossings are designed to be at-grade. The approximate length of the selected section along east-west section is 7.5 km and 8.5 km along the North-West section. Its average width is 8.0m. At proposed stop locations, a 2.5m platform with 60m length is provided. Electrically powered light rail vehicles are chosen for Addis Ababa project and it is proposed to operate at the center of the roadway crossing at-grade. (CREC, 2012, p27)

Along the network, there are three kinds of at-grade crossings where the LRT, vehicles, and pedestrian modes cross each other. These are roundabouts, junctions and U-turns. This study focuses on the roundabouts and junctions which are the main conflict spots. The study identified for analysis two roundabouts along the East-West line (CMC and Salitemihiret) as shown in Figure 3.2 and one junction along the North-South route (Adey Abeba) as shown in Figure 3.3.

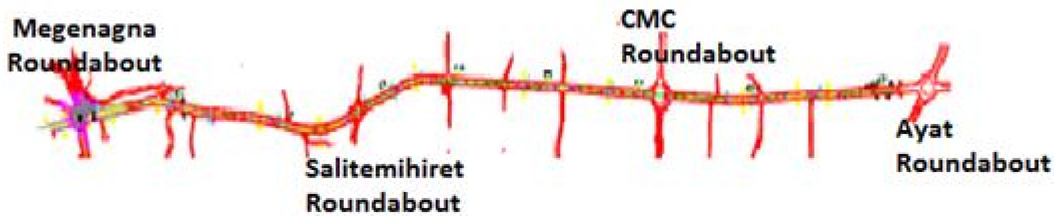


Figure 3.2: Section of East - West Route

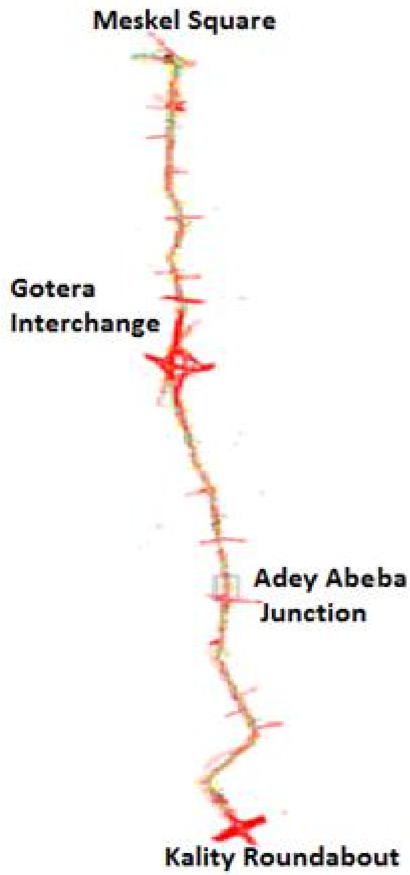


Figure 3.3: Section North - South Route

3.2.2 Intersection characteristics

(a) CMC Roundabout

The CMC roundabout connects major streets from four directions. The East and Westbound directions have four lanes running parallel to the LRT line. The south and northbound lines have two lanes each. The southbound direction is not currently operational and only the other three lines are currently used by motorists. The city government has a short term plan of connecting this roundabout to the Kotebe – Kara route via the southbound direction. It is therefore required to calculate the future generated traffic of this direction based on the current traffic volume and the research is conducted based on this adjusted data. Figure 3.4 illustrates the CMC roundabout.

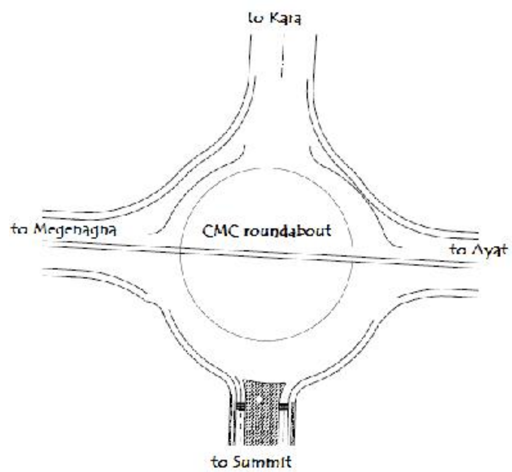


Figure 3.4: CMC Roundabout

(b) Salitemihiret Roundabout

This roundabout connects major streets from four directions. The East and Westbound directions have four lanes running parallel to the LRT line. The South and Northbound lines have two lanes each. As all directions are currently operational, no volume adjustment is made on the data used for the analysis. Figure 3.5 illustrates the Salitemihiret roundabout.

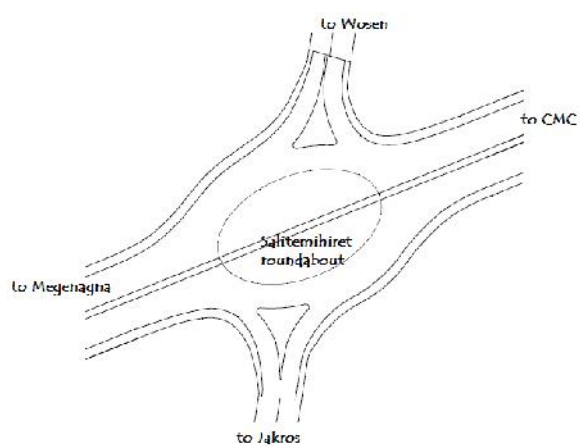


Figure 3.5 Salitemihiret Roundabout

(c) Adey Abeba Junction

This junction connects major streets from four directions. The North and South bound directions have three lanes running parallel to the LRT line. The East and West bound lines have two lanes each. As all directions are currently operating in full capacity, no volume adjustment is made on the data used for the analysis. Figure 3.6 illustrates the Adey Abeba junction.

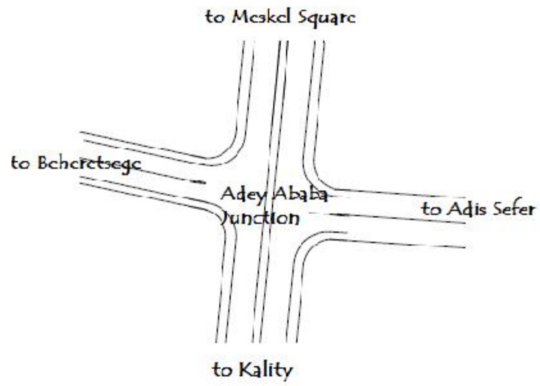


Figure 3.6: Adey Ababa Junction

3.2.3 Traffic flow/alignment characteristics

According to local people's daily travel activities and bus operation hours, it is suggested that E-W Line and N-S Line shall run from 6:00 to 22:00, totally 16 hours per day. Line and equipment maintenance shall be done at rest hours. Table 3.1 show the hourly LRT frequency of daily operation schedule of E-W Line and N-S Line. The maximum design travel speed is 70km/h, but the average travel speed is 20km/h. Trains stop at each station for 30 seconds. The E-W Line has 22 stations, with average spacing of 0.81km while the N-S Line has 22 stations, with average spacing of 0.77km. (CREC, 2012, p33)

Table 3.1: Daily Operation Schedules of E-W Line and N-S Line (CREC, 2012)

Design Time	Initial Stage (LRT frequency/hour)	Short Term (LRT frequency/hour)	Long Term (LRT frequency/hour)
6:00 – 7:00	8	8	10
7:00 – 8:00	10	11	15
8:00 – 9:00	10	11	15
9:00 – 10:00	8	9	12
10:00 – 11:00	8	9	12
11:00 – 12:00	8	9	12
12:00 – 13:00	8	9	12
13:00 – 14:00	8	9	12
14:00 – 15:00	8	9	12
15:00 – 16:00	8	9	12
16:00 – 17:00	8	9	12
17:00 – 18:00	10	11	15
18:00 – 19:00	10	11	15
19:00 – 20:00	8	9	10
20:00 – 21:00	8	8	10
21:00 – 22:00	8	8	10

A comprehensive assessment of the traffic characteristics of the East-West corridor was prepared by the Urban Transport Study carried out in 2005. The study recorded significantly high volumes of traffic along most sections of this road. The analysis of traffic survey data shows that the East-West Corridor is experiencing daily traffic volumes of the order of 20000 to 38000 vehicles. The traffic along Megenangna to CMC section is observed to have increased at 15% per annum over this same period. This magnitude of traffic growth rate is used in this study for both routes (ICT, 2012, p177).

3.3 Research Design

3.3.1 Data and Collection Procedure

The required data for analysis are listed below; sources used for data collection are also shown.

I) Geometry of intersection (recorded from site observation)
- Number of approaching lanes and configuration
- Size and capacity of intersections
- Existing curb demarcation and channelization features

II) Vehicular Operation (recorded from site observation)
- Traffic Volume data at rail/road crossing/intersections

III) Rail operation (CREC, 2012)
- LRT operating speed profile through grade crossing
- LRT hourly frequency
- LRT vehicles capacity and size
- Station type and location

IV) Pedestrians (CREC, 2012)
- Pedestrians crossing facilities locations

The data collection process was planned and performed through evaluation of spot selection criteria, sample selection, data collection time validation.

Vehicular traffic count is done manually on the weekdays of August 11-23 and November 10-15, 2014 using three observers from the Addis Ababa Transport Bureau together with the researcher. CMC and Salitemihret roundabouts from the east-west route and Adey Ababa junction from the north-south route are selected locations for the traffic count. The time for the data collection is 7:00 – 8:30 AM and 17:30 – 19:00 PM.

Review of the preliminary design of the AALRT Project, the conflict spots of LRT with vehicular and pedestrian modes is at junctions, U-turns, and LRT stations. List of these spots with relative distances are summarized in the Tables 3.2, 3.3, 3.4 and 3.5. Existing geometric parameters of selected intersections are collected and presented in Table 3.6.

Morning and afternoon peak hour traffic movement counts of intersections along the selected alignment were collected from site. The data is collected in 30 minutes interval and the maximum value is converted into hourly rate for analysis. The hourly peak values are shown in Tables 3.7 and 3.8.

1. Junction and U-turns

As provided in the project design of the AALRT (SWEROAS, 2014), Tables 3.2 and 3.3 show junctions and U-turns along the East-West (Megenagna – Ayat) and the North-South (Meskel square – Kality) lines respectively.

Table 3.2: Intersections along East-West Line

No	Name	Location	Type	Width(m)
1	Megenagna Roundabout	14+405 - 14+674	Grade separated	
2	Ministry of Mines U-turn	15+790 – 15+810	Level crossing	20
3	Salitemihiret Roundabout (west & left side)	17+142 – 17+167	Level crossing	25
		17+262 – 17+287		25
4	CMC Mikael U - turn	18+990 – 19+010	Level crossing	20
5	CMC Roundabout (west & left side)	20+067 – 20+092	Level crossing	25
		20+216 – 20+241		25
8	Ayat Village Entrance	21+940 – 21+960	Level crossing	20
9	Ayat Roundabout	LRT ends before this station		

Table 3.3: Intersections along North-South Line

No	Name	Location	Type	Width (m)
1	Meskel Square Junction	9+670	Grade separated	
2	Meshualekia Roundabout (North & South side)	10+069 – 10+094	Level crossing	25
		10+145 – 10+170		25
3	Agona U- turn	12+225	Grade separated	
4	Gotera Oilybia U- turn	13+700	Grade separated	
5	Adey Abeba Junction	15+721– 15+755	Level crossing	34
6	VOLVO company U - turn	16+854 – 16+874	Level crossing	20
7	Kality Roundabout	18+504		

2. LRT Stations

Tables 3.4 and 3.5 depict LRT stations as proposed in the schematic design of the AALRT (CREC, 2012) along the East-West (Megenagna – Ayat) and the North-South (Meskel square – Kality) lines respectively.

