ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

Assessing Major Safety Issues on Highway-Railroad Grade Crossings along the Addis Ababa Light Rail Transit

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in a partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Railway Engineering Stream)

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The undersigned have examined the thesis entitled 'Assessing Major Safety Issues on Highway-Railroad Grade Crossings along the Addis Ababa Light Rail Transit' presented by Berhanu G/yohannes, a candidate for the degree of Master of Science and hereby certify that it is worthy of acceptance.

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Berhanu G/yohannes

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ABSTRACT

Of the whole railway line, the major part where frequent accidents occur is highway-railroad at grade crossings. The grade crossings along Addis Ababa Light Rail Transit (AA LRT) are located at areas with high pedestrian and vehicular traffic. Therefore safety levels at AALRT grade crossings will be major concern during operation. This research study assessed major safety issue at highway-railroad at grade crossings along AA LRT using accident rating models and highway-railroad level crossing engineering design guidelines and standards.

The study identified the design and construction of highway-railroad level crossings along AALRT satisfied most of the design guidelines and criteria outlined by American Railway Engineering and Maintenance-Of-Way Association AREMA manual, Chinese standard GB50090, Federal Highway Association FHWA handbook and manual on uniform traffic control devices MUTCDS.

Despite being compliant to the above design standards, level crossings at Tsehay Realestate roundabout, Salitemihiret roundabout, Adey Ababa and Sebategna junction found to have highest accident number. The geometry of the crossings and the traffic volume operating at these sections of AALRT are found to be major reasons for such high accident rate.

For type 'F' traffic control system the smallest expected accident number per year is 0.28 at Kality side Meshualekiya roundabout level crossing. This result is higher than 0.075 a threshold value for the use of type 'G' traffic control system. Therefore the gates at the level crossings of AALRT should start operation.

When gates are operational, accident frequencies from US DOT model are greater than 0.2 on the above hazardous level crossings. This 0.2 accident/year is the threshold value for grade separation. Therefore level crossings at Tsehay Realestate roundabout, Salitemihiret roundabout, Adey Ababa and Sebategna junction should be considered for grade separation if the cost of grade separation can be economically justified based on fully allocated life-cycle costs.

Key words: Highway-railroad grade crossing safety, Light rail transit system, design standards, accident rating models

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ACRONYMS

AACRA- Addis Ababa City Road Authority

AADT- Annual Average Daily Traffic

AALRT- Addis Ababa Light Rail Transit

AASHTO- American Association of State Highway and Transportation Officials

ADT- Average Daily Traffic

AREMA- American Railway Engineering and Maintenance-of-Way Association

CREC- China Railway Group Limited

EAF- Expected Accident Frequency

ERC- Ethiopian Railway Corporation

E-W LINE- East-West Line

FHWA- Federal Highway Administration

HI- Hazard Index

ICT- International Consultants and Technocrats Pvt. Ltd.

LRT- Light Rail Transit

MTA- Metropolitan Transport Authority

MUTCD- Manual on Uniform Traffic Control Devices

NA- Not Applicable

N-S LINE- North-South Line

NTF- Night Time Factor

OCC- Operation Control and Communication

PAS- Primary Arterial System

SCF- Seasonal Conversion Factor

TCD- Traffic Control Devices

USDOT- United State Department of Transportation

CHAPTER 1 INTRODUCTION

1.1 Background

Over the last years, the Ethiopian federal authorities have significantly increased funding for transportation and communication. Through Road Sector Development Program 40,797 km of both paved and unpaved roads constructed by the end of 2007 (World Bank, 2014). However, the transportation problem in the country especially in the capital Addis Ababa couldn't be solved. This resulted the need to develop the national railway network including the capital Addis Ababa and major cities of the country.

These corridor development projects range from phase one to phase five in order to construct 5000km railway network for passenger and freight transportation (ERC, 2010). The Addis Ababa light rail transit project (AA LRT) was part of phase one national program. The project included two routes of the East-West line with an approximate length of 17km stretched between Ayat roundabout and Torhiloch and the North-South line with the same length stretched from Menilik II square to Kality roundabout. Therefore the railway corridors are expected to pass through densely populated areas. This can pose significant challenges as these areas are likely to have many grade crossings.

Highway-railroad grade crossing safety is an integral part of Addis Ababa light rail transit operation and culture which involves the daily cooperative effort of many stakeholders. Because oncoming trains cannot stop for vehicles whose drivers violate traffic laws when approaching railroad tracks (Jeng *O.-J., 2005)*. Therefore highway-rail grade crossings are equipped with Traffic control devices (TCDs) to remind highway users that they must stop for trains. Any violation of such TCD represents the opportunity for a collision between a highway vehicle and a train, which can result in casualties, extensive property damage, and even the release of hazardous materials.

The most economical approach to eliminate accident cost at crossing is arguably to close it; however, communities are often opposed to closing existing grade crossings in their area because of a perceived loss of convenience, as well as concerns about increased emergency service response time and reduced access to schools and other strategic places. If a crossing cannot be closed, other approaches must be considered by critically evaluating crossings for accident level. These include:-

- Grade separation
- Community education and awareness
- Train crew education and field operations testing to monitor rules compliance
- Crossing safety technology
- Crossing resurfacing
- Installation of warning devices
- Track and signal inspection and maintenance

Above all regulations and standards regarding to design consideration, signaling principle and traffic operation at such section of the railway network has to be developed (Rose, J.G. 2009).

This topic of highway-rail grade crossing Safety has been extensively researched over the years in other countries, primarily with a focus on investigating existing conditions which might have encouraged drivers not to take reasonable precautions. The purpose of this research study is to assess grade crossings along Addis Ababa Light Rail Transit for safety based on standards and accident measuring models. The study constitutes evaluating grade crossings from design point of view, prioritize crossings that have the most need for safety and operational improvement to comply with requirements of safety using hazard index model, predict accidents at a crossing and possible safety measures and mitigation if it is determined that the crossings are hazardous. Results from this study are expected to identify principal technical challenges related to grade crossings safety and gives a mechanism to identify hazardous crossings for upgrading and maintenance. This will facilitate the traffic operation planning, development, construction, and management of light rail project in Addis Ababa.

1.2 Statement of the Problem

Of the whole railway line, the major part where frequent accidents occur is railroad-highway at grade crossings. Besides to this most of AA LRT grade crossings are located at areas with high pedestrian and vehicular traffic, which increases the risk of collisions. The geometry of the crossing along the two lines of AALRT is either U-turn (Ayat village entrance, CMC Mikael and office of Ministry of Mines crossings along East-West line and VOLVO company crossing on North- South line), roundabout (Tsehay real estate and

Salitemihret roundabout crossings along East-West line and Meshualekia roundabout crossing of North- South line) or junction (Sebategna and Adey Abeba crossings along North- South line). In addition to such geometrical complexity, on such section of railway track, the traffic segments that operate is also increased like pedestrians, vehicle drivers and train drivers. Therefore the likelihood of accidents at grade crossing will be diversified and amplified as result of conflict between these traffic segments.

Lack of previous experience and considering the above factors, an assessment of major safety issues on highway-railroad level crossings along the Addis Ababa light rail transit have to be performed.

1.3 Objectives

1.3.1 General Objectives

The general objective of the study is to asses major safety issues at highway – railroad grade crossing and suggest possible design and provisional solution. The lack of previous study on the context of Ethiopia, this study can be used as an initial for further study.

1.3.2 Specific Objectives

The specific objectives of the study involves:-

1. Evaluating grade crossings from design point of view and determining the adequacy of traffic control devices at highway- railway grade crossing using standards

2. Prioritize crossings that have the most need for safety and operational improvement to comply with requirements of safety using hazard index model

3. Predict accidents at a crossing and provide possible safety measures and mitigation if a crossing is determined to be hazardous.

1.4 Organization of the Thesis

This thesis is organized into six chapters. Chapter 1 presents an introduction to the background of the study, the problem statement, and research objectives. Chapter 2 reviews pertinent literature related to this research, including studies of factors affecting motorist safety at highway-rail level crossing, different accident rating models and review of highway-rail level crossing manuals. Chapter 3 describes the methodology for data collection process and data analysis Chapter 4 presents different types of data used in this research study. Chapter 5 discuss the result of data analysis including compliance of AALRT level crossings to design standards. Chapter 6 includes conclusions and suggestions for future research on highway-rail level crossing safety. References and appendices are available at the end of this thesis.

1.5 Scope and Limitation of the Study

This study is oriented toward analysis of highway safety problems for the two lines of Addis Ababa light rail transit. The study is restricted to those factors having to do with level of exposure like number of trains per day, highway vehicle volume, protection factors and physical condition of the location, such as crossing occupation time, number of lanes and main tracks, type of highway and highway surface type. Highway gradient, illumination, distractive influences, visibility and vehicle driver-related factors are not directly investigated. The highway-railroad crossing at Kality Gumruk is not treated by this research because the crossing is not part of AALRT operation.

The accident rating models used in this study may not perfectly represent the case of crossings along AALRT. As the light rail transit operated since September 2015 enough crossing performance and accident databases are unavailable. If there were such database, typical accident rating models could have been developed that may result better modeling and acute analysis.

CHAPTER 2 LITREATURE REVIEW

The proposed topic of this thesis has been addressed previously by numerous researchers in the field. Hence this section provides an overview of studies that investigate highway-rail grade crossing safety based on accident rating models and compliance with design standards.

2.1 Factors That Increase the Frequency and Number of Accidents

Traffic accident trend in Ethiopia is increasing from time to time. The most common reason for those accidents is failure of yielding by drivers. At highway-railroad level crossings the conflict between highway vehicles and trains increase which makes highway-railroad level crossings vulnerable locations for accident usually results in fatalities, personal injuries and property damage. However these types of accidents can be avoided by either closing the crossing to highway traffic or by grade separating the crossings. The first alternative would not be accepted by the communities for loss of convenience, reduced access and extended travel time. The second alternative also uneconomical as investment cost of grade separating is higher. This guided researchers to critically analyze factors that increase the probability and number of accidents in order to propose improvements to enhance safety at highway-railroad level crossings. These factors can be grouped in to three major categories:-

- Highway and train traffic pattern
- Traffic control devices
- Crossing Geometry and Physical Characteristics

2.1.1 Highway and train traffic pattern

Factors under this category are determining for accident to happen at level crossings. Some of the most important parameters under this category studied by many researchers are:

1. **Highway traffic volume (V) and Train Volume (T)**

Highway and train volumes are import factors used by most of accident rating models. The use of vehicle and train volumes as predictors of accidents and indicators of hazard simply recognizes that a vehicle and a train must be present to have a collision (Schoppert, 1968). As the highway and train volume increases, the probability of the simultaneous arrival of a vehicle and train at a crossing also increases (Beggs, 1952).