Table 3.4: LRT: Stations along East-West Line

No	Name	Mileage	Spacing (km)	Station type	Location
1	EW9	14+780	0.24	Ground	Megenagna Interchange east side
2	EW8	15+740	0.96	Ground	North of Ethiopian Geology Survey Bureau
3	EW7	16+590	0.85	Ground	Southeast of Telecom Office
4	EW6	17+500	0.91	Ground	South gate of Management Institute
5	EW5	18+225	0.73	Ground	Southeast of Civil Service Institute
6	EW4	19+230	1.01	Ground	
7	EW3	19+890	0.66	Ground	
8	EW2	21+040	1.15	Ground	
9	EW1	22+300		Ground	
10	Terminal	22+464		Ground	
	Average		0.81		

Table 3.5: LRT Stations along North-South Line

No	Name	Mileage	Spacing (km)	Station type	Location
1	NS15	10+350		Ground	Meshualekia Bridge South side
2	NS14	10+850	0.50	Ground	
3	NS13	11+600	0.75	Ground	
4	NS12	12+189	0.59	Ground	
5	NS11	13+969	1.79	Ground	
6	NS10	14+840	0.87	Ground	
7	NS9	15+825	0.98	Ground	
8	NS8	16+595	0.77	Ground	
9	NS7	17+205	0.61	Ground	
10	NS6	18+180	0.98	Ground	
11	Terminal	18+384			
	Average		0.87		

3. Intersection Geometric Data

Table 3.6 shows geometric data of the at-grade intersections as collected from field and design documents.

Table 3.6: Geometric Data of At-Grade Intersections

No	Intersection	Location	Number of lanes				LRT crossing distance (m)
			North bound	South bound	East bound	West bound	
1	CMC Roundabout	20+154	2	2	4	4	174
2	Salitemihiret Roundabout	17+215	3	3	4	4	145
3	Adey Abeba Junction	15+736	3	3	2	2	34

4. Traffic Volume

Tables 3.7 and 3.8 depict the Morning (AM) and Afternoon (PM) traffic volumes for CMC, Salitemihiret, and Adey Abeba Intersections of the Addis Ababa LRT. The vehicle count was made on August 2014 at CMC and Salitemihiret roundabouts, and on November 2014 at Adey Abeba junction.

Table 3.7: Traffic Count Data for Morning (AM) peak hour (in vehicles/hr)

	South bound			North bound			West bound			East bound		
Spot	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
CMC roundabout	0	2	0	982	0	186	390	1058	0	12	684	336
Salitemihiret roundabout	156	898	246	216	498	276	1254	1518	948	200	1124	132
Adeyabeba junction	446	1344	48	252	1420	86	162	116	288	1534	246	88

Table 3.8: Traffic Count Data for Afternoon (PM) peak hour (in vehicle/hr)

	South bound			North bound			West bound			East bound		
Spot	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
CMC roundabout	0	0	0	648	0	312	376	1134	0	0	1316	900
Salitemihiret roundabout	672	1362	484	276	756	824	1118	1426	456	522	1206	538
Adeyabeba junction	268	456	82	382	386	60	102	114	172	238	272	158

3.3.2 Data Analysis Procedure

3.3.2(a) Operational traffic volume analysis

Two study horizons were analyzed as part of the operational traffic analysis.

Existing Condition – Current (2014) traffic data, in which the analysis is based, is counted and adjusted to accommodate expected changes on roadway/intersection configurations in the near future.

Future Condition – Assumes a future time period in which the LRT is in place and resume stable operational condition (Year 2018). The analysis is based on revised roadway/intersection configurations, modified geometry and existing turning movement counts. The appropriate assumptions and adjustments have to be made on the operational traffic volumes.

Upon quantifying volume per lane for each direction some assumptions are made. The lanes are assigned based on existing geometry of the intersections, iteration have been done in order to optimize the practical assignment of lanes to each direction based on lane volumes. The right-turns are assumed to be segregated from the equation as they do not interfere with the intersection operation.

Referring the Addis Ababa traffic management study made in 2011 a 15% annual traffic growth rate is assumed. In addition the light rail transit system is designed to take a 30% share of the public transport. This study assumes the modal shift to the LRT system will achieve equilibrium within three years period (2016-2018). During this time the growth rate reduces to 5% (i.e total growth rate of 15% less modal shift of 10%). The AALRT system hourly train frequencies are 10 for initial stage, 11 for short term, and 15 for long term conditions as indicated in Table 3.1(ICT, 2012, p177 and CREC, 2012, p10).

3.3.2(b) Initial Analysis - Feasibility of crossing/intersection at-grade operation

A primary assessment of the at-grade crossings feasibility is based on hourly train frequency and the roadway volume. Threshold volumes are set by the ITE chart relevant to this study. (Refer Figure 2.9). The Addis Ababa LRT line is planned to operate with hourly train frequencies of 10, 11 and 15 for the initial (Year 2015), short term (Year 2018) and long term (year 2026) stages respectively. The threshold volumes for these frequencies are taken from the chart and are indicated in Table 3.9.

Table 3.9: Threshold Values for At-grade Crossing Feasibility

LRT frequency per hour	Peak hour volume per lane		
	At-grade operation Feasible Condition	Feasible with LRT delay	Grade Separation required
10	<834	>834 and <1172	>1172
11	<813	>813 and <1163	>1163
15	<731	>731 and <1131	>1131

The initial screening is based upon readily available planning-level information regarding the project description, roadway volumes and number of lanes, and train frequencies. The Initial Screening is based upon the estimated peak hour per-lane volume of traffic crossing the LRT alignment (highest directional volume). After the technical analysis has been completed, each crossing should be assigned to one of three categories: At- grade operation with full preemption is feasible, possible at-grade operation with LRT delay or grade separation is required.

3.3.2(c) Detailed Analysis - Feasibility of crossing/intersection at-grade operation

A detailed operational evaluation is performed taking into account peak period movement-by-movement analysis of roadway traffic in conjunction with assessment of potential impacts to rail operations due to priority control. It also provides more refined assessment of feasibility of at grade operation and identifies operational trade-offs between roadway traffic and rail operations.

The Detailed analysis phase utilizes all available planning information and includes conceptual design plans for the crossings. A number of inputs are required for this analysis. Geometric and traffic operational conditions at each crossing should be identified. Geometric conditions include the length of the crossing, lane configuration near the crossing. Considering the available space and capacity of downstream lanes, existing geometry might need modification to utilize the maximum capacity of the intersection.

3.3.2(d) Vehicular Traffic operation assessment

The traffic operation assessment procedure, developed by Los Angeles County Transport in 2003, is a multi-step evaluation of the capacity and performance of signal controlled intersections. It includes;

- Compute LRT crossing occupation time – The impact of rail operation on the intersection performance is dependent on the train occupation time and it has to be identified bases on train speed, crossing length, and type of controlling device.
- Compute influence zone queue – The influence zone queue is the queue which builds from an adjacent signalized intersection along the cross street towards the grade crossing. The results of the existing condition analysis and queue length analysis need to be summarized for each intersection.
- Evaluate cross street queues versus available storage – The extent of queuing along the cross street should be compared to the roadway geometry to determine whether either the crossing spillback queue is impacting an adjacent major intersection or if an adjacent major intersection is generating an influence zone queue which would impact the grade crossing.
- Compute the demand volume-to-capacity ratio of the crossing/intersection with and without the impact of LRT operation to evaluate the impact of pre-emption.

***LRT crossing occupation time*:** The first step in evaluating the impact of LRT crossing on the intersection operation is quantifying the time required for the train to cross the spot. Two cases can be used to determine the train occupation time. The first case is when full priority is given to the LRT and the other movements are prohibited whenever a train arrives at the crossing. In this case barrier gates are required to block vehicles entering the crossing and time is provided for gate closing/opening operation with the appropriate warning time. The second case is when the train is required to stop at the crossing until it is allowed to cross. In this condition the time required by the train to decelerate/ accelerate at the stopping point are to be included in train crossing time.

The total traffic blockage time (T_b) is computed as;

$$T_b = T_C + T_{GC} + T_{GO},$$

Where;

T_C, crossing time, = (length of LRT train + length of crossing)/ LRT speed
T_{GC}: warning and gate closing time
T_{GO}: gate opening and startup time

Queue analysis**:** The vehicular queue generated in each direction during crossing occupation by LRT is computed based on blockage time (T_b), approaching (V_{TL}) and discharging (V_{qd} flow rate of vehicles at the intersection.

The number of vehicles crossing at each lane (V_D) is computed as;

$$V_D = (T_b + T_{qc}) * V_{TL}$$

Where;

T_b, total traffic blockage time
T_{qc}: queue clearance time = $(V_{TL} * T_b)/ (V_{qd} - V_{TL})$

Impact of preemption**:** According to the Metropolitan Transport Authority of Los Angeles County recommendations, the analysis methodology of evaluating the impact of pre-emption requires the following stages:

- Identify useable green phase ratio for non-compatible phase;
- Adjust useable green phase ratio to reflect train frequency;
- Evaluate base case volume/capacity of Intersection; and
- Apply V/C adjustment

After the operational analysis is performed, crossings are categorized as either at grade or grade separated based upon consideration of the detailed data analysis and further consideration of possible priority strategies. In the event traffic signals are provided, the signals may be pre-empted or priority control may be utilized. With priority control, either “full” or “partial” priority can be provided. If the intersection is operating at or close to capacity, it may not be possible to provide pre-emption or high priority for LRT movements, but delays under partial priority operation may be acceptable from an LRT operations perspective.

An evaluation of the impact on cross street vehicle is to be accomplished to verify the capacity of the roadway. This requires the calculation of adjusted V/C to the intersection for scenarios of full preemption with existing geometry, full preemption with modified geometry for unusual intersections of wider crossings, and conditional priority with LRT delay condition.

The detail Step-by-step procedure for evaluation of the impact of LRT impact of preemption analysis is indicated in the following section.

Step 1: Identify useable Green phase ratio for non-compatible phase

Useable Green Phase Ratio (GC_{NC}): represents proportion of signal cycle at controlling Intersection that is useable for non-compatible roadway movements when grade crossing is blocked by gates. It is computed by averaging "Worst Case" condition when gate blockage is during non-compatible signal phases and "Best Case" condition when gate blockage is during compatible signal phases.

"Best Case" GC_1 – Condition when crossing gates are down during LRT compatible phase:

- If $GC_T > GC_C$ then GC_{NC} is reduced by the amount to which GC_T exceeds GC_C and the resulting capacity factor is: $GC_1 = GC_{NC} - (GC_T - GC_C)$
- Otherwise, if $GC_C > GC_T$ then, there is no impact to GC_{NC} since the gate blockage occurs during the compatible phase and the resulting capacity factor is: $GC_1 = GC_{NC}$

"Worst Case" GC_2 – Condition when crossing gates are down during non-LRT compatible phase

- If $GC_{NC} > GC_T$ then, the remaining amount of GC_{NC} is the difference between GC_{NC} and GC_T and the resulting capacity factor is: $GC_2 = GC_{NC} – GC_T$
- If $GC_{NC} < GC_T$ then the entire phase is blocked by the crossing gates; therefore

$$GC_2 = 0$$

"Average Case"

Assuming train arrivals are random with respect to the traffic signal, the average available signal split to serve the non-compatible traffic is approximately the average of the two conditions as noted above,

$$GC_{NC} = (GC_1 + GC_2) / 2$$

Where:

- GC_{NC}: Green phase time/Cycle time for non-LRT compatible movements at the intersection
- GC_C: Green phase time/Cycle time for compatible movements; GC_C=1.0 - GC_{NC}
- GC_T: Gate down time / Cycle time representing proportion of cycle that crossing gates will block the cross street
- GC_T – Gate down time / Total cycle time: This factor should be computed by dividing total estimated gate down time at grade crossing by typical signal cycle time at controlling intersection in seconds.

Step 2: Adjust useable Green phase ratio to reflect train frequency

When no train is present, there is no capacity impact; the likelihood of this is 1.0 minus the likelihood of a train being present during a given cycle. Therefore, the weighted capacity factor can be computed by adding the two impacts with the likelihood weights, if

L_T: Likelihood of train impact in signal cycle computed as trains / hour divided by number of traffic signal cycles per hour at controlling intersection; and

GC_{NC}: Average capacity factor on non-compatible green proportion with gates blocking crossing, computed as described in Step 1.

Then the weighted average is computed as the sum of the following conditions:

No Train 1.0 (no impact) x (1 - LT) Plus Train: GC_{NC} (train impact) x L_T

$$F_T = 1.0 - L_T + (F_{NC} \times L_T)$$

Step 3: Evaluate base case Volume to Capacity ratio of controlling Intersection

The controlling Intersection Volume to Capacity ratio, without the impact of grade crossing is expressed as:

$$\text{Volume/Capacity ratio} = V/C_0$$

Step 4: Apply Volume to Capacity ratio adjustment

The adjusted Volume to Capacity ratio of controlling Intersection with grade crossing is expressed as:

$$V/C_{ADJ} = V/C_0 / F_T$$

It is therefore possible to compute the impact of LRT operation on the capacity of an intersection following the above steps.

At the conclusion of the analysis phase, the following information and conclusions will be available:

- Preliminary disposition of at-grade or grade separated;
- Concept designs of all options, at grade and/or grade separated; designs should address issues such as complex or unusual geometry, pedestrian issues, etc.
- Traffic operations analysis such as identification of controlling intersection, capacity and LOS, projected queuing versus available storage
- Priority control options for at-grade alternatives, traffic signal or gates with proposed stop lines; conceptual definition of proposed method of traffic control;
- Train operational impacts: rail operating speed profile through grade crossings with assessment of possible train delays at traffic signal controlled locations; and
- Special studies: Any supplemental studies required as a result of site-specific considerations which could affect the crossing disposition

3.3.2 (e) Pedestrian operation assessment

The procedures followed to asses' pedestrian operation are;

- Compute average pedestrian crossing interval – The performance of pedestrian crossing facilities along a route is evaluated based on the average distance a pedestrian travel to get a crossing.
- Evaluate safety and operation of pedestrian crossing facilities through identifications of safety concerns and develop potential solutions.

4. Analysis and Results

4.1 Operational traffic volumes

The traffic volumes of each intersection are analyzed in this section. Whenever field counted data is not representatives of the future condition, necessary adjustments are made based on site specific conditions. For CMC Roundabout, existing traffic volumes are adjusted to incorporate the effect of currently inactive southbound direction which is expected to start operation in the near future. The basis for the adjustment is that it will generate similar volume as the northbound direction. Salitemihiret and Adey Abeba intersections do not need any volume adjustment for the analysis.

The traffic volumes used for initial and detail analysis for the selected intersections are indicated in the tables below. Table 4.1 depicts traffic volumes at CMC Roundabout for morning (AM) and afternoon (PM) peak hours. Similarly, Table 4.2 and Table 4.3 illustrate the morning and afternoon peak hour traffic volumes for Salitemihiret Roundabout and Adey Abeba Junctions respectively.

Table 4.1: Traffic Volumes at CMC Roundabout for AM and PM Peak Hour

	Southbound			Northbound			Westbound			Eastbound		
AM Peak Hour	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
Current Volume (Vehicle/hr)	0	2	0	982	0	186	390	1058	0	12	684	336
Adjusted Volume (Vehicle/hr)	186	491	491	491	491	186	390	1058	336	336	684	336
Number of lanes	2	2	1	2	2	1	2	3	1	2	3	1
Vehicle/hr/lane	93	246	491	246	246	186	195	353	336	168	228	336
PM Peak Hour												
Current Volume (Vehicle/hr)	0	0	0	648	0	312	376	1134	0	0	1316	900
Adjusted Volume (Vehicle/hr)	312	324	324	324	324	312	376	1134	900	900	1316	900
Number of lanes	2	2	1	2	2	1	2	3	1	2	3	1
Vehicle/hr/lane	156	162	324	162	162	312	188	378	900	450	439	900

Table 4.2: Traffic Volumes at Salitemihiret Roundabout for AM and PM Peak Hour

	Southbound			Northbound			Westbound			Eastbound		
AM Peak Hour	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
Current Volume (Vehicle/hr)	156	898	246	216	498	276	1074	1088	948	200	924	132
Number of lanes	2	2	1	2	2	1	2	3	1	2	3	1
Vehicle/hr/lane	78	449	246	108	249	276	537	363	948	100	308	132
PM Peak Hour												
Current Volume (Vehicle/hr)	672	1102	484	276	756	824	938	1208	456	522	1138	538
Number of lanes	2	2	1	2	2	1	2	3	1	2	3	1
Vehicle/hr/lane	336	551	484	138	378	824	469	403	456	261	379	538

Table 4.3: Traffic Volumes at Adey Ababa Junction for AM and PM Peak Hour

	Southbound			Northbound			Westbound			Eastbound		
AM Peak Hour	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
Current Volume (Vehicle/hr)	336	980	48	252	936	86	162	128	288	354	206	88
Number of lanes	1	2	1	1	2	1	1	1	1	1	1	1
Vehicle/hr/lane	336	490	48	252	468	86	162	128	288	354	206	88
PM Peak Hour												
Current Volume (Vehicle/hr)	268	912	82	382	772	60	102	114	172	238	272	158
Number of lanes	1	2	1	1	2	1	1	1	1	1	1	1
Vehicle/hr/lane	268	456	82	382	386	60	102	114	172	238	272	158

4.2 Initial analysis for at-grade operation feasibility

The initial screening analysis for feasibility of intersection at-grade operation is performed based on forecasted traffic volumes as discussed in the research methodology. From the preliminary assessment of traffic volumes and downstream corridor capacity the intersection shall have the following lane arrangement:

- West and Eastbound directions shall be of five lanes, two left-turn and three straight lanes for CMC and Salitemihiret Roundabouts while they have one straight and one left lane for Adey Abeba Junction.
- North and Southbound directions shall have four lanes, two lanes each for left-turn and straight directions for CMC and Salitemihiret Roundabouts while they have two straight and one left turn lanes for Adey Abeba Junction.
- A separate right-turn lane shall be furnished for each direction

The forecasted traffic volumes for initial assessment of at-grade operation feasibility are indicated in the Tables 4.4 – Table4.9.

Table 4.4: Traffic Volumes Forecast at CMC Roundabout for AM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	93	**246**	491	246	246	186	195	353	336	168	228	336
2015	107	282	565	282	282	214	224	406	386	193	262	386
2016	112	296	593	296	296	225	235	426	406	203	275	406
2017	118	311	623	311	311	236	247	447	426	213	289	426
2018	124	327	654	327	327	248	260	469	447	224	304	447
2019	137	361	722	361	361	274	287	519	494	247	335	494
2020	151	399	798	399	399	302	317	573	546	273	371	546
2021	167	441	882	441	441	334	350	633	604	302	410	604
2022	185	487	975	487	487	369	387	700	667	333	453	667
2023	204	538	1077	538	538	408	428	***773***	737	368	500	737
2024	225	595	1190	595	595	451	473	855	814	407	553	814
2025	249	657	1315	657	657	498	522	944	900	450	611	900
2026	275	726	1453	726	726	550	577	1044	994	497	675	994

Table 4.5: Traffic Volumes Forecast at CMC Roundabout for PM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	156	162	324	162	162	312	188	378	900	450	439	900
2015	179	186	373	186	186	359	216	435	1035	518	504	1035
2016	188	196	391	196	196	377	227	456	1087	543	530	1087
2017	198	205	411	205	205	396	238	479	1141	571	556	1141
2018	208	216	431	216	216	415	250	503	1198	599	584	1198
2019	229	238	477	238	238	459	277	556	1324	662	645	1324
2020	254	263	527	263	263	507	306	614	1463	731	713	1463
2021	280	291	582	291	291	560	338	679	1617	***808***	788	1617
2022	310	322	643	322	322	619	373	750	1786	893	871	1786
2023	342	355	711	355	355	684	412	829	1974	987	962	1974
2024	378	393	785	393	393	756	456	916	2181	***1091***	1063	2181
2025	418	434	868	434	434	836	503	1012	2410	1205	1175	2410
2026	462	479	959	479	479	923	556	1119	2663	1332	1298	2663

Table 4.6: Traffic Volumes Forecast at Salitemihiret Roundabout for AM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	78	449	246	108	249	276	537	363	948	100	308	132
2015	90	516	283	124	286	317	618	417	1090	115	354	152
2016	94	542	297	130	301	333	648	438	1145	121	372	159
2017	99	569	312	137	316	350	681	460	1202	127	391	167
2018	104	598	327	144	331	367	715	483	1262	133	410	176
2019	115	661	362	159	366	406	***790***	534	1395	147	453	194
2020	127	730	400	176	405	449	873	590	1541	163	501	215
2021	140	806	442	194	447	496	965	651	1703	180	553	237
2022	155	891	488	214	494	548	1066	720	1882	198	611	262
2023	171	985	540	237	546	605	***1178***	795	2079	219	676	290
2024	189	1088	596	262	603	669	1301	879	2297	242	746	320
2025	209	1202	659	289	667	739	1438	971	2539	268	825	353
2026	231	1329	728	320	737	817	1589	1073	2805	296	911	391