2. Highway and Train Speed

Speed have an effect on both accident frequency and severity as a driver lacks control over either highway or rail vehicle with higher speed.

2.1.2 Traffic Control Devices

Different traffic control devices are used to inform drivers about the presence of highway-rail level crossing. These devices broadly classified as passive and active warning devices. Passive TCDS display constant message with regard to time. Advance warning signs, pavement markings and crossbucks are the common passive warning devices (MUTCD, 2003). Active warning devices generate a variable message based on the approaching of trains. When a train approaches a highway-rail grade crossing that employs active TCDs, lights will flash, bells will ring and a gate may descend to a horizontal position, blocking traffic movements. Once all trains have cleared the intersection, the active TCDs will return to their dormant states, until the next train activates the intersections control circuitry. All traffic control devices are not equally efficient in reducing accidents. Protection coefficients (factors) are used to measure the comparative effectiveness of traffic control devices.

The most comprehensive study on protection factors was made by Hedley (Hedley, 1979) to determine the effect of changes in protection devices had on accident experience. He used the records of Wabash Railroad over a 20- year period. His data included 321 crossings at which the protection had been changed.

William J. Hedley found the crossings protected by automatic gates had the lowest accident experience, whereas those with non-automatic gates had the highest. An accident factor was obtained for ten types of protection. Using these data and assuming a value of one for non-reflectorized crossbucks, the relative hazards associated with various types of protection are obtained. Table 2-1 illustrates the results for protections used at level crossings of AALRT. These values are adopted for use in determining the hazard indices (New Hampshire model) for different protection types (P) in this study.

Table 2-1 Relative Hazard Associated with Various Types of Grade Crossing Protection (Hedley, 1979)

Type of Protection	Hazard Index
Automatic gates	0.1
Flashing light signals, multi-track	0.6
Automatic bell	0.8
Painted crossbucks	1.0

2.1.3 Crossing Geometry and Physical Characteristics

Highway-railroad crossings are characterized by factors like crossing angle, horizontal alignment of highway and railroad, sight distance and surrounding factors such as highway type and highway surface type. These factors are secondary based on their role on level crossing accidents (Thomas G. Schultz, 1965).

The Peabody and Dimmick studied 1,254 crossings of which more than 60 percent were in urban locations. They investigated the effect of traffic volumes, sight distances, vertical and horizontal alignment, surface types, and number of tracks on level crossing accident. Peabody and Dimmick found only train and highway volumes and the type of protection were significantly related to the number of accidents. The horizontal alignments of the highway and the railroad had no significant influence on the safety of grade crossings (Halkias, John A., 1987).

2.2 Accident Rating Models

The effect of factors discussed so far, on highway-railroad level crossing, have received a great amount of attention by many researchers. Previous researchers developed a number of statistical accident prediction and hazard index models to investigate the relationship between crash frequency and number versus characteristics of grade crossing, highway traffic, train traffic and protection devices. A highway vehicle and train arriving at a level crossing the same time will collide. Therefore the two most obvious variable, which affect the probability of a crash, are highway and railroad traffic. The type and degree of protection may also be important and hence early research and accident models were developed fundamentally from these three variables. Those accident models can be classified as relative formula (hazard index) which ranks crossings in relative terms and absolute formulas (accident prediction formulas) which give actual collision occurrence frequency at a crossing. Both relative and absolute formulas can be used to provide ranking of crossings on the basis of their relative hazards (*Yoassry M.E. and Rahim F.B. (2000)*). The following are some of hazard index and accident prediction formulas.

2.2.1 Hazard Index Models

The hazard index reflects the probability of a train-vehicle accident at a crossing. Models for hazard indices range from very simple to very complex relationships. A review of the results of some of research efforts applicable to this study are identified and discussed below.

1. **Federal Aid Highway Deficiency Study Model**

This model gives the hazard index based on the two fundamental factors of grade crossing safety which are rail volume (R) and highway volume (V)

$$HI = \frac{VR}{1000}$$

2. **New Hampshire Model**

This model is very simple hazard index, which states that for a given warning device class the relative hazard index is proportional to the product of the average vehicular volume (V) and the average train volume (R). The New Hampshire formula is useful for its combination of power and simplicity (*Yoassry M.E. and Rahim F.B. (2000)*).

$$HI = VRP_f$$

Where;

P_f is the protection factor for each crossing device (Crossbucks, flashing lights and gates). According to FHWA handbook, 2007, the value of P_f is as follows

Pf = 0.1 for automatic gates

= 0.6 for flashing lights

= 1.0 for signs only

Bezkorovainy (Blythe, J.D., 1956) analyzed 180 railroad crossings in Lincoln, Nebraska using eleven hazard index formulae and concluded that each formula gave essentially the same accident potential rankings for crossings. It is concluded by Bezhorovainy that the New Hampshire formula best fits the composite arithmetic average of all the rankings as determined from the eleven tested formulae.

3. Warren Henery Model

In 1934 Henery examined various factors that increased the likelihood of accident for a given volume of daily train and highway traffic to build a hazard index model. The factors considered by Henery were view (Q), attention (At), user (U), daily train (R) and highway traffic (V) (Thomas G. Schultz, 1965).

$$HI = VR(1 + Q + A_t + U)$$

4. Contra Costa Model

They suggest that the product of vehicles and trains per day in the above models was not a good measure of hazard or exposure because it gave too much weight to the highway traffic (Farhad I. 1978). However they considered that the number of trains per day was proportional to the hazard and exposure. Contra costa model assumed a random distribution of vehicle arrivals to express the index of hazard, as follow:

$$HI = RZ\left(1 - 2.718^{\frac{-V*t}{1400Z}}\right)$$

In which

R = number of trains per day
Z = number of traffic lanes
V = number of highway vehicles per day
T = time, in min/day, that the crossing is blocked

Overall, the basic difference between the several hazard indices that have been proposed over the last several years is in their analytical sophistication. But there is general agreement that current techniques for computing the relative hazard of rail-highway crossings are reliable (Farhad I. 1978).

From the above research findings on hazard indices New Hampshire model will be used as hazard index in this research. Also Contra Costa Model will be used as a check or comparative value for the result of New Hampshire Model.

2.2.2 Accident Prediction Models

There are a number of accident prediction models developed by different researchers. Some of them are discussed below

1. **Peabody-Dimmick Model**

L.E. Peabody and T.B. Dimmick analyzed data on 3,563 rural crossings in 29 states for five year study period. The formula used to determine the expected number of accidents in five years is:

$$A_5 = 1.28 \frac{(V^{0.170})(R^{0.151})}{P^{0.171}} + K$$

Where

A_5 = expected number of accidents in five years

V = average daily vehicular traffic

R = average daily train traffic

P = protection coefficient

The relationship between warning device and accident factor $P^{0.171}$ and the value of K can be determined from charts in FHWA grade crossing handbook. (FHWA, 2007)

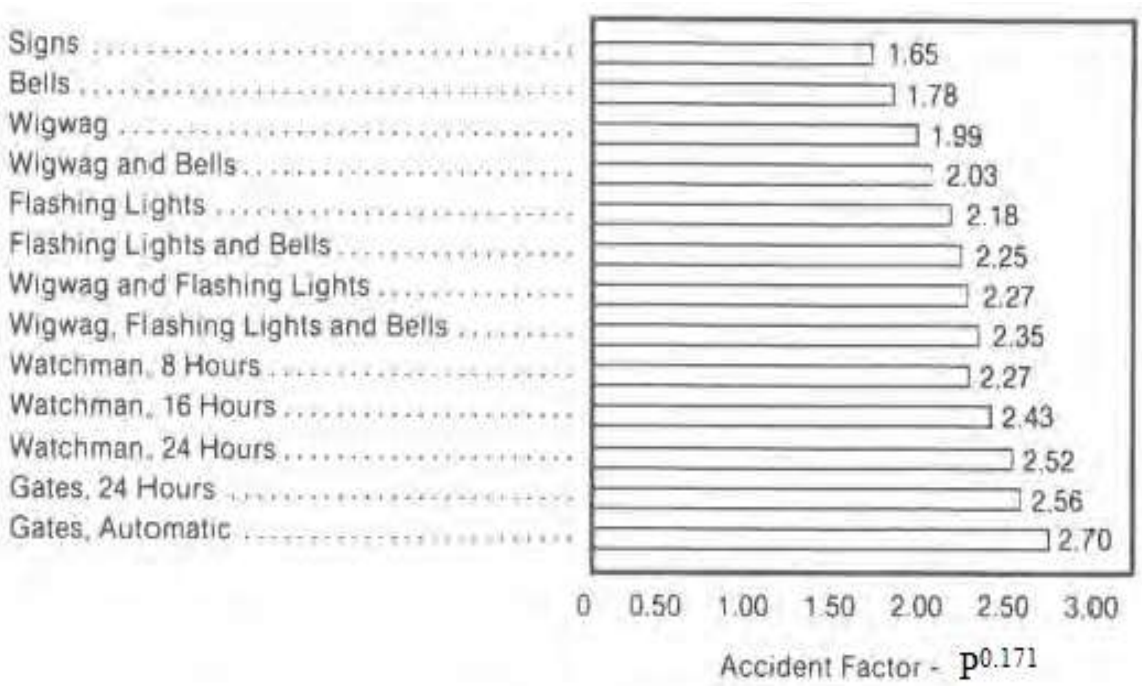

Figure 2-1 Relationship between Warning Device and Accident Factor $P^{0.171}$

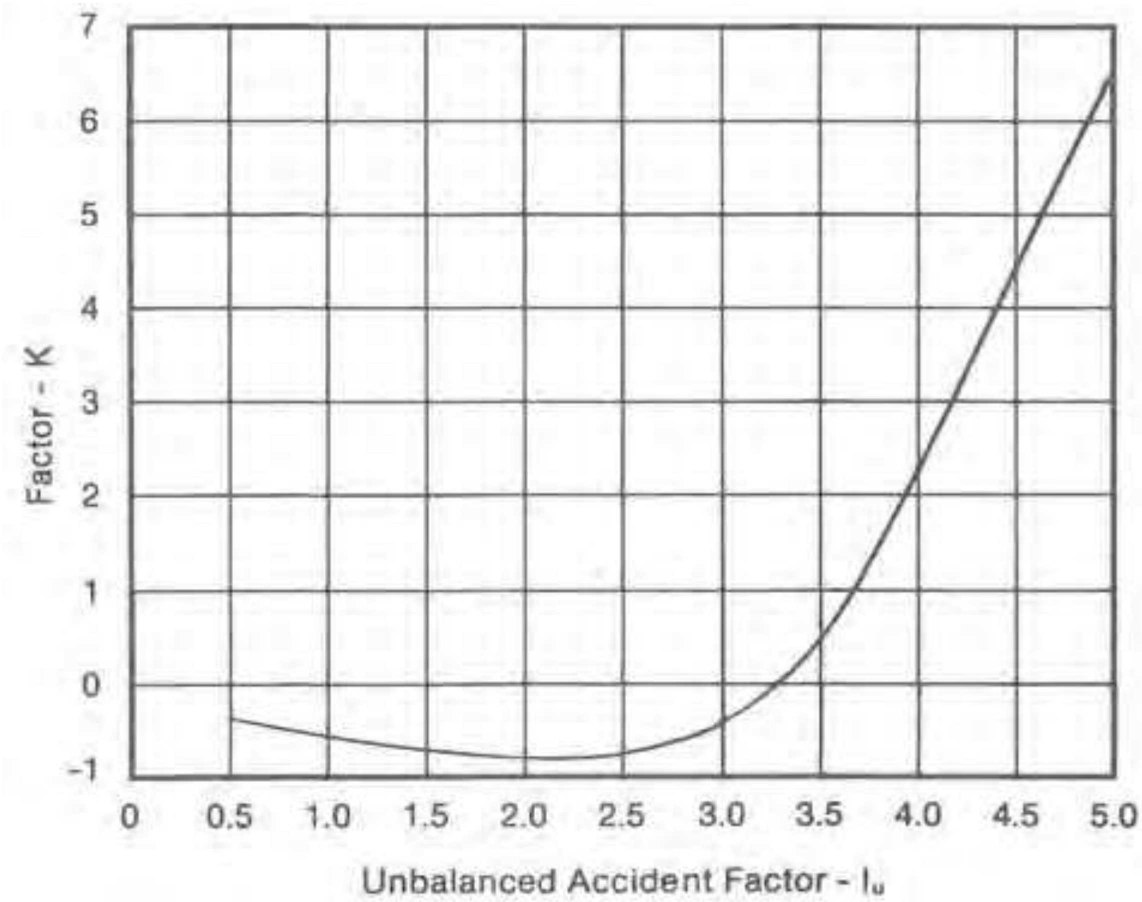

Figure 2-2 Relationship between K and Unbalanced Accident Factor - Iu

Where $I_u = 1.28 \frac{(V^{0.170})(R^{0.151})}{P^{0.171}}$

2. Expected Accident Frequency Model (EAF)

This model is developed 30 years ago from collected data from a number of US state highway agencies and universities to predict the number of crashes per year at a given crossing (*Yoassry M.E. and Rahim F.B., 2000).* The resulting formula is:

$$EAF = A * B * R$$

Where

A = vehicular traffic factor based on 10year ADT
B = factor based on existing warning device
R = average daily train traffic

Factor 'A' for any value of ADT can be determined from the following regression analysis formula. (FHWA, 2007)

$$A = 1.35135 * 10^{-6} * (2 * 10^{-10} * ADT^3 - 10^{-5} * ADT^2 + ADT - 67)$$

The protection factor 'B' can be determined from the following table according to the existing warning device and type of area urban or rural.

Table 2-2 The protection factor 'B' (FHWA, 2007)

Warning Devices	B' Factor
Crossbucks, highway volume less than 500 per day	3.89
Crossbucks, Urban	3.06
Flashing light, Urban	0.23
Gates, Urban	0.08

3. US DOT Accident Prediction Model

This model calculates expected annual number of accidents at a crossing using three formulas. (FHWA, 2007)

- A basic formula that contains geometric and traffic factors from the inventory file.
- A formula that contains accident history at s crossing.
- A formula that incorporates the effect of existing warning devices.

I. Basic Formula: this was developed based on nonlinear regression analysis

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$$

Where;

a = initial collision prediction, collisions per year at the crossing

K = formula constant

EI = factor for exposure index based on product of highway and train traffic

MT = factor for number of main tracks

DT = factor for number of through trains per day during daylight

HP = factor for highway paved (yes or no)

MS = factor for maximum timetable speed

HT = factor for highway type

HL = factor for number of highway lanes

Different sets of equations are used for each of the three categories of traffic control devices to determine the value of each factor, as shown in Table 2-3

Table 2-3 U.S. DOT Collision Prediction Equations for Crossing Characteristic Factors

Crossing category	Formula constant	Exposure index factor	Main Track Factor	Day Thru Train Factor	Highway paved Factor	Max.Speed Factor	Highway Type Factor	Highway Lanes Factors
	K	EI	MT	DT	HP	MS	HT	HL
Passive	0.00227	$\left(\frac{c*t+0.2}{0.2}\right)^{0.3334}$	$e^{0.2094mt}$	$\left(\frac{d+0.2}{0.2}\right)^{0.1336}$	$e^{-0.6160(hp-1)}$	$e^{0.0077ms}$	$e^{-0.1000(ht-1)}$	1
Flashing Lights	0.00365	$\left(\frac{c*t+0.2}{0.2}\right)^{0.2953}$	$e^{0.1088mt}$	$\left(\frac{d+0.2}{0.2}\right)^{0.0470}$	1	1	1	$e^{0.1380(hl-1)}$
Gates	0.00109	$\left(\frac{c*t+0.2}{0.2}\right)^{0.3116}$	$e^{0.2912mt}$	1	1	1	1	$e^{0.1036(hl-1)}$

c = Annual average number of highway vehicles per day
t = Average total train movements per day
mt = Number of main tracks
d = Average number of thru trains per day during daylight
hp = Highway paved, yes = 1.0, no = 2.0
ms = Maximum timetable speed, mph
hl = Number of highway lanes
ht = Highway type factor value

Highway type	ht
Interstate	1
Other freeway and expressway	2
Other principal arterial	3
Minor arterial	4
Collector	5
Local	6

II. Accident history formula: which can be expressed as:

$$B = \frac{T_o}{T_o + T}(a) + \frac{T_o}{T_o + T}\left(\frac{N}{T}\right)$$

Where

B = second collision prediction, collisions per year at the crossing

a = initial collision prediction from basic formula, collisions per year at the crossing

$\frac{N}{T}$ = Collision history prediction, collisions per year, where N is the number of observed collisions in T years at the crossing

To = formula weighting factor $\frac{1}{(0.05+a)}$

III. Normalizing equation

According to the 2003 normalizing constants, the final crash prediction is computed as

$$A \begin{cases} = 0.6500*B \text{ for passive devices only} \\ = 0.5001*B \text{ for passive devices + flashing lights} \\ = 0.5725*B \text{ for gates} \end{cases}$$

Where A is final accident prediction, crashes per year.

Recent researches has proved that EAF model fell short of identifying the most hazardous crossing that need warning device upgrade. Whereas the USDOT model captured a higher number of hazardous crossings than EAF model (*Yoassry M.E. and Rahim F.B., 2000).* Due to this confirmation and its wide use in the preferred manuals discussed below, USDOT model will be used in this research to predict accidents and the result will be counter checked by EAF model.

2.3 Review on Guidelines and Design Standards for Highway-Rail Grade Crossing

Although our country Ethiopia didn't have any grade crossing design, construction, operation and maintenance standard, it is necessary to compile information from other countries where standards have been implemented. Therefore the national railway network development project is expected to be in compliance with widely applied standards such as American Railway Engineering and Maintenance-Of-Way Association AREMA manual, Chinese standard GB50090, manual on uniform traffic control devices MUTCDS and Federal Highway Association FHWA handbook.

2.3.1 The American Railway Engineering and Maintenance-of-Way Association (AREMA)

The American Railway Engineering and Maintenance-of-Way Association (AREMA) is a technical association that develops manual which serves as the primary source for railroad design specifications. The manual is prepared by a collection of railroad professionals with extensive expertise in the railroad industry. Part 8 of Chapter 5, Volume 1 (Track) of the "Manual for Railway Engineering" is dedicated entirely to design recommendations for railroad-highway at-grade crossings. The guidelines in this section facilitate the decision-making process when evaluating design alternatives to improve safety at highway-rail grade crossings and in dimensioning different geometrical parameters. The recommendation of this manual for highway- railroad grade crossing with respect to crossing characteristics such as location, width of crossing and crossing surface material, roadway characteristics such as alignment, approach grade and surface condition and track structures summarized below (AREMA, 2013)

I. Crossing characteristics

Highway railroad grade crossing should not be located where the crossing frequently blocked by standing or slow moving trains. Such location includes the vicinity of:-

- rail yards and terminals,
- switching leads,
- tracks used for meeting or passing trains,
- either highway or railroad curves
- Turnouts, crossovers, rail crossings or railroad bridges would fall within the limits of or in close proximity to the crossing.

When it is necessary to cross tracks at such locations, grade separation of the roadway and railroad is highly recommended.

The width of crossings should not be less than that of the adjacent traveled way plus 30.5cm on each side as measured perpendicular to the roadway. Any crossing surface materials can be used but the use of unconsolidated crossing materials (ballast, dirt, gravel) should generally be avoided on main tracks.

II. Roadway Characteristics

As much as possible the roadway should intersect the railroad at or nearly at right angles. The number of traffic lanes and the width of the roadway section, including shoulders, should be uniform on both sides of the crossing. Access ways to the road in vicinity of highway railroad grade crossing should be avoided. From sight distance, rideability, breaking and acceleration distance point of view the highway-railroad grade crossing be made as level as practical

Roadway approach grade desirable if it made to be level with railroad section at the crossing. But in some instances the roadway vertical alignment may not meet acceptable geometrics because of restrictive topography or limitations of right-of-way. Hence to prevent low height vehicle from becoming caught on the tracks, the approaching road tapered to the crossing to maintain level plane at the crossing with top of the rails for distance of at least 0.6m from the outer rail (AASHTO, 2004). The surface of highway should also not be more than 75mm higher or lower than the top of nearest rail at a point 9m from rail.

III. Track structures

All ties at the crossing and also for at least 6m beyond each end of the crossing should be fully plated with double shoulder ties. There shall be no rail joint at or at least 6m distance from each side of the crossing. The flange way width and depth should not be less than 75mm and 50mm respectively.