Table 4.7: Traffic Volumes Forecast at Salitemihiret Roundabout for PM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	336	551	484	138	378	824	469	403	456	261	379	538
2015	386	634	557	159	435	948	539	463	524	300	436	619
2016	406	665	584	167	456	995	566	486	551	315	458	650
2017	426	699	614	175	479	1045	595	511	578	331	481	682
2018	447	734	644	184	503	1097	624	536	607	347	505	716
2019	494	***811***	712	203	556	1212	690	592	671	384	558	791
2020	546	896	787	224	614	1339	762	655	741	424	617	875
2021	604	990	869	248	679	1480	842	723	819	469	681	966
2022	667	***1094***	961	274	750	1635	931	799	905	518	753	1068
2023	737	1208	1062	303	829	1807	1029	883	1000	572	832	1180
2024	814	1335	1173	334	916	1997	1137	976	1105	633	919	1304
2025	900	1476	1296	370	1012	2207	1256	1078	1221	699	1016	1441
2026	994	1630	1432	408	1119	2438	1388	1192	1349	772	1122	1592

Table 4.8: Traffic Volumes Forecast at Adey Ababa Junction for AM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	336	490	48	252	468	86	162	128	288	354	206	88
2015	386	564	55	290	538	99	186	147	331	407	237	101
2016	406	592	58	304	565	104	196	155	348	427	249	106
2017	426	621	61	320	593	109	205	162	365	449	261	112
2018	447	652	64	335	623	114	216	170	383	471	274	117
2019	494	721	71	371	688	127	238	188	424	521	303	129
2020	546	***797***	78	410	761	140	263	208	468	575	335	143
2021	604	880	86	453	841	154	291	230	517	636	370	158
2022	667	973	95	500	929	171	322	254	572	703	409	175
2023	737	***1075***	105	553	1026	189	355	281	632	776	452	193
2024	814	1188	116	611	1134	208	393	310	698	858	499	213
2025	900	1312	129	675	1253	230	434	343	771	948	552	236
2026	994	1450	142	746	1385	254	479	379	852	1048	610	260

Table 4.9: Traffic Volumes Forecast at Adey Ababa Junction for PM Peak Hour

Year	Southbound			Northbound			Westbound			Eastbound		
	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
2014	268	456	82	382	386	60	102	114	172	238	272	158
2015	308	524	94	439	444	69	117	131	198	274	313	182
2016	324	551	99	461	466	72	123	138	208	287	328	191
2017	340	578	104	484	489	76	129	145	218	302	345	200
2018	357	607	109	509	514	80	136	152	229	317	362	210
2019	394	671	121	562	568	88	150	168	253	350	400	232
2020	436	741	133	621	627	98	166	185	280	387	442	257
2021	481	***819***	147	686	693	108	183	205	309	427	489	284
2022	532	905	163	758	766	119	202	226	341	472	540	314
2023	588	1000	180	838	847	132	224	250	377	522	597	347
2024	649	***1105***	199	926	935	145	247	276	417	577	659	383
2025	718	1221	220	1023	1034	161	273	305	461	637	728	423
2026	793	1349	243	1130	1142	178	302	337	509	704	805	468

The initial screening results for CMC Roundabout show that Westbound straight lane (WBS) during morning peak hour and East bound left lanes (EBL) during PM peak hour are the high volume lanes, of which EBL is the most critical lane of the intersection. Certain right turns, namely Eastbound and Westbound, also have high volumes during PM peak hour. However, right turns do not conflict with any of the intersection movement including the LRT operation; therefore these lanes are excluded while analyzing the initial screenings analysis. Similar analysis for Salitemihiret Roundabout shows that Westbound left lane (WBL) during morning peak hour and Southbound straight lanes (SBS) are the high volume lanes, of which SBS is the most critical lane of the intersection. For Adey Abeba junction Southbound straight lane during morning peak hour is the most critical lane of the intersection. Therefore based on this screening, Table 4.10 summarizes the most critical lanes of the three intersections and shows traffic volumes for forecasted period of time.

Table 4.10: Traffic Volumes for Critical Lanes

Crossing Intersection	Critical lane	Peak hour volume per lane								
		2018	2019	2020	2021	2022	2023	2024	2025	2026
CMC	EBL –PM Peak Hour	599	662	731	**808**	893	987	**1091**	1205	1332
Salitemihiret	SBS–PM Peak Hour	734	**811**	896	990	**1094**	1208	1335	1476	1630
Adey Abeba	SBS– AM Peak Hour	652	721	**797**	880	973	**1075**	1188	1312	1450

Conclusively, after evaluating the results using the ITE Chart; the following findings can be deduced regarding at-grade operation feasibility for each intersection. Threshold volumes of ITE chart are shown in Table 3.9.

CMC Roundabout

- Until 2021, LRT operation with full preemption is possible.
- Further till 2024, operation if LRT delay is accepted (without full preemption).

Salitemihiret Roundabout

- Until 2019, LRT operation with full preemption is possible.
- Further till 2022, operation if LRT delay is accepted (without full preemption).

Adey Ababa Junction

- Until 2020, LRT operation with full preemption is possible.
- Further till 2023, operation if LRT delay is accepted (without full preemption).

4.3 Detailed analysis for at-grade operation feasibility

4.3.1 Computation of LRT crossing occupation time

Table 4.10 and 4.11 indicate the time required by the LRT train to cross the intersections with full pre-emption and with train delay. The difference between the two analyses is the time required for gate closing/opening for full preemption case.

Table 4.11: Train Crossing Occupation Time for Full Pre-emption Case

Description	**CMC**	**Salitemihiret**	**Adey Abeba**
Number of LRT vehicles per hour (N_{LRT})	10	10	10
LRT speed at crossing in km/hr (V_{LRT})	20	20	20
LRT length in m (L_{LRT})	30	30	30
Length of Crossing in m (S_{cr})	174	145	34
Crossing occupation time in seconds ($T_c = (L_{LRT} + S_{cr}) / V_{LRT}$)	37	32	12
Warning and gate closing time in seconds (T_{GC})	20	20	20
Gate opening and start up time in seconds (T_{GO})	10	10	10
Traffic blokage time in seconds (TCR $= T_C + T_{GC} + T_{GO}$)	**67**	**62**	**42**

Table 4.12: Train Crossing Occupation Time for Conditional Priority Case

Description	**CMC**	**Salitemihiret**	**Adey Abeba**
Number of LRT vehicles per hour (N_{LRT})	10	10	10
LRT speed at crossing in km/hr (V_{LRT})	20	20	20
LRT length in m (L_{LRT})	30	30	30
Length of Crossing in m (S_{cr})	174	145	34
Crossing occupation time in seconds ($T_c = (L_{LRT} + S_{cr}) / V_{LRT}$)	37	32	12
Deceleration time to stop in seconds (T_{De})	5	5	5
Acceleration time to normal speed time in seconds (T_{Ac})	5	5	5
Traffic blokage time in seconds (TCR $= T_C + T_{De} + T_{Ac}$)	**47**	**42**	**22**

The crossing occupation time for CMC and Salitemihiret intersections are higher than normal values due to the larger distance; the LRT has to travel and will have a negative effect over the capacity of the intersection. But, the values for Adey Abeba are within acceptable limit.

4.3.2 Queue Analysis

The anticipated queue of conflicting vehicular movements during full preemption of LRT is evaluated in this section. The analysis is performed based on gate blockage time by the LRT and arriving rate of each direction vehicles during peak hour. The following tables indicate buildup queue from the intersection for full preemption scenario. Year 2018 traffic volumes are used for the analysis. The conflicting (non-compatible) directions relevant for this analysis are SBL, SBS, NBL, NBS, WBL and EBL. Table 4.13, 4.14, 4.15, 4.16, 4.17, and 4.18 show the computation of generated queue during full preemption of LRT at CMC, Salitemihiret, and Adey Abeba intersections during morning and afternoon peak hours.

Table 4.13: Queue Analysis at CMC for AM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	67	67	67	67	67	67	67	67	67	67	67	67
Approach volume per lane (Vehicle/hr/lane)		124	327	654	327	327	248	260	469	447	224	304	447
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.03	0.09	0.18	0.09	0.09	0.07	0.07	0.13	0.12	0.06	0.08	0.12
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL}$ x T_b	2.29	6.06	12.11	6.06	6.06	4.59	4.81	8.70	8.29	4.15	5.63	8.29
Queue clearance time(s)	$T_{qc}= L_q/(V_{qd}-V_{TL})$	4.65	13.86	34.99	13.86	13.86	10.00	10.56	21.90	20.54	8.90	12.69	20.54
Vehicles delayed by crossing (vehicle)	$V_D=(T_b+T_{qc})*V_{TL}$	2.5	7.3	18.5	7.3	7.3	5.3	5.6	11.6	10.8	4.7	6.7	10.8

Table 4.14: Queue Analysis at CMC for PM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	67	67	67	67	67	67	67	67	67	67	67	67
Approach volume per lane (Vehicle/hr/lane)		208	216	431	216	216	415	250	503	1198	599	584	1198
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.06	0.06	0.12	0.06	0.06	0.12	0.07	0.14	0.33	0.17	0.16	0.33
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL}$ x T_b	3.85	4.00	7.99	4.00	4.00	7.70	4.64	9.33	22.21	11.10	10.82	22.21
Queue clearance time(s)	$T_{qc}= L_q/(V_{qd}-V_{TL})$	8.19	8.54	19.59	8.54	8.54	18.67	10.12	24.04	113.90	30.72	29.61	113.90
Vehicles delayed by crossing (vehicle)	$V_D=(T_b+T_{qc})*V_{TL}$	4.3	4.5	10.3	4.5	4.5	9.9	5.3	12.7	60.1	16.2	15.6	60.1

Table 4.15: Queue Analysis at Salitemihiret for AM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	62	62	62	62	62	62	62	62	62	62	62	62
Approach volume per lane (Vehicle/hr/lane)		104	598	327	144	331	367	715	483	1262	133	410	176
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.03	0.17	0.09	0.04	0.09	0.10	0.20	0.13	0.35	0.04	0.11	0.05
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL} \times T_b$	1.77	10.21	5.59	2.46	5.66	6.28	12.21	8.25	21.56	2.27	7.00	3.00
Queue clearance time(s)	$T_{qc} = L_q/(V_{qd}-V_{TL})$	3.56	28.23	12.81	5.03	13.00	14.74	37.10	20.95	121.66	4.63	16.92	6.27
Vehicles delayed by crossing (vehicle)	$V_D = (T_b+T_{qc})*V_{TL}$	1.9	14.9	6.8	2.7	6.9	7.8	19.6	11.1	64.2	2.4	8.9	3.3

Table 4.16: Queue Analysis at Salitemihiret for PM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	62	62	62	62	62	62	62	62	62	62	62	62
Approach volume per lane (Vehicle/hr/lane)		447	734	644	184	503	1097	624	536	607	347	505	716
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.12	0.20	0.18	0.05	0.14	0.30	0.17	0.15	0.17	0.10	0.14	0.20
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL} \times T_b$	7.64	12.53	11.01	3.14	8.60	18.74	10.67	9.16	10.37	5.94	8.63	12.24
Queue clearance time(s)	$T_{qc} = L_q/(V_{qd}-V_{TL})$	18.94	38.67	31.56	6.58	22.16	84.01	30.10	24.17	28.88	13.76	22.26	37.21
Vehicles delayed by crossing (vehicle)	$V_D = (T_b+T_{qc})*V_{TL}$	10.0	20.4	16.7	3.5	11.7	44.3	15.9	12.8	15.2	7.3	11.7	19.6