Generally railroad design criteria relative to horizontal and vertical curvature, gradient and superelevation tend to be more restrictive than the corresponding criteria for roadway pavements, it is typically necessary and generally more economical to first establish the governing track geometrics and then design or adjust the roadway geometrics accordingly.

2.3.2 Chinese standard (GB50090-2006 PRC)

GB50090-2006 PRC Code for design of railway line is developed compiled by the First Survey &. Design Institute of China Railway in June 2006. This Code mainly includes General Provisions regarding to design, construction and operation of Plane and Profile of Railway Line, Distribution of Stations and Crossings of Railway and Road. Part 5.2 of chapter 5 of GB50090-2006 is dedicated entirely to design recommendations for railroad-highway at-grade crossings similarly as AREMA manual (GB50090, 2006).

According to this manual grade crossing should conform to the following provisions.

There should be no grade crossing set within station or on both Sides Bridge and culvert. Unless unfavorable condition dictates grade crossing should not be located at the curve section.

The grade crossing between railway and road should be of right angle intersection, in case of bevel, the intersection angle should be larger than 45°.

The length of grade crossing pavement along road should be extended out of outmost rail for 0.5-2.0m. The width of level crossing in urban areas should not be less than carriageway width plus walkway width

The flange clearance width and depth at grade crossing should be 70-100 mm and 45-60mm respectively.

There should be no common rail joint within grade crossing pavement, if it cannot be avoided, rails should be welded or frozen.

2.3.3 Manual on Uniform Traffic Control Devices (MUTCD)

The purpose of traffic control at highway-rail grade crossings is to permit safe, efficient and integrated operation of rail and highway traffic. Highway vehicles approaching a highway-rail grade crossing should be prepared to yield and stop if necessary if a train is at or approaching the crossing. The standards used for the installation and maintenance of traffic control devices on all public roads are defined by MUTCD published by the FHWA for the purpose of standardizing all traffic control devices, including road markings, highway signs, and traffic signals. Part 8 and 10 of the MUTCD contains specific guidelines for railroad-highway at-grade crossings. This section provides a comprehensive set of guidelines outlining the proper design, size, and placement of signs, pavement markings, light signals, and traffic control signals at-grade crossings (FHWA, 2007) Guidelines provided by the MUTCD continue to serve as the principal source for traffic control devices at-grade crossings for this research paper.

The traffic control devices defined by MUTCD are categorized in to two major classes as passive devices and active devices.

A. Passive Traffic Control System

Passive traffic control systems includes signs and pavement markings. Based on geometrical and location conditions of level crossings along AALRT those traffic control signs can be classified as minimum and supplemental passive traffic control signs.

I. Minimum passive traffic control signs

1. Crossbucks signs (R15-1)

Crossbuck is retroreflectorized white background X-shape with black lettered RAILROAD CROSSING words. At least one crossbuck sign shall be used on the right side of each highway approach to LRT level crossing. In the absence of automatic gates and if there are two or more tracks at the highway-light rail transit grade crossing, the number of tracks shall be indicated on a supplemental Number of Tracks (R15-2) sign of inverted T shape mounted below the Crossbuck sign in the manner and at the height indicated in Figure 2-3 (MUTCD, 2003)

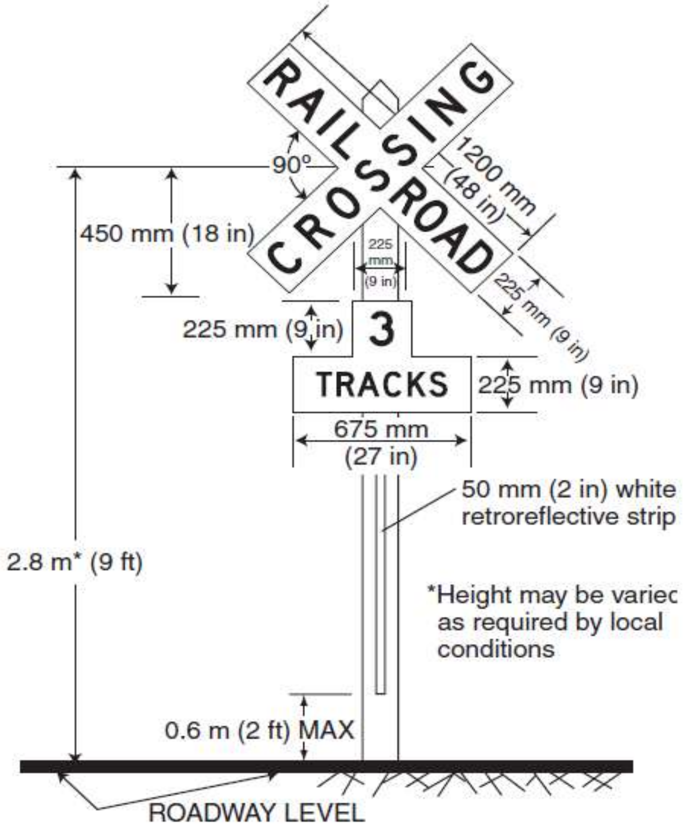

Figure 2-3 Highway-Rail Grade Crossing (Crossbuck) Regulatory Signs

2. Stop (R1-1) and Yield (R1-2) Sign

The use of Stop (R1-1) and Yield (R1-2) at should be limited LRT level crossings subject to the following characteristics (MUTCD Section 10C.04)

- Crossing with secondary roadways of low traffic volume and low speed limit.
- Light rail transit speeds do not exceed 40 km/h
- If at an intersection of two roadways, the intersection does not meet the warrants for a traffic control signal

As the characteristics of level crossings along AALRT are different from the aforementioned conditions, Stop (R1-1) and Yield (R1-2) signs may not be used. Due to this Stop Ahead (W3-1) or Yield Ahead (W3-2) Advance Warning signs and A DO NOT STOP ON TRACKS (R8-8) sign may not also be used.

Figure 2-4 Stop (R1-1), Yield (R1-2), Stop Ahead (W3-1), and Yield Ahead (W3-2) signs

3. Stop Here on Red

Stop Here on Red (R10-6) sign may be used at locations where vehicles frequently violate the stop line or where it is not obvious to road users where to stop.

4. Advance warning signs (W10 series)

A Highway-Rail Grade Crossing Advance Warning (W10-1) signs shall be used on each highway in advance of every highway-rail grade crossing except in the following circumstances: (MUTCD, Section 8B.04 page 667)

- On an approach to a highway-rail grade crossing from a T-intersection with a parallel highway, if the distance from the edge of the track to the edge of the parallel roadway is less than 30 m, or
- On low-volume, low-speed highways crossing minor spurs or other tracks that are infrequently used and are flagged by train crews; or
- In business districts where active highway-rail grade crossing traffic control devices are in use; or
- Where physical conditions do not permit even a partially effective display of the sign.

Figure 2-5 Advance warning signs (W10-1) and Stop Here on Red

5. **Emergency Notification (I-13 or I-13a) sign**

An Emergency Notification (I-13 or I-13a) sign should be installed at all highway-light rail transit grade crossings on semiexclusive alignments to provide for emergency notification. The sign should have a white message on blue background.

II. **Supplemental passive traffic control signs**

These passive traffic signs are optional signs used at LRT level crossings for a better clarity. Supplementary traffic signs includes LOOK Sign (R15-8), EXEMPT (R15-3) sign and the divided highway with light rail transit crossing (R15-7) sign as shown the figure 2-6 below

Figure 2-6 Supplemental passive traffic control signs

The other passive traffic control systems are road markings. Pavement markings in advance of a highway-light rail transit grade crossing consist of an X, the letters RR, a no-passing, and certain transverse lines. Pavement markings may not be required in urban areas where posted speed limit is less than 60km/hr.

B. **Active Traffic Control Devices**

An active traffic control devices includes all devices at highway-rail crossing that gives warning on the approach or the presence of train. MUTCD 2003 edition lists the following standard (commonly found at many grade crossings) active devices and guidance for their application.

1. **Flashing light signal**

A standard flashing light includes two red lights flashing alternatively facing the approach highway. The support used for the lights should also include a standard crossbuck sign and “multiple tracks” R15-2 sign, in the case of more than one track. Bells or other audible devices may be included in the assembly to provide further warning to highway users. In case of multilane highways, high speed two lane highways or where the terrain or topography of the approaching highway is such that the sight of a roadside mounted signal light could not be readily seen by an approaching driver due to vertical or horizontal curves Cantilever Flashing-Light Signal are used.

Flashing lights are used at highway-light rail transit grade crossings if the train speed exceeds 60km/hr at intersection or 40km/hr on the other locations like U-turns.

2. Automatic Gate

This device consists of drive unit and gate arm. The derive unit could be mounted on the pole of flashing- light signal or on a stand-alone support. Gate arms shall be fully retroreflectorized on both sides by alternate red and white strips at 45^o diagonal. There should be at least three lights on the gate arm in such a way that the tip light is continuously illuminated and the others alternately flash when the gate is activated and lowered. The gates should cover the approaching highway to block all motor vehicles from being driven around the gate without crossing the centerline.

Automatic gates and flashing-light signals are used at highway-light rail transit grade crossings if the train speed exceeds 60km/hr at intersection or 40km/hr on the other locations like U-turns.

3. Four-Quadrant Gate Systems

Four-quadrant gate systems consist of a series of automatic flashing-light signals and gates where the gates extend across both the approach and departure side of roadway lanes. Unlike two-quadrant gate systems, four-quadrant gates provide additional visual constraint and inhibit nearly all traffic movements over the crossing after the gates have been lowered. But the Gate arm design, colors, and lighting requirements shall be the same as the two quadrant system.

Four quadrant gate system should only be used in locations with constant warning time train detection.

4. Traffic Control Signals

Traffic control signals may be used instead of flashing light signals at highway-railroad level crossings where train movements are slower than 40km/hr

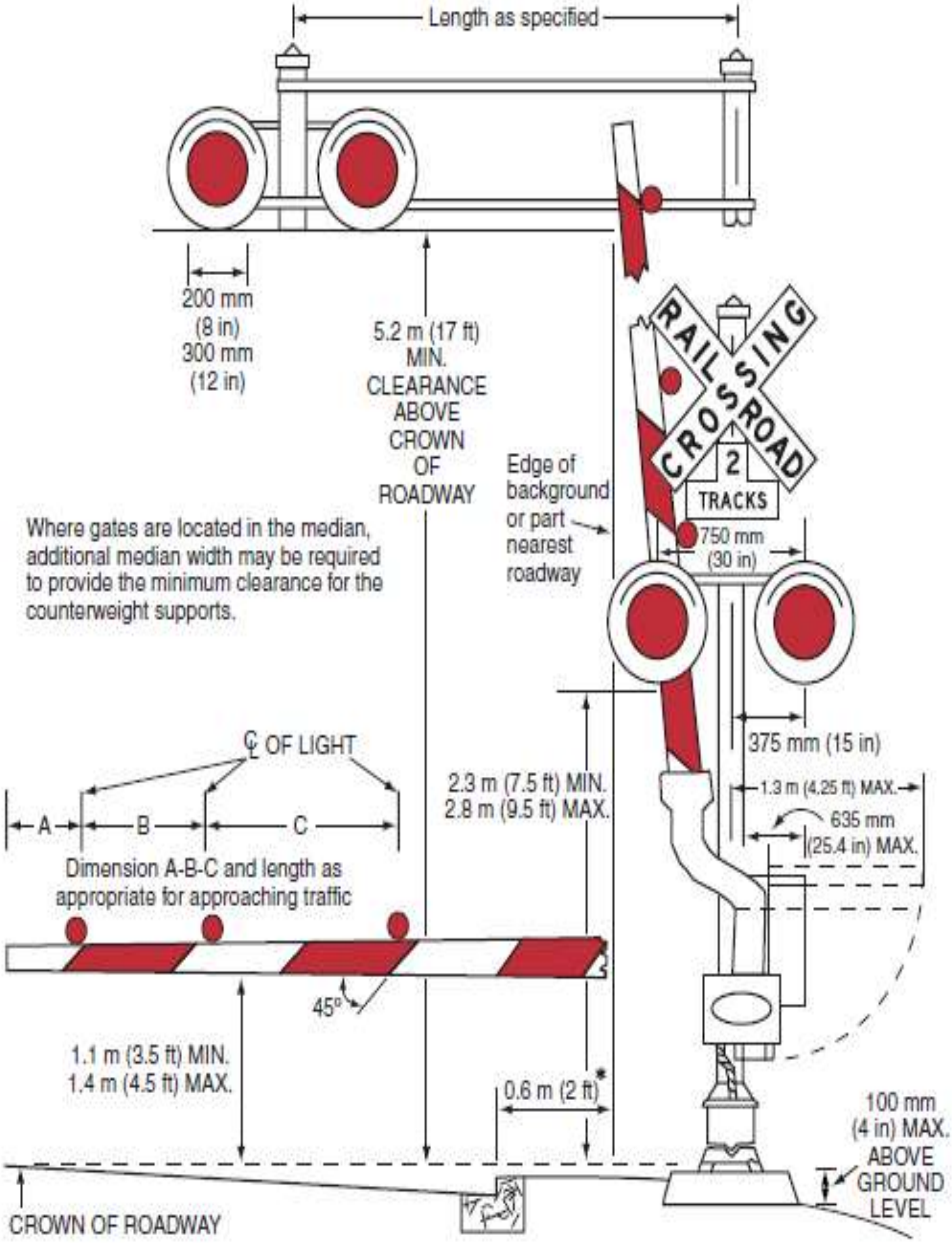

Figure 2-7 Composite Drawing of Active Traffic Control Devices

2.3.4 Federal Highway Association Railroad-Highway Grade Crossing Handbook

The FHWA railroad-highway grade crossing hand book provides a compiled information from several standards, including the MUTCD, the USDOT, the Transportation Research Board, AASHTO, and AREMA. Whether it is for the casual individual just interested in learning about at grade crossings, or the professional engineer searching for design standards, the "Railroad Highway Grade Crossing Handbook" provides valuable information. The handbook has been an especially important source for gathering information summarized in this report. The handbook contains general information about the development of at-grade crossings and the laws that govern them; a detailed analysis of the components that make up the crossing; an assessment of crossing safety and operation; an analysis of the use of proper traffic control devices; a discussion outlining means of ranking crossings using hazard index model and model to determine accident frequency at a crossing (FHWA, 2007). To enhance safety at highway-railroad level crossings FHWA highway railroad level crossing handbook proposes the following site improvements

- The ideal crossing geometry is a 90^o intersection of highway to track. If the intersection between track and highway cannot be made at right angle, the variation from 90^o should not be greater than 20
- Highway-railroad grade crossings should be illuminated if there is a night time train operation with low train speed.
- Crossing surface should be reasonably smooth, otherwise the drivers attention at crossings may devote primarily to choosing the smoothest path rather than avoiding accidents

Besides to the above site improvements the handbook outlines guidance to operational alternatives and selection criteria. These alternatives ranges from providing different traffic control system to closing crossing to either mode of transportation based on the conditions summarized below.

I. Minimum traffic control devices

All highway-railroad level crossings should be equipped with minimum passive devices described in MUTCD.

II. Active devices

Active devices with automatic gates should be considered at highway-rail grade crossings whenever one or more of the following conditions exist:

- If there is multiple main tracks through the crossing
- If highway-railroad level crossings are located in close proximity to commercial area, industrial plant or schools
- If the average number of trains per day exceeds 20 trains
- Annual average daily traffic (AADT) exceeds 2,000 in urban areas
- The expected accident frequency as calculated by the U.S. DOT Accident Prediction formula, exceeds 0.075.

III. Grade Separation

a) Highway-rail grade crossings with automatic gate should be considered for grade separation across the railroad right of way whenever the cost of grade separation can be economically justified based on fully allocated life-cycle costs and one or more of the following conditions exist:

- If there are an average of 50 or more passenger trains per day in urban areas
- Passenger train crossing exposure (the product of the number of passenger trains per day and AADT) exceeds 400,000 in urban areas or 100,000 in rural areas.
- The expected accident frequency for active devices with gates, as calculated by the U.S. DOT Accident Prediction Formula, exceeds 0.2.

b) Highway-rail grade crossings with automatic gate should be considered for grade separation or otherwise eliminated across the railroad right of way whenever one or more of the following conditions exist:

- An average of 75 or more passenger trains per day in urban areas
- Crossing exposure (the product of the number of trains per day and AADT) exceeds 1 million in urban areas
- Passenger train crossing exposure (the product of the number of passenger trains per day and AADT) exceeds 800,000 in urban areas
- The expected accident frequency for active devices with gates, as calculated by the U.S. DOT Accident Prediction Formula including five-year accident history, exceeds 0.5.

CHAPTER 3 RESEARCH METHODOLOGY

This study focuses on the analysis of major safety issues on highway-railroad grade crossing along the two lines of Addis Ababa Light Rail Transit (AALRT) using accident rating models and guide line and design standards.

3.1 Study Area

Data used in this study collected from the two lines of AALRT. The East-West line runs from Ayat roundabout to Torhiloch having a length of 17.35km. There are about five level crossings along this line at a location of Ayat village enterance, Salitemihiret and Tsehay real estate roundabout, CMC Mikael and Office of Ministry of mines (CREC, 2012). The North-South line stretches from Menilik II square to kality roundabout having a length of 16.9km. Along this line there are two junction type level crossings at Sebategna and AdeyAbaba junction and one U-turn level crossing type at VOLVO Company.

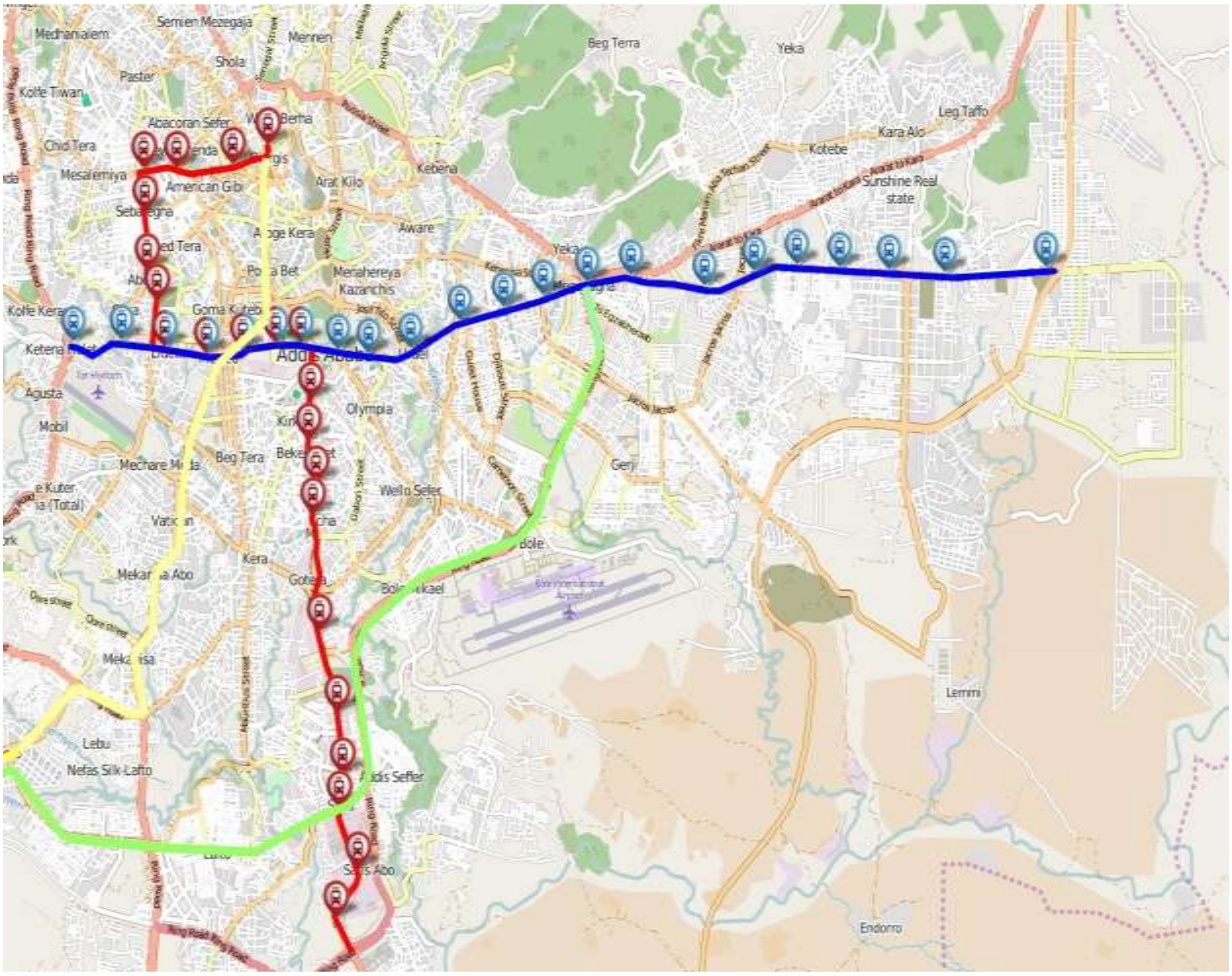

Figure 3-1 Addis Ababa Light Rail Transit (AALRT) Project

All crossings had two train tracks and used four-quadrant protection gates, traffic control signals and crossbucks on both sides of the tracks. The train speed limit around the level crossings is 20km/hr.