Table 4.17: Queue Analysis at Adey Abeba for AM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	42	42	42	42	42	42	42	41.5	42	42	41.5	42
Approach volume per lane (Vehicle/hr/lane)		447	652	64	335	623	114	216	170.4	383	471	274.2	117
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.12	0.18	0.02	0.09	0.17	0.03	0.06		0.11	0.13	0.1	0.03
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.5	0.53	0.53	0.5	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL} \times T_b$	5.16	7.52	0.74	3.87	7.19	1.32	2.49	2.0	4.42	5.44	3.2	1.35
Queue clearance time(s)	$T_{qc} = L_q/(V_{qd}-V_{TL})$	12.78	21.71	1.45	8.90	20.26	2.66	5.32	4.1	10.50	13.70	7.0	2.73
Vehicles delayed by crossing (vehicle)	$V_D = (T_b+T_{qc})*V_{TL}$	6.7	11.5	0.8	4.7	10.7	1.4	2.8	2.2	5.5	7.2	3.7	1.4

Table 4.18: Queue Analysis at Adey Abeba for PM Peak Hour

	Lane Group	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
Traffic blockage time (s)	T_b	42	42	42	42	42	42	42	42	42	42	42	42
Approach volume per lane (Vehicle/hr/lane)		357	607	109	509	514	80	136	152	229	317	362	210
Approach volume per lane (Vehicle/s/lane)	V_{TL}	0.10	0.17	0.03	0.14	0.14	0.02	0.04	0.04	0.06	0.09	0.10	0.06
Queue discharge rate (Vehicle/hr/lane)		1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
Queue discharge rate (Vehicle/s/lane)	V_{qd}	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Queue length at crossing completion (vehicle)	$L_q = V_{TL} \times T_b$	4.11	7.00	1.26	5.87	5.93	0.92	1.57	1.75	2.64	3.65	4.18	2.43
Queue clearance time(s)	$T_{qc} = L_q/(V_{qd}-V_{TL})$	9.60	19.49	2.53	15.17	15.39	1.82	3.20	3.60	5.69	8.31	9.78	5.17
Vehicles delayed by crossing (vehicle)	$V_D = (T_b+T_{qc})*V_{TL}$	5.1	10.3	1.3	8.0	8.1	1.0	1.7	1.9	3.0	4.4	5.2	2.7

The amount of vehicles accumulation at the intersection during full-preemption condition is summarized in Table 4.19 taking the larger value from the two peaks for every direction. The indicate figures are only for conflicting movements with the Light rail vehicles. The geometry of the intersection has to be modified in order to accommodate the indicated vehicle queue.

Table 4.19: Vehicle Queue during Pre-emption

Intersection / Lane Group	SBL	SBS	NBL	NBS	WBL	WBS	EBL	EBS
CMC Roundabout	5	8	8	7	6	N/A	17	N/A
Salitemihiret Roundabout	10	21	4	12	20	N/A	8	N/A
Adey Abeba Junction	7	N/A	8	N/A	3	3	8	6

4.3.3 Intersection capacity without the Impact of LRT

The intersection operational assessment is based on the evaluation of the level of service, ratio of vehicle volume to capacity with and without the impact of the LRT operation.

The traffic condition at the initial stage of LRT operation (i.e. year 2018) is analyzed below. The V/C values shown in here are calculated without the impact of LRT operation computation and are based on the following assumptions:

- The intersection will be signalized and the green time proportions of the signal phases are assigned based on the arrival rate (Vehicles/hr) of each direction.
- The left and straight are considered to operate within the same phase by taking the larger value, and the right turn is assumed to have exclusive lane that do not conflict with other operations.
- Discharge rate of 1900 vehicles per hour is taken (HCM 2000)

Table 4.20: Traffic Condition at CMC Roundabout without LRT Impact

	CMC Roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM Peak Hour	Vehicle/hr/lane	124	327	654	327	327	248	260	469	447	224	304	447
	Green time ratio	0.23	0.23	1.00	0.23	0.23	1.00	0.33	0.33	1.00	0.21	0.21	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	435	435	1,900	435	435	1,900	625	625	1,900	404	404	1,900
	V/C	0.28	0.75	0.34	0.75	0.75	0.13	0.42	0.75	0.24	0.55	0.75	0.24
PM Peak Hour	Vehicle/hr/lane	208	216	431	216	216	415	250	503	1,198	599	584	1,198
	Green time ratio	0.14	0.14	1.00	0.14	0.14	1.00	0.33	0.33	1.00	0.39	0.39	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	267	267	1,900	267	267	1,900	623	623	1,900	742	742	1,900
	V/C	0.78	0.81	0.23	0.81	0.81	0.22	0.40	0.81	0.63	0.81	0.79	0.63

Table 4.21: Traffic Condition at Salitemihiret roundabout without LRT

	Salitemihiret roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM Peak Hour	Vehicle/hr/lane	104	598	327	144	331	367	715	483	1,262	133	410	176
	Green time ratio	0.29	0.29	1.00	0.16	0.16	1.00	0.35	0.35	1.00	0.20	0.20	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	553	553	1,900	307	307	1,900	661	661	1,900	379	379	1,900
	V/C	0.19	1.08	0.17	0.47	1.08	0.19	1.08	0.73	0.66	0.35	1.08	0.09
PM Peak Hour	Vehicle/hr/lane	447	734	644	184	503	1,097	624	536	607	347	505	716
	Green time ratio	0.31	0.31	1.00	0.21	0.21	1.00	0.26	0.26	1.00	0.21	0.21	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	589.03	589.03	1,900	404.09	404.09	1,900	501.37	501.37	1,900	405.51	405.51	1,900
	V/C	0.76	1.25	0.34	0.45	1.25	0.58	1.25	1.07	0.32	0.86	1.25	0.38

Table 4.22: Traffic Condition at Adey Ababa Junction without LRT

	Adey Abeba Junction												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM Peak Hour	Vehicle/hr/lane	447	652	64	335	623	114	216	170	383	471	274	117
	Green time ratio	0.33	0.33	1.00	0.32	0.32	1.00	0.11	0.11	1.00	0.24	0.24	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	631.61	631.61	1,900	603.26	603.26	1,900	208.82	208.82	1,900	456.31	456.31	1,900
	V/C	0.71	1.03	0.03	0.56	1.03	0.06	1.03	0.82	0.20	1.03	0.60	0.06
PM Peak Hour	Vehicle/hr/lane	357	607	109	509	514	80	136	152	229	317	362	210
	Green time ratio	0.37	0.37	1.00	0.31	0.31	1.00	0.09	0.09	1.00	0.22	0.22	1.00
	Discharge rate (Vehicle/hr)	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900	1,900
	Adjusted discharge rate	705.54	705.54	1,900	597.23	597.23	1,900	176.38	176.38	1,900	420.85	420.85	1,900
	V/C	0.51	0.86	0.06	0.85	0.86	0.04	0.77	0.86	0.12	0.75	0.86	0.11

The volume-to-capacity of the crossings without the influence of LRT operation is summarized in Table 4.22 as follows:

Table 4.23: Summarized Volume to Capacity Ratio without LRT Impact

Intersection	Peak Hour	SBL	SBS	SBR	NBL	NBS	NBR	WBL	WBS	WBR	EBL	EBS	EBR
CMC	AM	0.28	0.75	0.34	0.75	0.75	0.13	0.42	0.75	0.24	0.55	0.75	0.24
	PM	0.78	.0.81	0.23	0.81	0.81	0.22	0.4	0.81	0.63	0.81	0.79	0.63
Salitemihiret	AM	0.19	**1.08**	0.17	0.47	**1.08**	0.19	**1.08**	0.73	0.66	0.35	**1.08**	0.09
	PM	0.76	**1.25**	0.34	0.45	**1.25**	0.58	**1.25**	**1.07**	0.32	0.86	**1.25**	0.38
Adey Abeba	AM	0.71	**1.03**	0.03	0.56	**1.03**	0.06	**1.03**	0.82	0.2	**1.03**	0.6	0.06
	PM	0.51	0.86	0.06	0.85	0.86	0.04	0.77	0.86	0.12	0.75	0.86	0.11

The V/C ratio is a basic parameter in evaluating capacity interns of vehicular mode. The values of V/C ratio of the CMC roundabout without LRT impact are all under 0.90 which is an equivalent of LOS D according to Transport research board recommendations and the operation of the crossing is functional.

The results for Salitemihiret Roundabout indicates that SBS, NBS, WBL, WBS, and EBS lanes during AM peak and SBS, NBS, WBS, and EBS lanes during PM peak are already over 0.90 (threshold value for LOS D) without the effect of LRT. This indicates that the vehicular operation at the crossing is over saturated even before the introduction of LRT. These values will increase even more when LRT preemption is included.

The same analysis for Adey Abeba Junction indicates SBS, NBS, WBL, and EBL directions are over saturated during AM peak while other lanes are under saturation and functional without the impact of LRT operation.

4.3.4 Intersection capacity with the Impact of LRT

An evaluation of the impact on cross street vehicle is to be accomplished to verify the capacity of the roadway. This requires the calculation of adjusted V/C to the intersection for different scenarios.

Three scenarios are evaluated as follows:

1. Scenario 1: Full preemption with current geometry of intersection
2. Scenario 2: Full preemption but modified geometry to reduce train occupation time for CMC and Salitemihiret roundabouts. Adey Abeba junction does not need this case as it has a simple geometry and further adjustment is not possible. It is assumed that the two roundabouts at CMC and Salitemihiret can be reduced to normal junction just like the Adey Abeba. In this scenario the train crossing occupation time can reduce to 42 seconds for full preemption case.(as shown in Table 4.12); and
3. Scenario 3: LRT delay is allowed and the LRT operation is considered as one phase. The LRT stops at the crossing until a compatible green phase is on. In this situation, the LRT will not have any impact on the capacity of the intersection and the V/c ratio is the same as the value obtained without the impact of LRT operation.

The adjusted volume-to-capacity ratio is calculated using the following steps:

- The usable green time ratios of Non-compatible phases is computed assuming a 100 seconds signal cycle and the proportion of green time for each direction is proportioned based on vehicle arriving rate;
- Adjustment of green time ratio to reflect train frequency; and
- Using the delay analysis parameters computed below, the V/c calculated without the impact of LRT is adjusted.

The Volume to capacity adjustment parameters for all the three intersections are computed and shown in Table 4.24.