3.2 Data Description and Collection Methods

The data used in this study can be categorized in to four major categories

3.2.1 Traffic Control device information's

Traffic control device information includes data about the type and number of active and passive traffic warning devices installed at AALRT level crossing. These data are collected through onsite observation using inventory form developed for this study (Appendix A).

3.2.2 Railroad information

Data used under this category includes average daily and daylight train volume, maximum time table speed of train at crossing and number of tracks. These data are collected by reviewing light rail transit design and operation documents, onsite observation and consulting AALRT operation control and communication (OCC) unit.

3.2.3 Highway information

The important set of data from this category was the annual average daily traffic (AADT) traversing the highway-railroad level crossing. To collect this data a team of enumerators were organized and preparation including orientation and familiarization training to Addis Ababa City Road (AACRA) traffic count format (Appendix B) were given. The counts were undertaken for seven consecutive days from Monday, 23 May to Sunday, 29 May, 2016. Each daytime count covered 12 hours, commencing at 06:30 and finished at 18:30. In addition night time count for two day of the above period, namely Tuesday, 22 May and Saturday, 28 May, 2016 performed from video records of AALRT Operation Control and Communication unit (OCC). Throughout the census period, each of the traffic count teams at all Highway-railroad level crossings were supervised.

Other data of this category such as functional type of road, highway surface type and highway speed are collected from AACRA design standardization and documentation office interview and onsite observational survey.

3.2.4 Crossing Physical Characteristics Information

Data that characterize crossings in this study include crossing location, angle, surface material, rail joint and anchorage, flange way width and depth. Most of these data are collected by onsite observation using inventory form (Appendix A).

3.3 Method of Data Analysis

Before analyzing crossings for safety by models, compliance of AALRT level crossings with guidelines and design standards for highway-railroad grade crossing is performed. The design standards used in this research are The American Railway Engineering and Maintenance-of-Way Association (AREMA), Chinese standard (GB50090-2006 PRC) and Manual on Uniform Traffic Control Devices (MUTCD). By summarizing the recommendation and guidelines of these standards discussed under the literature review part of this study, evaluation format shown in the table 3-1 is developed.

Table 3-1 AALRT level Crossing Evaluation Format based on Design Standards

S.N.	Basic Crossing Design Criteria	Design Standards Recommendation			Inventory Result	Evaluation Result
		AREMA	GB50090-2006 PRC	MUTCD		
1	**Crossing Physical Parameters**					
	1.1 Location	Straight section of track	Straight section of track	NA		
	1.2 Width of Crossing	Carriageway + walkway	Carriageway + walkway	NA		
	1.3 Crossing Surface Material	Consolidated dirt, gravel free surface	Hard and durable materials easy to repair.	NA		
2	**Roadway Parameters**					
	2.1 Roadway Alignment	Roadway should intersect the railroad at or nearly at right angles	Roadway should intersect the railroad at or nearly at right angles	NA		
	2.2 length of Level Plane Beyond Outer Rail	At least 0.6m	Between 0.5-2m	NA		
	2.3 Roadway Surface Material	-	-	NA		
3	**Railway Track Parameter**					
	3.1 Rail Type	CWR	CWR	NA		
	3.2 Rail Ties	Fully plated with double shoulder ties	-	NA		
	3.3 Flangeway Width	At least 75mm	Between 70-100mm	NA		
	3.4 Flangeway Depth	At least 50mm	Between 45-60mm	NA		

S.N.	Basic Crossing Design Criteria	Design Standards Recommendation			Inventory Result	Evaluation Result
		AREMA	GB50090-2006 PRC	MUTCD		
4	**Traffic Control Devices (TCD)**					
	4.1 Crossbucks (R15-1)	NA	NA	Necessary sign based on Section 10C.02		
	4.2 Number of Track (R15-2)	NA	NA	Supplemental based on Section 10C.02		
	4.3 Stop (R1-1) or Yield (R1-2)	NA	NA	NA based on Section 10C.04		
	4.4 Advance warning signs (W1)	NA	NA	NA based on Section 8B.04		
	4.5 Emergency Notification Sign (I-13)	NA	NA	Necessary sign based on Section 10C.21		
	4.6 Pavement Marking	NA	NA	NA based on Section 10C.23		
	4.7 Signs + Flashing lights	NA	NA	used under medium traffic if train speed ≥60km/hr based on Section 10D.02		
	4.8 Signs + Flashing Light + Gate Systems	NA	NA	Used under heavy traffic if train speed ≥60km/hr based on Section 10D.03		
	4.9 Signs + Traffic Signal + Gate Systems	NA	NA	Used under heavy traffic if train speed ≤ 60km/hr based on Section 10D.05		

Once compliance of level crossings to design standards checked, the relative accident level at each crossing of AALRT is determined by hazard index model. The hazard index model used in this research is New Hampshire model as outlined in the literature review part of this paper (Blythe, J.D., 1956). The result of New Hampshire model is counter checked by contra costa model. Then highway-railroad level crossings along the AALRT are ranked according to their hazard index values. The higher the hazard index, the greater the need for improvements.

Then expected accident on these crossings is estimated using US DOT accident prediction model as discussed in chapter two. Expected Accident Frequency (EAF) model is also used to conform the result of US DOT. The framework of the study is generalized in figure 3-2 below

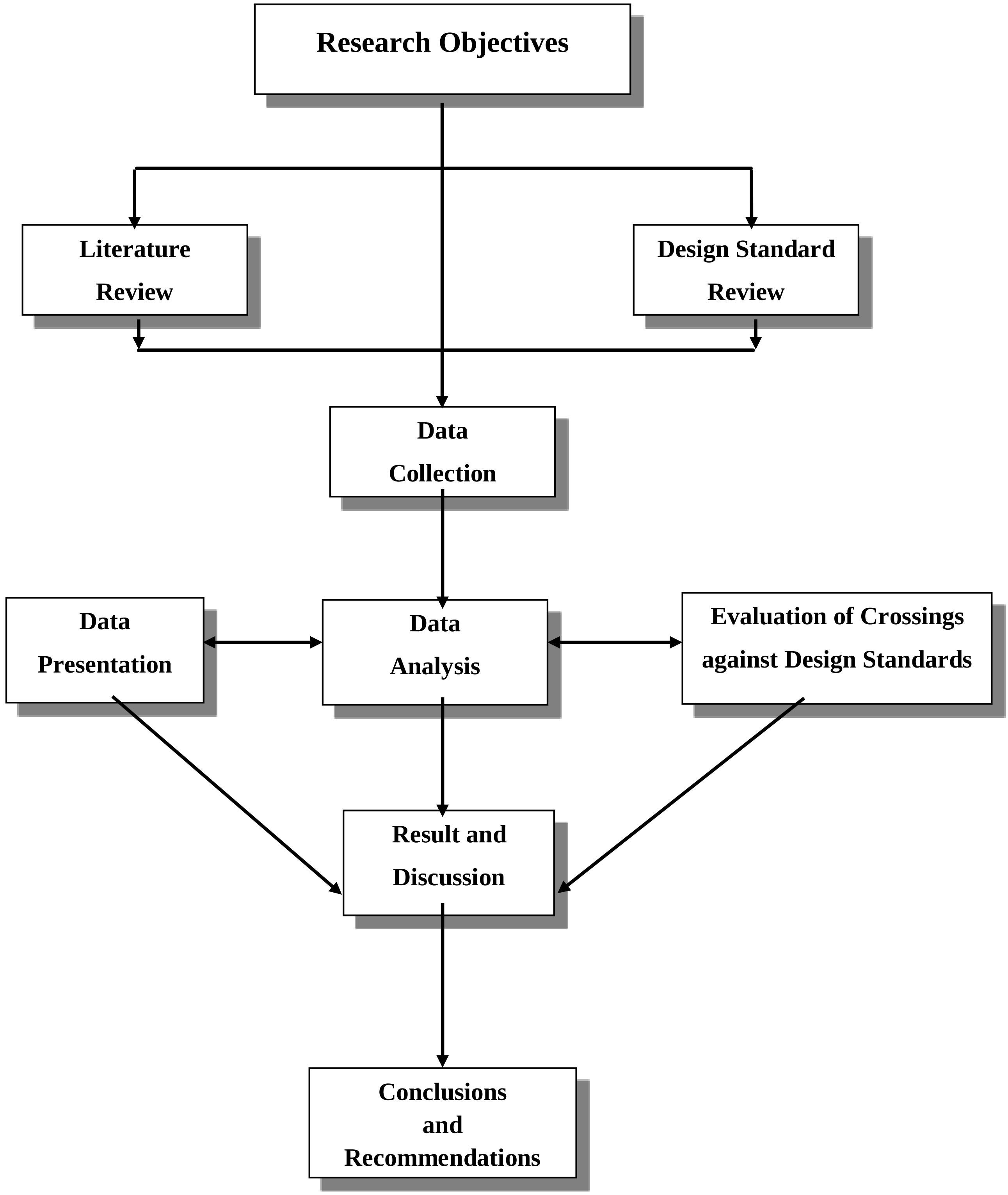

Figure 3-2 Methodology Framework

CHAPTER 4 DATA PRESENTATION AND ANALYSIS

4.1 Data Presentation

The data used in this study can be classified as crossing physical characteristics data, traffic control system data, highway traffic data and train traffic data. The result of data collection is presented below.

4.1.1 Crossing Physical Characteristics Data

The crossing along AALRT can be categorized in to three major class based on geometry of crossing.

I. Roundabout Section

There are three roundabout level crossings around CMC Tsehay Realestate roundabout and Salitemihiret roundabout along the E-W line and Meshualekiya roundabout on N-S line.

II. U-turn Section

There are three U-turn level crossings along the E-W line at Ayat village entrance, CMC Mikael and around office of ministry of mines. On the N-S line there is only one U-turn crossing around VOLVO Company.

III. Junction

There are two junction level crossings along N-S line at Sebategna and Adey Ababa.

To identify crossing physical characteristics along AALRT, an inventory survey was performed. The result of inventory is presented in the table 4-1 below

Table 4-1 Summery of Data from Inventory Survey on AALRT Level Crossings

S.N.	Crossing Name	Location	Crossing Width	Crossing Angle	Crossing Surface	No of Track	Rail Joint	Rail Tie	Flangeway		Length of Level Plane
									Width	Depth	
E-W Line											
1	Ayat Village Entrance U-Turn	21+940	20m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
2	Tsehay Realestate RA (Ayat & Megenagna Side)	20+216	25m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
		20+067	25m	Close to 90^o							
3	CMC Mikael U-Turn	18+990	20m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
4	Salitemihiret RA (Ayat & Megenagna Side)	17+262	25m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
		17+142	25m	Close to 90^o							
5	Office of Ministry of Mines U-turn	15+790	20m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
N-S Line											
6	VOLVO Company U-Turn	16+874	20m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
7	Adey Ababa Junction	15+755	34m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
8	Meshualekiya RA (Kality & Meskel Sq. Side)	10+170	25m	Close to 90^o	Concrete	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m
		10+094	25m	Close to 90^o							
9	Sebategna Junction		20m	Close to 90^o	Rubber	2	CWR	Fully plated double shoulder ties	75mm	45mm	≥2m

4.1.2 Traffic Control System

Since Addis Ababa is the administrative and economical capital of Ethiopia, many of AALRT level crossings are located at business centers. Such as Sebategna, Adey Ababa, CMC, Gurdshola etc. the highway roads along AALRT are primary arterial streets (PAS) subjected of heavy daily vehicular traffic of order 20,000 to 38,000 vehicles (ICT,2012). The operating speed limit on these roads is the urban speed limit of 50km/hr. the level crossings are also subjected of frequent train traffic with an average headway of 15min. (OCC, time table manual). The aforementioned condition of highway and rail traffic increases train-vehicle conflicts which may amplify the frequency and number of accidents. To minimize such risk the operating speed of trains around level crossing is limited to 20km/hr. besides to this there are different traffic controlling systems installed at the level crossings. The traffic control system used at level crossings is the same for the major categories of level crossings along AALRT. The result of inventory is presented on the table 4-2 below

Table 4-2 Number and Tyepe of Traffic Control System Used at AALRT level Crossings

S.N.	Crossing Category	Number of Traffic Control Systems			
		CrossBucks	Traffic Signals	Bells	Four Quadrant Gates System
1	Roundabout Crossings	4	4	4	1
2	U-Turn Crossings	4	8	4	1
3	Junction Crossings	4	8	4	1

4.1.3 Highway Traffic Data

Vehicle Classification

A total of five general classes were used for recording the traffic. These are described below to indicate the class characteristics and types of vehicles indicated in each class.

Cars

Cars are motor vehicles with seating capacity of not more than 12 persons. This class has 2 axels, 4 tires with less than 3m length and 3.5 ton weight. Vehicles in this class includes standard car, wagons, pickups and minibuses.

Light Vehicles

This class includes large bus and single rear axle trucks with 6 tires, 3-7.5m length and 3.5-12 ton weight.

Medium Vehicles

These are groups of vehicles with dual rear axle with 10 tires. This class has nearly the same weight and dimension to light vehicles

Heavy vehicles

Heavy vehicle of this category includes all heavy goods vehicles with 4 axles, 14 tires, greater than 7.5m length and more than 12 ton weight.

Articulated

Articulated vehicle class includes semi-trailer and heavy goods vehicles with more than 5 axles.

The raw traffic data recorded on these class of vehicles is summarized in Appendix C. These indicates the level of traffic and their compositions for each of the seven count days on the level crossing of AALRT.

Night time factor is needed to adjust the average day time traffic (12hours) in order to estimate the average day time traffic in a way that reflects 24 hours traffic flow on the level crossings. The night factor for each vehicle class has been developed after dividing the 24 hour traffic by the day time (12hour) traffic recorded on the night time traffic count days.

Once the night time factor determined the Average Daily Traffic (ADT) is obtained by taking the average of 12 hour count for seven days multiplied by night time factor.

The Annual Average Daily Traffic (AADT) is calculated by multiplying average daily traffic (ADT) by seasonal conversion factor (SCF). As shown in the tables below greater than 85% of the traffic volume at AALRT level crossings is made of cars which are the daily users of the crossings. Therefore seasonal conversion factor (SCF) of one is used to determine annual average daily traffic. The final annual average daily traffic (AADT) at AALRT level crossings are summarized in the table 4-3 below.

Table 4-3Annual Average Daily Traffic (AADT) at AALRT Level Crossings

S.N.	Crossing Name	AADT (V)
E-W Line		
1	Ayat Village Enterance U-Turn	2742
2	Tsehay Realestate RA Ayat Side	10504
3	Tsehay Realestate RA Megenagna Side	5947
4	CMC Mikael U-Turn	5548
5	Salitemihiret RA Ayat Side	15090
6	Salitemihiret RA Megenagna Side	14149
7	Office of Minstry of Mines U-turn	5382
N-S Line		
8	VOLVOCampony U-Turn	4680
9	Adey Ababa Junction	15510
10	Meshualekiya RA Kality Side	608
11	Meshualekiya RA Meskel Sq. Side	2884
12	Sebategna Junction	9916

4.1.4 Train Traffic Data

The light rail vehicles have a length of 30m. The operation time of AALRT is classified as Peak hour (8:00-19:00) and flat time (6:00-8:00 and 19:00-22:00). Trains operating during these period are commercial train traffic. There are also three non-commercial trains dispatched from each ends of AALRT at 4:30am. During the peak hours one coupled train sets is used. The time table and operational manual outlined in the technical detail document used by AALRT Operation Control and communication (OCC) unit is summarized in the table 4-4 below. From this document there are a total of 122 trip per day on each line. Where 92 of them are performed during the daylight time from 6:00AM to 18:00PM.

Table 4-4 AALRT timetable and Trip distribution

Time of Day	No of Trips by One Train sets	Number of Operating Trains		Total Trip	Type of Trip
		Coupled Train Sets	Single Train Sets		
E-W line					
00:00-6:00 AM	1	-	6	6	Uncommercial trip
6:00-8:00 AM	2	-	6	12	Commercial trips
8:00AM-18:00PM	10	1	7	80	
18:00-19:00PM	1	-	6	6	
19:00-22:00PM	3	-	6	18	
Total train trip per day along E-W line				**122**	
N-S line					
00:00-6:00 AM	1	-	6	6	Uncommercial trip
6:00-8:00 AM	2	-	6	12	Commercial trips
8:00AM-18:00PM	10	1	7	80	
18:00-19:00PM	1	-	6	6	
19:00-22:00PM	3	-	6	18	
Total train trip per day along E-W line				**122**	

During all these trips LRT trains have full priority at level crossings by prohibiting other movements using traffic control systems. The duration of time that the level crossings are closed for other movements is called traffic blockage time (T_b). This time is a function of train speed, crossing width, and type of traffic control system given by:

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

Where:

T_C is crossing time, = (Length of LRT train + Width of crossing)/ LRT speed

T_{GC} is warning and gate closing time assumed to be 20 second (MTA and MUTCD, 2003)

T_{GO} is gate opening and startup time assumed to be 10 second (MUTCD, 2003)

The traffic blockage time for each level crossing of AALRT is presented in the table 4-5 below for 20km/hr train speed at such locations.

Table 4-5 Traffic blockage time at AALRT level crossings

S.N.	Crossing Name	Crossing Width (W_{Cr}) in m	Train Length (L_T) in m		Crossing time (T_C) in Sec. $=(L_T+W_{Cr})/V_T$		Traffic Blockage time (T_b) in Sec. $= T_C+T_{GC}+T_{GO}$	
			Coupled Train Sets	Single Train Sets	Coupled Train Sets	Single Train Sets	Coupled Train Sets	Single Train Sets
E-W Line								
1	Ayat Village Entrance U-Turn	20	60	30	14.4	9	44.4	39
2	Tsehay Realestate RA (Ayat & Megenagna Side)	20	60	30	14.4	9	44.4	39
		20			14.4	9	44.4	39
3	CMC Mikael U-Turn	20	60	30	14.4	9	44.4	39
4	Salitemihiret RA (Ayat & Megenagna Side)	20	60	30	14.4	9	44.4	39
		20			14.4	9	44.4	39
5	Office of Ministry of Mines U-turn	20	60	30	14.4	9	44.4	39
N-S line								
6	VOLVO Company U-Turn	20	60	30	14.4	9	44.4	39
7	Adey Ababa Junction	34	60	30	16.92	11.52	46.92	41.52
8	Meshualekiya RA (Kality & Meskel Sq. Side)	20	60	30	14.4	9	44.4	39
		20			14.4	9	44.4	39
9	Sebategna Junction	20	60	30	14.4	9	44.4	39

4.2 Data Analysis

The data presented above analyzed for safety based on compliance to highway-railroad level crossing design standards and accident rating models outlined on the research methodology.

4.2.1 Evaluation of AALRT Level Crossings Based Design Standards and Guidelines

Evaluation of AALRT level crossings with respect to design standards is presented in the table 4-6 below.