Table 4.24: Volume to Capacity Ratio adjustment Parameters

Delay Parameters	CMC		Salitemihiret		Adey Ababa
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1
Gate blockage time(s)	67	42	62	42	42
Signal cycle (s) assume	100	100	100	100	100
Non-compatible green time (s)	70	70	70	70	70
Compatible green time (s)	30	30	30	30	30
Train frequency (train per hr)	10	10	10	10	10
GC_T	0.67	0.42	0.62	0.42	0.42
GC_{NC}	0.7	0.7	0.7	0.7	0.7
GC_C	0.3	0.3	0.3	0.3	0.3
Best case	$GC_T > GC_C$	$GC_T > GC_C$	$GC_T > GC_C$	$GC_T > GC_C$	$GC_T > GC_C$
$GC_1 =$ $GC_{NC} - (GC_T - GC_C)$	0.33	0.58	0.38	0.58	0.58
Worst case	$GC_{NC} > GC_T$	$GC_{NC} > GC_T$	$GC_{NC} > GC_T$	$GC_{NC} > GC_T$	$GC_{NC} > GC_T$
$GC_2 = GC_{NC} – GC_T$	0.03	0.28	0.08	0.28	0.28
Average case					
$GC_{NC} =$ $(GC_1 + GC_2) / 2$	0.18	0.43	0.23	0.43	0.43
Train Weighted Capacity Factor					
L_T	0.28	0.28	0.28	0.28	0.28
$F_T =$ $1.0 - L_T + (GC_{NC} \times L_T)$	0.77	0.84	0.79	0.84	0.84

Using the adjustment parameters, the volume to capacity ratio of the intersections for the different scenarios is shown in Tables 4.25, 4.26, and 4.27 for CMC, Salitemihiret, Adey Abeba intersections respectively. These results show that the impact of ten preemptions per hour is sufficient to raise the V/C of the conflicting directions well beyond capacity. After the operational analysis is performed, crossings are categorized as either at grade or grade separated based upon consideration of detail data analysis and further consideration of possible priority strategies.

Table 4.25: Volumee to Capacity Ratio of CMC Roundabout with LRT Impact

	CMC Roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	V/c without LRT impact	0.28	0.75	0.34	0.75	0.75	0.13	0.42	0.75	0.24	0.55	0.75	0.24
	Scenario 1	0.37	0.97	0.45	0.97	0.97	0.17	0.54	0.97	0.30	0.72	0.97	0.30
	Scenario 2	0.34	0.89	0.41	0.89	0.89	0.15	0.49	0.89	0.28	0.66	0.89	0.28
	Scenario 3	0.28	0.75	0.34	0.75	0.75	0.13	0.42	0.75	0.24	0.55	0.75	0.24
PM peak	V/c without LRT impact	0.78	0.81	0.23	0.81	0.81	0.22	0.40	0.81	0.63	0.81	0.79	0.63
	Scenario 1	1.01	1.05	0.29	1.05	1.05	0.28	0.52	1.05	0.82	1.05	1.02	0.82
	Scenario 2	0.92	0.96	0.27	0.96	0.96	0.26	0.48	0.96	0.75	0.96	0.93	0.75
	Scenario 3	0.78	0.81	0.23	0.81	0.81	0.22	0.40	0.81	0.63	0.81	0.79	0.63

Table 4.26: Volume to Capacity Ratio of Salitemihiret Roundabout with LRT Impact

	Salitemihiret Roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	V/c without LRT impact	0.19	1.08	0.17	0.47	1.08	0.19	1.08	0.73	0.66	0.35	1.08	0.09
	Scenario 1	0.24	1.38	0.22	0.60	1.38	0.25	1.38	0.93	0.84	0.45	1.38	0.12
	Scenario 2	0.22	1.28	0.20	0.56	1.28	0.23	1.28	0.87	0.79	0.42	1.28	0.11
	Scenario 3	0.19	1.08	0.17	0.47	1.08	0.19	1.08	0.73	0.66	0.35	1.08	0.09
PM peak	V/c without LRT impact	0.76	1.25	0.34	0.45	1.25	0.58	1.25	1.07	0.32	0.86	1.25	0.38
	Scenario 1	0.97	1.58	0.43	0.58	1.58	0.73	1.58	1.36	0.41	1.09	1.58	0.48
	Scenario 2	0.90	1.48	0.40	0.54	1.48	0.69	1.48	1.27	0.38	1.02	1.48	0.45
	Scenario 3	0.76	1.25	0.34	0.45	1.25	0.58	1.25	1.07	0.32	0.86	1.25	0.38

Table 4.27: Volume to Capacity Ratio of Adey Abeba Junction with LRT Impact

	Adey Abeba Junction												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	V/c without LRT impact	0.71	1.03	0.03	0.56	1.03	0.06	1.03	0.82	0.2	1.03	0.6	0.06
	Scenario 1	0.84	1.23	0.04	0.66	1.23	0.07	1.23	0.97	0.24	1.23	0.71	0.07
	Scenario 3	0.71	1.03	0.03	0.56	1.03	0.06	1.03	0.82	0.2	1.03	0.6	0.06
	V/c without LRT impact	0.86	0.06	0.85	0.86	0.04	0.77	0.86	0.12	0.75	0.86	0.11	0.07
	Scenario 1	1.02	0.07	1.01	1.02	0.05	0.91	1.02	0.14	0.89	1.02	0.13	0.06
	Scenario 3	0.86	0.06	0.85	0.86	0.04	0.77	0.86	0.12	0.75	0.86	0.11	0.07

The V/C ratios at the intersections are adjusted to reflect the impact of LRT as shown in Tables 4.24-4.26 for the different scenarios indicated. When the LRT operation is included with CMC Roundabout analysis, the V/C values of all lanes except WBL raise above 0.90 (LOS D threshold value) for both scenarios 1 & 2 leading to unacceptable operation (excessive vehicular delays). The analysis results at Salitemihiret Roundabout are also beyond LOS D except NBL lane indicating unacceptable delays to vehicles. The results for Adey Abeba junction are similar except EBS lane.

The results of the detail analyze, as shown above, indicate that further geometric improvements are required to improve vehicular delays induced by the impact of LRT operation. This is achieved through the provision of additional lanes for over saturated lanes near the intersections. Accordingly the following lane configurations are used for each intersection.

- For CMC intersection, it shall be of 6 lanes along the North-South directions and 7 lanes along the East-West directions.
- For Salitemihiret intersection, it shall be of 7 lanes along all the four directions.
- Adey Abeba junction shall be of 6 lanes along the North-South directions and 5 lanes along the East-West directions.

V/C values are reevaluated after geometric improvements and the results are shown below in Tables 4.27-4.29.

Table 4.28: Revised Volume to Capacity Ratio at CMC Roundabout

	CMC Roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	Number of lanes	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**4**	**1**	**2**	**4**	**1**
	Scenario 1	0.44	0.77	0.45	0.77	0.51	0.17	0.57	0.77	0.30	0.75	0.77	0.30
	Scenario 2	0.39	0.69	0.40	0.69	0.46	0.15	0.51	0.69	0.27	0.68	0.69	0.27
	Scenario 3	0.34	0.59	0.34	0.59	0.39	0.13	0.44	0.59	0.24	0.58	0.59	0.24
PM peak	Number of lanes	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**4**	**1**	**2**	**4**	**1**
	Scenario 1	1.31	0.91	0.29	0.91	0.91	0.28	0.60	0.91	0.82	0.91	0.66	0.82
	Scenario 2	1.18	0.81	0.26	0.81	0.81	0.25	0.54	0.81	0.73	0.81	0.60	0.73
	Scenario 3	1.01	0.70	0.23	0.70	0.70	0.22	0.46	0.70	0.63	0.70	0.51	0.63

Table 4.29: Revised Volume to Capacity Ratio at Salitemihiret Roundabout

	Salitemihiret Roundabout												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	Number of lanes	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**
	Scenario 1	0.27	1.03	0.21	0.67	1.03	0.23	1.03	0.52	0.79	0.45	1.03	0.11
	Scenario 2	0.25	0.98	0.20	0.64	0.98	0.22	0.98	0.50	0.75	0.42	0.98	0.10
	Scenario 3	0.23	0.86	0.17	0.56	0.86	0.19	0.86	0.44	0.66	0.37	0.86	0.09
PM peak	Number of lanes	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**
	Scenario 1	1.24	1.02	0.41	0.75	1.02	0.69	1.02	0.66	0.38	0.94	1.02	0.45
	Scenario 2	1.18	0.97	0.38	0.71	0.97	0.65	0.97	0.62	0.36	0.89	0.97	0.43
	Scenario 3	1.04	0.85	0.34	0.62	0.85	0.58	0.85	0.55	0.32	0.78	0.85	0.38

Table 4.30: Revised Volume to Capacity Ratio at Adey Abeba Junction

	Adey Abeba Junction												
		Southbound			Northbound			Westbound			Eastbound		
	Lane Group	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
AM peak	Number of lanes	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**2**	**1**	**2**	**2**	**1**
	Scenario 1	0.38	0.75	0.04	0.30	0.75	0.07	0.75	0.59	0.24	0.75	0.43	0.07
	Scenario 3	0.32	0.63	0.03	0.25	0.63	0.06	0.63	0.50	0.20	0.63	0.37	0.06
PM peak	Number of lanes	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**2**	**1**	**2**	**2**	**1**
	Scenario 1	0.63	0.07	0.47	0.63	0.05	0.56	0.63	0.14	0.55	0.63	0.13	0.06
	Scenario 3	0.53	0.06	0.39	0.53	0.04	0.47	0.53	0.12	0.46	0.53	0.11	0.07

After revision of the V/C ratio values; at CMC Roundabout all lanes, except WBL and EBS during PM peak hour, exhibit unacceptable delay range (below LOS D) for Scenarios 1. In the case of Scenario 2, only NBL lane has unacceptable value. Scenario 3 only NBL has unacceptable value. This makes both scenarios 2 and 3 possible operations for the intersection.

At Salitemihiret Roundabout the results for Scenarios 1, and 2 are still beyond LOS D making both Scenarios unfeasible, but for Scenario 3 with the exception of NBL lane the results are acceptable (LOS D or above). Therefore Scenario 3 is a feasible operation for this intersection. Similar analysis for Adey Abeba Junction indicates that the delays are acceptable for both cases and each type of operations is feasible for the intersection.

4.4 Analysis of Pedestrian Crossing Facilities

According to the schematic design of the AALRT, pedestrian crossings are provided at junctions and station locations. The Addis Ababa City Road Authority (AACRA) is planning to build 5 overpass bridges with pedestrian facility in the near future. Two of them are along the East-West line and the rest three units are along the North-South line. The relative distances of these facilities are shown in Table 4.31 for the East-West line and Table 4.32 for the North-South line.

Table 4.31: Pedestrian Facilities along the East-West Route

Crossing	Location	Distance (m)
Megenagna Square	14674	
EW9	14780	106
EW8	15740	960
Ministry of Mines U-turn	15800	60
EW7	16590	790
Salitemihret Roundabout - West side	17155	565
Salitemihret Roundabout - East side	17275	120
EW6	17500	225
AACRA overpass	18150	650
EW5	18225	75
AACRA overpass	18660	435
CMC Mikael u - turn	19000	340
EW4	19230	230
EW3	19890	660
CMC Roundabout – West side	20080	190
CMC Roundabout – East side	20229	149
EW2	21040	811
Ayat village entrance	21950	910
Average Distance		428

Table 4.32: Pedestrian Facilities along the North-South Route

Crossing	Location	Distance (m)
Meskel square	9670	
Meshualekia Roundabout	10120	450
NS15	10350	230
NS14	10850	500
NS13	11600	750
NS12	12189	589
Agona U- turn	12225	36
Gotera oilybia U- turn	13700	1475
NS11	13969	269
NS10	14840	871
Adey abeba junction	15738	898
NS9	15825	87
NS8	16595	770
VOLVO company U- turn	16864	269
NS7	17205	341
NS6	18180	975
NS5	18384	204
Kality Roundabout	18504	120
Average Distance		520

The research has identified the following operational and safety issues at pedestrian crossings

- The above analysis shows that a maximum distance to be covered by a pedestrian to find a crossing is half of the average crossing interval. This is 214m and 260m for East-West and North-South routes respectively;
- Pedestrian conflicts at stations where pathways are oriented in such a way that pedestrians tend to cross both tracks at the same time. As LRVs approach from both directions, there is an evident safety concern for crossing pedestrians;
- Path ways are designed perpendicular to the tracks alignment and crossing pedestrians are not forced to face the direction from which LRVs approaches as they walk along the crossing path; and
- The lack of refuge space between the LRT and vehicular right-of-way for trespassing pedestrians has a safety issue.

5. Conclusions and Recommendations

5.1 Conclusions

Assessment of the analysis results show that the factors affecting operation of at-grade crossings of the AALRT are;

- Geometry of intersection;
- LRT frequency, crossing occupation time, degree of priority, and preemption effect;
- Number and flow rate of vehicles; and
- Type of pedestrian crossing facilities.

Based on the initial screening results, the intersections can operate at-grade with full preemption to LRT till the year 2019, 2020 and 2021 for Salitemihiret, Adey Abeba and CMC intersections respectively. Each intersection may operate at-grade for further three years with LRT conditional priority. In this case, the LRT will hold at the crossing until convenient phase is actuated.

LRT crossing occupation time: LRT crossing durations have been computed for both cases of full preemption and conditional priority. The results for the first case (i.e. full preemption operation with gates) are 67, 62 and 47 seconds for CMC, Salitemihiret, and Adey Abeba intersections respectively. The crossing time at Adey Abeba Junction is equivalent to a typical crossing time and it is acceptable; however, crossing time at the other two intersections are excessive due to the unusually long crossing distances. Similarly, for the second case (i.e. conditional priority operation without gate), the time requirement for the intersections are 47, 42, and 22 seconds for CMC, Salitemihiret, and Adey Abeba intersections respectively. Crossing occupation time could be reduced by changing the geometry of the roundabout into normal junction.

Queue Analysis: Vehicle queue generated during crossing blockage by the LRT are computed. For CMC intersection, the most affected direction is EBL where 17 vehicles are accumulated. Similarly at Salitemihiret, SBS and WBL lanes collect 21 & 20 vehicles. The same analysis for Adey Abeba results in 12 & 11 vehicles at SBS and NBS lanes. The complex roundabout geometry of the CMC and Salitemihret intersections results high queue accumulation around the roundabout. This queue can influence or even block the through traffic parallel to the LRT. It can also create a bottleneck and other direction crossers can be trapped on the LRT right-of-way resulting in safety concern. Turning lanes that are able to accommodate the indicated amount of vehicles for each direction is required near the intersection for smooth operation.

Detail analysis findings: The geometry of the crossings is revised to improve capacity of the intersections. By modified lane configurations, crossing capacities can be enhanced and delays can be contained within acceptable range of LOS D or above. Accordingly resulting lane configuration and subsequent operational effects are discussed as follows;

- The lane configurations that are suitable for CMC intersections feasible at-grade operation are of 6 lanes along the North-South directions and 7 lanes along the East-West directions. The direction of these lanes will be 2 left turn, 3 straight, and 1 right turn for North-South direction. 2 left turn, 4 straight, and 1 right turn for East-West direction.

- The lane configurations that are suitable for Salitemihiret intersections feasible at-grade operation are of 7 lanes for both the North-South and East-West directions. The direction of these lanes will be 2 left turn, 4 straight, and 1 right turn.

- For Adey Abeba junction the lane configuration required based on the detail analysis is of 6 lanes along the North-South directions and 5 lanes along the East-West directions. The direction of these lanes will be 2 left turn, 3 straight, and 1 right turn for North-South direction. 2 left turn, 2 straight, and 1 right turn for East-West direction.

Based on the analysis made there are three types of operations; they are full preemption priority with current crossing distance maintained, full preemption priority with reduced crossing distance, and conditional priority with LRT delay. For Adey Ababa junction the second option is not available as the crossing distance cannot be further reduced.

The resulting V/C values computed with new lane configurations indicate which possible types of operation and priority scheme for each crossing;

- At CMC roundabout full preemption with reduced crossing distance and conditional priority are feasible. Full priority with current geometry is not a feasible type of operation as resulting delays are excessive.
- At Salitemihiret roundabout full preemption operation is not feasible. Conditional priority with LRT delay is a feasible type of operation.
- For Adey Abeba junction both full preemption and conditional type of operations are feasible

The analysis performed for pedestrian movement shows that the average crossing distance interval is about 250m. This is the maximum distance a pedestrian has to travel to reach his/her destination across street. This is a manageable distance and there is no need for additional pedestrian facilities along the selected route.

There are two major safety issues concerning pedestrian crossing facilities along the LRT right-of-way. The first issue is that the orientation of pedestrian pathways does not assist pedestrians to face approaching light rail vehicles. As light rail vehicles come from both directions, pedestrians get confused and it is a safety concern. Secondly, trespassing and LRT passengers have to cross vehicular right-of-way to cross street or access trains. As there is no neutral refuge area in-between there is a safety risk.

5.2 Recommendations

Following the concluding remarks and concept designs the following recommendations are proposed for the Addis Ababa Light Rail Transit at-grade crossings:

The first question to be addressed concerning the feasibility of these crossings is ‘when to grade separate?’ As per the outputs of the study, the crossings are recommended to operate at-grade till the threshold years of 2022, 2023, and 2024 for Saitemihiret, Adey Abeba, and CMC intersections respectively. Although the crossings are expected to operate at-grade for the specified periods of time, the following series of action points are required to supplement the feasibility of crossings;

Geometric improvements: Intersections have to be redesigned to have a simple geometry as much as possible. This includes modifying the crossing distance wherever required to reduce crossing occupation time, and furnishing additional lanes at intersection approach to channelize vehicles as per their turning movement. The additional lanes should run to length at least equal to the length of generated queue of vehicles in the respective direction.

Priority scheme: Two types of priority schemes are used depending on specific properties of the crossing. Either full priority is given to the LRT or conditional priority is given and some delay to LRT is negotiable. Accordingly the recommended lane configuration and priority type for the AALRT at-grade crossings are given below.

CMC roundabout: The East-West lines shall have 7 lanes (2 left, 4 straight, and 1 right) and the North-South lines shall have 6 lanes (2 left, 3 straight, and 1 right) near the intersection. The recommended priority scheme for this intersection is a) modify the crossing to reduce crossing distance and operate with full preemption or, b) if costs do not allow this, it is advised to keep the existing crossing distance and operate with conditional priority. In this case, whenever LRT approach the crossing it has to stop till a compatible green phase signal is actuated.

Salitemihiret Roundabout: The East-West lines shall have 7 lanes (2 left, 4 straight, and 1 right) and the North-South lines shall have 6 lanes (2 left, 3 straight, and 1 right) near the intersection. The only recommended priority scheme for this intersection is conditional priority. Modification of crossing distance will have no effect on the operation of the intersection.

Adey Abeba Junction: The East-West lines shall have 5 lanes (2 left, 2 straight, and 1 right) and the North-South lines shall have 6 lanes (2 left, 3 straight, and 1 right) near the intersection. This junction can operate with full priority for the LRT keeping existing crossing distance.

If cost-benefit analysis do not allow the elimination of these crossings or funding is not available at the specified milestone years of 2022, 2023, and 2024 for Salitemihiret, Adey Abeba and CMC intersections respectively, geometry of the intersection can be modified to increase capacity.

Traffic Control Systems: For vehicular traffic, a separate traffic signal should be installed. Signal phasing and time should coordinate with LRT operation. LRT warning signs, pre-signals or signal progressions should be installed and in case of full preemption operation with gates is recommended. For conditional priority operation, a non-gated alignment controlled by separate LRV signal indications is recommended.

Left turns across LRV tracks pose both capacity and safety concerns. These turns should either be provided and protected or prohibited and redirected. Left turn lanes should have sufficient vehicle storage distance. Therefore the provision of adequate storage areas (turn bays) for turning traffic is recommended. Vehicles should be channelized near crossing using channelization devices (traffic dots or flexible posts).

Demand Management Strategies: The following recommendations are forwarded to peak hour travel demand and subsequently reduce traffic congestions at LRT-Highway crossings.

- An intelligence transport system that includes message signs, radio reports and internet information about traffic condition has to be implemented. This will inform drivers about traffic condition, reduce delay and improve safety;
- Traffic management centers that are equipped with the necessary manpower, up-to-date surveillance system, and car moving equipments need to be organized. This unit will prevent, identify and respond to incidents caused by disabled cars, accidents and dangerous driving;
- Flexible working time: Companies should have flexible working hours. For example, rather than all employees working 8:30 to 5:30, some might work 8:00 to 4:30, and others 9:00 to 6:00. This shifts travel from peak to off-peak periods;
- LRT system should be able to provide high quality service in terms of convenience and frequency to attract sufficient travelers from other modes of transport;
- Freight trucks should be restrict during rush hours; and
- A reliable and efficient telecommunication system has to be aspired to substitute for physical travel. Sales and field workers would be able to work without the need to move and self-employed people would be are able to work from a home office. This will allow people to avoid traveling under congested conditions.

Pedestrian crossings: In order to avert the issues identified concerning pedestrian crossings facilities in the AALRT project, the following counter measures are recommended;

- Pedestrian pathways should be z-crossing channelization type so that pedestrian face in the direction of approaching train while crossing; and
- Pedestrian refuge area between tracks and roadway should be provided at crossings and stations to projects pedestrians from parallel traffic.

6. Proposals for Future Studies

Traffic management in general and evaluation of LRT at-grade crossings in particular is a vast significant study area. Furthermore; as the country is planning to implement more transport projects in coming years, the need for more researches on the subject is critical and timely. Due to its importance, there are many ways of continuing this research concept. Consequently; some of the areas that the author thinks require further studies are presented below.

- Preparation of Guidelines for the Design and Implementation of Grade Crossings: Currently, studies on the subject of LRT-Highway crossings evaluation are being performed by adaptation of procedures developed in other countries (mainly in the US). Methodologies used in these methods have to be thoroughly reviewed to check their adaptation and applicability in local context. Therefore, there is the need for the preparation of local standard manual for the evaluation of LRT crossings is vital and a study for its preparation is needed.

- Computation of LRT Impact Parameters on Crossings: Traditional LRT-Highway crossing capacity analyses procedures do not adequately address the effect of train operations on the capacity of crossings. There are no specific LRT impact parameters that define its effect on crossing capacity. A research can be designed to identify and quantify these impact parameters and one can use these parameters to evaluate the capacity of any LRT-Highway crossing.

- Methods to Improve the Capacity of LRT-Highway Crossings: Crossing capacity: Further researches on the area of Traffic Demand Management (TDM) can be performed to identify methods that can help to improve the capacity of crossing and reduce the impact o preemption without the need for grade separation facility. This will help to prolong the need for high cost constructions.

- The Problem of the Effect of Old Cars and Attitude of Drivers on LRT-Highway Crossings: There is a significant number of old cars running in the street of Addis Ababa and their effect on crossing operation have to be studied. In addition, Drivers attitude in respecting road use rules is a concern. Therefore, a study could be conducted to identify the associated problems and come up with recommendations

- Evaluation of At-Grade Pedestrian Crossings on LRT-Highway Operation: A research may be conducted to evaluate the feasibility of at-grade pedestrian crossings in detail. Risks associated with this kind of facilities have to be identified and corrective measures can be devised.

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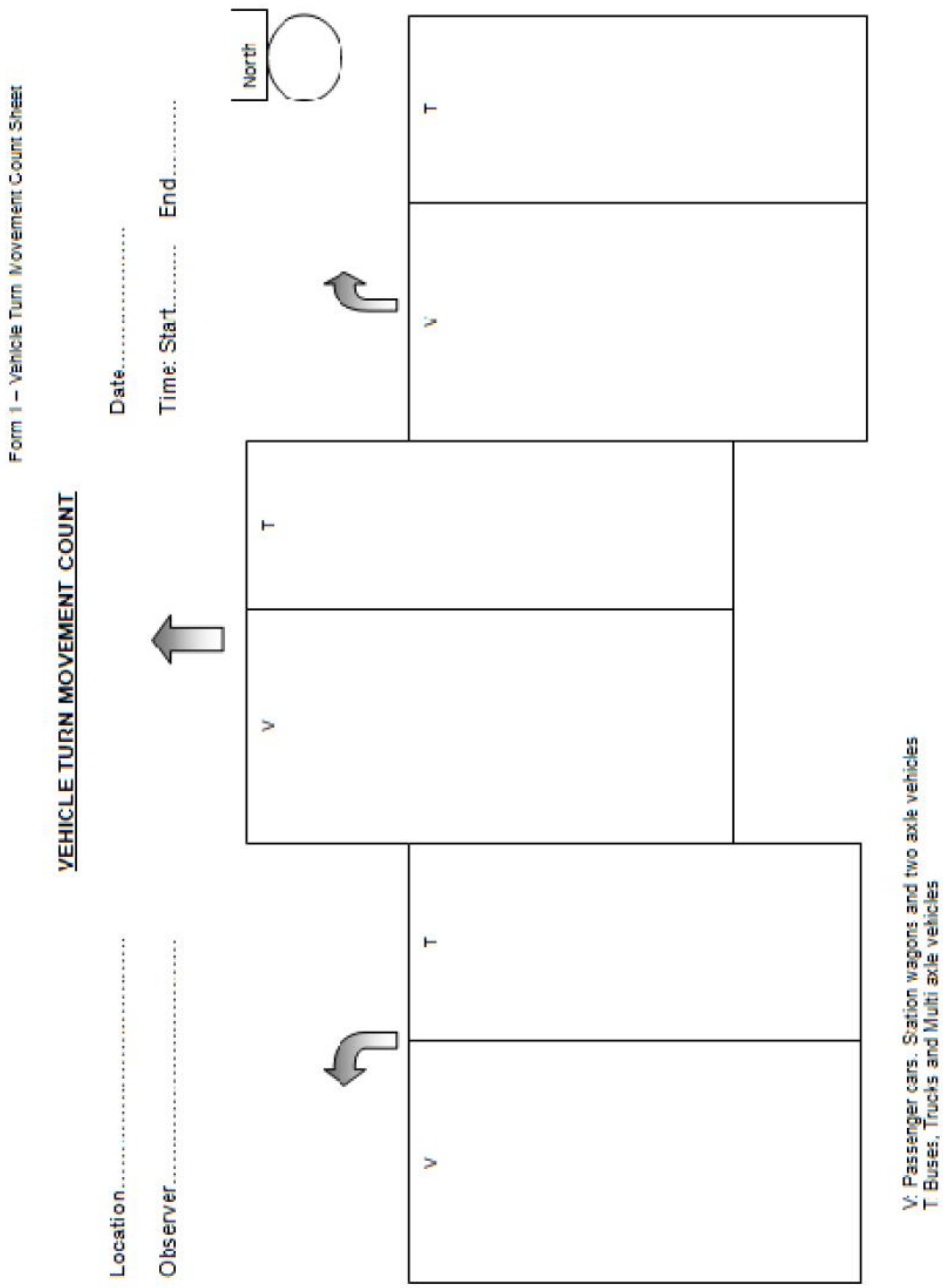
APPENDIXES

Appendix A1 Traffic turn movement count sheet



Appendix A2 Vehicle count summary sheet

Form 2 – Vehicle Count Summary Sheet

VEHICLE COUNT SUMMARY

Location.....................................

Observer.....................................

Date.....................

Time: Start.......... End...........

Time	From North				From South				Total N- S	From East				From West				Total E-W	Total All
	Right	Straight	Left	Total	Right	Straight	Left	Total		Right	Straight	Left	Total	Right	Straight	Left	Total		

Appendix A3 Traffic count data for CMC roundabout AM peak

CMC - AM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
7:00 -7:30	small veh	0	1	2	428	0	54	98	376	0	5	78	66
	Bus & truck	0	0	0	19	0	0	22	38	0	0	6	24
7:30 - 8:00	small veh	0	0	1	375	0	57	129	394	0	6	180	96
	Bus & truck	0	0	0	21	0	3	16	45	0	0	27	18
8:00 - 8:30	small veh	0	0	0	301	0	54	124	318	0	4	150	60
	Bus & truck	0	0	0	18	0	12	15	23	0	0	54	15
	small veh	0	2	0	856	0	114	258	788	0	12	360	192
	Bus & truck	0	0	0	42	0	24	44	90	0	0	108	48
	Bus & truck after PCU factor of 3	0	0	0	126	0	72	132	270	0	0	324	144
Veh/hr		0	2	0	982	0	186	390	1058	0	12	684	336

Appendix A4 Traffic count data for CMC roundabout PM peak

CMC - PM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
17:00 -17:30	small veh	0	0	0	151	0	21	67	372	0	0	228	363
	Bus & truck	0	0	0	34	0	12	4	61	0	0	84	24
17:30 - 18:00	small veh	0	0	0	169	0	43	67	384	0	0	406	366
	Bus & truck	0	0	0	24	0	8	12	42	0	0	36	18
18:00 -18:30	small veh	0	0	0	252	0	120	137	368	0	0	354	346
	Bus & truck	0	0	0	12	0	6	17	48	0	0	60	28
	small veh	0	0	0	504	0	240	274	768	0	0	812	732
	Bus & truck	0	0	0	48	0	24	34	122	0	0	168	56
	Bus & truck after PCU factor of 3	0	0	0	144	0	72	102	366	0	0	504	168
Veh/hr		0	0	0	648	0	312	376	1134	0	0	1316	900

Appendix A5 Traffic count data for Salitemihiret roundabout AM peak

Salitemihiret - AM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
7:00 -7:30	small veh	21	264	81	48	186	36	426	225	257	34	240	54
	Bus & truck	18	23	9	6	19	9	26	34	38	5	40	0
7:30 - 8:00	small veh	24	287	84	76	151	84	407	442	348	46	298	66
	Bus & truck	10	31	12	8	21	18	29	34	42	18	52	0
8:00 - 8:30	small veh	17	216	67	84	168	58	418	395	302	18	306	62
	Bus & truck	2	54	13	6	18	15	37	32	37	1	47	0
	small veh	48	574	168	168	372	168	852	884	696	92	612	132
	Bus & truck	36	108	26	16	42	36	74	68	84	36	104	0
	Bus & truck after PCU factor of 3	108	324	78	48	126	108	222	204	252	108	312	0
Veh/hr		156	898	246	216	498	276	1074	1088	948	200	924	132

Appendix A6 Traffic count data for Salitemihiret roundabout PM peak

Salitemihiret - PM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
17:00 -17:30	small veh	114	378	95	66	192	205	318	364	88	180	336	92
	Bus & truck	42	30	13	11	12	19	36	63	17	12	42	22
17:30 - 18:00	small veh	168	422	128	84	270	286	334	388	114	204	398	128
	Bus & truck	56	43	38	18	36	42	45	72	38	19	57	47
18:00 -18:30	small veh	136	405	108	83	256	267	304	355	106	176	378	96
	Bus & truck	48	33	35	13	32	39	44	63	22	11	38	34
	small veh	336	844	256	168	540	572	668	776	228	408	796	256
	Bus & truck	112	86	76	36	72	84	90	144	76	38	114	94
	Bus & truck after PCU factor of 3	336	258	228	108	216	252	270	432	228	114	342	282
Veh/hr		672	1102	484	276	756	824	938	1208	456	522	1138	538

Appendix A7 Traffic count data for Adey Ababa Junction AM peak

Adey Ababa - AM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
7:00 -7:30	small veh	72	254	24	90	240	18	18	30	58	85	63	14
	Bus & truck	6	62	22	14	53	6	5	2	13	17	1	2
7:30 - 8:00	small veh	88	262	13	84	276	19	48	42	102	126	88	7
	Bus & truck	24	76	0	0	64	8	0	3	6	12	3	5
8:00 - 8:30	small veh	96	258	24	65	252	11	63	58	78	95	54	17
	Bus & truck	18	67	0	0	55	0	6	2	14	7	5	9
	small veh	192	524	48	168	552	38	126	116	204	252	176	34
	Bus & truck	48	152	0	28	128	16	12	4	28	34	10	18
	Bus & truck after PCU factor of 3	144	456	0	84	384	48	36	12	84	102	30	54
Veh/hr		336	980	48	252	936	86	162	128	288	354	206	88

Appendix A8 Traffic count data for Adey Ababa Junction PM peak

Adey Ababa - PM Peak

Time	Type of veh	South bound			North bound			West bound			East bound		
		Left	Straight	Right	Left	Straight	Right	Left	Straight	Right	Left	Straight	Right
17:00 -17:30	small veh	45	179	17	108	154	18	29	27	42	64	76	28
	Bus & truck	22	51	8	13	56	4	5	7	4	6	11	15
17:30 - 18:00	small veh	54	228	14	116	182	10	36	33	68	83	94	34
	Bus & truck	14	76	3	25	68	2	5	8	6	12	14	12
18:00 -18:30	small veh	68	188	11	96	158	12	32	30	55	66	81	31
	Bus & truck	11	59	4	11	44	0	2	8	5	9	9	14
	small veh	136	456	34	232	364	36	72	66	136	166	188	68
	Bus & truck	44	152	16	50	136	8	10	16	12	24	28	30
	Bus & truck after PCU factor of 3	132	456	48	150	408	24	30	48	36	72	84	90
Veh/hr		268	912	82	382	772	60	102	114	172	238	272	158