Table 4-6 Evaluation of AALRT Level Crossings Based Design Standards and Guidelines

S.N.	Basic Crossing Design Criteria	Design Standards Recommendation			Inventory Result	Evaluation Result
		AREMA	GB50090-2006 PRC	MUTCD		
1	Crossing Physical Parameters					
	1.1 Location	Straight section of track	Straight section of track	NA	Straight section of track	Satisfy both standards
	1.2 Width of Crossing	Carriageway + walkway	Carriageway + walkway	NA	20m	Satisfy both standards
	1.3 Crossing Surface Material	Consolidated dirt, gravel free surface	Hard and durable materials easy to repair.	NA	Rubber	Satisfy both standards
2	Roadway Parameters					
	2.1 Roadway Alignment	Roadway should intersect the railroad at or nearly at right angles	Roadway should intersect the railroad at or nearly at right angles	NA	Closer to 90^{o} crossing angle	Satisfy both standards
	2.2 length of Level Plane Beyond Outer Rail	At least 0.6m	Between 0.5-2m	NA	≥2m	Satisfy both standards
	2.3 Roadway Surface Material	-	-	NA	Paved	
3	Railway Track Parameter					
	3.1 Rail Type	CWR	CWR	NA	CWR	Satisfy both standards
	3.2 Rail Ties	Fully plated with double shoulder ties	-	NA	Fully plated with double shoulder ties	Satisfy AREMA
	3.3 Flangeway Width	At least 75mm	Between 70-100mm	NA	75mm	Satisfy both standards
	3.4 Flangeway Depth	At least 50mm	Between 45-60mm	NA	45mm	Satisfy GB50090

S.N.	Basic Crossing Design Criteria	Design Standards Recommendation			Inventory Result	Evaluation Result
		AREMA	GB50090-2006 PRC	MUTCD		
4	Traffic Control Devices (TCD)					
	4.1 Crossbucks (R15-1)	NA	NA	Necessary sign based on Section 10C.02	4 at each Crossing	Satisfy MUTCD
	4.2 Number of Track (R15-2)	NA	NA	Supplemental based on Section 10C.02	Not used	Not necessary sign
	4.3 Stop (R1-1) or Yield (R1-2)	NA	NA	NA based on Section 10C.04	Not used	Not applicable to AALRT
	4.4 Advance warning signs (W1)	NA	NA	NA based on Section 8B.04	Not used	Not applicable to AALRT
	4.5 Emergency Notification Sign (I-13)	NA	NA	Necessary sign based on Section 10C.21	Not used	Should have been provided
	4.6 Pavement Marking	NA	NA	NA based on Section 10C.23	Not used	Not applicable to AALRT
	4.7 Signs + Flashing lights	NA	NA	used under medium traffic if train speed ≥60km/hr based on Section 10D.02	-	Not applicable to AALRT
	4.8 Signs + Flashing Light + Gate Systems	NA	NA	Used under heavy traffic if train speed ≥60km/hr based on Section 10D.03	-	Not applicable to AALRT
	4.9 Signs + Traffic Signal + Gate Systems	NA	NA	Used under heavy traffic if train speed ≤ 60km/hr based on Section 10D.05	Used at each crossings	Enough Active TCD for case of AALRT

4.2.2 Relative Accident at Level Crossings along AALRT

1. **New Hampshire Model**

Relative accident at level crossings of AALRT is determined by using New Hampshire model.

$$HI = VRP_f$$

In this equation V is annual average daily traffic (AADT) at each crossing and R is daily train volume which is 122 trains/day on each lines of AALRT.

P_f is the protection factor for each crossing device (Crossbucks, flashing lights and gates). Since the system of traffic control used at level crossings is signs + traffic signal+ gate systems (Type G), P_f = 0.1 is used according to FHWA handbook, 2007.

The relative accident level of AALRT level crossings from New Hampshire model is presented in table 4-7 below

Table 4-7 Relative accident level of AALRT level crossings using New Hampshire model

S.N.	Crossing Name	Vehicular Volume V in Vech/day	Train Volume R in Train/day	Protection factor P_f	Hazard Index HI = V*R* Pf	Rank
E-W Line						
1	Ayat Village Entrance U-Turn	2742	122	0.1	33454.11	11
2	Tsehay Realestate RA (Ayat & Megenagna Side)	10503	122	0.1	128142.46	4
		5947			72555.35	6
3	CMC Mikael U-Turn	5548	122	0.1	67689.02	7
4	Salitemihiret RA (Ayat & Megenagna Side)	15090	122	0.1	184098.98	2
		14149			172620.85	3
5	Office of Ministry of Mines U-turn	5382	122	0.1	65655.40	8
N-S Line						
6	VOLVO Company U-Turn	4680	122	0.1	57099.78	9
7	Adey Ababa Junction	15510	122	0.1	189220.78	1
8	Meshualekiya RA (Kality & Meskel Sq. Side)	608	122	0.1	7421.99	12
		2884			35179.07	10
9	Sebategna Junction	9916	122	0.1	120980.81	5

2. Contra Costa Model

The above New Hampshire result gave much weight to the highway traffic. Hence result is checked by using Contra Costa Model which considered that the number of trains per day was proportional to the hazard and exposure. Hazard level using this model is determined by:

$$HI = RZ\left(1 - 2.718^{\frac{-V*t}{1400Z}}\right)$$

Where

R = number of trains per day
Z = number of traffic lanes
V = number of highway vehicles per day
t = time, in min/day, that the crossing is blocked

From field observation and width of crossing the maximum number of lanes at AALRT level crossings is four. The total crossing blockage time per day is obtained by summing the product of crossing blockage for single trip by total trip per day for coupled and single train sets. There are 10 trips per day for coupled train sets. During a single trip of this train sets, all AALRT crossings are blocked for other movements for 44.44 sec except at Adey Ababa junction where it is closed for 46.92 second. For a single train set the crossings are closed for 39 seconds except at Adey Ababa closed for 41.52 second (from table 4-5). Therefore total crossing blockage time per day for Adey Ababa level crossing is

$$t = \frac{10 * 46.92 + 112 * 41.52}{60} = 85.32min/day$$

For all other level crossings of AALRT

$$t = \frac{10 * 44.44 + 112 * 39}{60} = 80.21min/day$$

The relative accident level of AALRT level crossings from Contra Costa model is presented in table 4-8 below

Table 4-8 Relative accident level of AALRT level crossings using Contra Costa model

S.N.	Crossing Name	Vehicular Volume (V) in Veh/day	Train Volume (R) in Train/day	No of Lane (Z)	Blocked time t in min/day	Contra Costa HI	Rank
E-W Line							
1	Ayat Village Entrance U-Turn	2742	122	4	80.21	488	-
2	Tsehay Realestate RA (Ayat & Megenagna Side)	10503	122	4	80.21	488	-
		5947			80.21	488	-
3	CMC Mikael U-Turn	5548	122	4	80.21	488	-
4	Salitemihiret RA (Ayat & Megenagna Side)	15090	122	4	80.21	488	-
		14149			80.21	488	-
5	Office of Ministry of Mines U-turn	5382	122	4	80.21	488	-
N-S Line							
6	VOLVO Company U-Turn	4680	122	4	80.21	488	-
7	Adey Ababa Junction	15510	122	5	85.32	610	Highest
8	Meshualekiya RA (Kality & Meskel Sq. Side)	608	122	4	80.21	487	Lowest
		2884			80.21	488	-
9	Sebategna Junction	9916	122	4	80.21	488	-

4.2.3 Expected Accidents at Level Crossings along AALRT

The expected accident at the level crossings of AALRT based on current operation conditions is determined by using US DOT accident prediction models and the result is counter checked using Expected Accident Frequency (EAF) model.

1. **US DOT Accident Prediction Model**

This model has three sub models to consider effects of geometry and traffic, accident history and existing controlling system. Currently gates at the level crossing of AALRT didn’t start operating even though they are functional. Therefore current traffic controlling system at level crossings of AALRT is combination of Signs and Traffic signals or Type ‘F’ system.

Based on this the expected future accident per year at the level crossings of AALRT computed using models of US DOT developed for flashing light controlling system. To determine the future accident, first calculate the factors in the basic formula of US DOT accident prediction model.

I. Basic Formula

$$a = K * EI * MT * DT * HP * MS * HT * HL$$

For type 'F' traffic control system the values of HP, MS, and HT is one for all level crossings and formula constant K is 0.00365 (FHWA handbook page 56). Other factors are calculated using the following formula for all level crossings:

$$\text{Factor for number of main tracks } (MT) = e^{0.1088mt}$$

Where mt is number of main tracks along AALRT = 2

$$MT = e^{\,0.1088*2} = 1.24$$

$$Factor\ for\ number\ of\ thru\ trains\ per\ day\ during\ day\ light\ (DT) = \left(\frac{d + 0.2}{0.2}\right)^{0.0470}$$

Where'd' is number of thru trains per day during daylight (6:00AM to 18:00PM) = 92 trains/day

$$DT = \left(\frac{92 + 0.2}{0.2}\right)^{0.0470} = 1.33$$

$$\text{Factor for number of highway lanes } (HL) = e^{0.1380*(hl-1)}$$

Where hl is number of lanes which is four at all level crossing of AALRT except at Adey Ababa where number of lane is five. Therefore

$$HL\ at\ Adey\ Ababa = e^{0.1380*(5-1)} = 1.7$$

$$HL\ at\ other\ crossings = e^{0.1380*(4-1)} = 1.51$$

$$let\ K * MT * DT * HP * MS * HT * HL = G$$

Therefore; initial collision per year (a) becomes = G*EI

$$where\ EI\ is\ factor\ for\ exposure\ index\ = \left(\frac{c * t + 0.2}{0.2}\right)^{0.2953}$$

Where t is average daily train traffic along AALRT = 122 trains/day on each line

If AALRT gates were operational (Type G system) DT, HP, MS, and HT is one for all level crossings and formula constant K is 0.00109. Other factors are calculated using the following formula

$$\text{Factor for number of main tracks } (MT) = e^{0.2912mt}$$

Where mt is number of main tracks along AALRT = 2

$$MT = e^{\ 0.2912*2} = 1.79$$

$$\text{Factor for number of highway lanes } (HL) = e^{0.1036*(hl-1)}$$

Where hl is number of lanes which is 4 at all level crossing of AALRT except at Adey Ababa where number of lane is 5. Therefore

$$HL\ at\ Adey\ Ababa = e^{0.1036*(5-1)} = 1.5$$

$$HL\ at\ other\ crossings = e^{0.1036*(4-1)} = 1.36$$

$$let\ K * MT * DT * HP * MS * HT * HL = G$$

Therefore; initial collision per year (a) becomes = G*EI

$$where\ EI\ is\ factor\ for\ exposure\ index\ = \left(\frac{c * 122 + 0.2}{0.2}\right)^{0.3116}$$

The value of EI and a for both cases is summarized in the table 4-9 below

Table 4-9 Initial collision per year at level crossings of AALRT for Type F (signs + traffic signal) and Type G (signs + traffic signal + automatic gate) traffic control system.

S.N.	Crossing Name	Crossing AADT in Vech/day	Exposure Index EI		G = K*MT*DT*HP*MS*HT*HL		Initial Collision/year a=G*EI		Percent of accident reduction due to Type G control system
			Type F	Type G	Type F	Type G	Type F	Type G	
E-W Line									
1	Ayat Village Entrance U-Turn	2742	68.83	86.94	0.00909	0.00265	0.63	0.23	63%
2	Tsehay Realestate RA (Ayat & Megenagna Side)	10503	102.33	132.12	0.00909	0.00265	0.93	0.35	62%
		5947	86.51	110.66	0.00909	0.00265	0.79	0.29	63%
3	CMC Mikael U-Turn	5548	84.75	108.29	0.00909	0.00265	0.77	0.29	63%
4	Salitemihiret RA (Ayat & Megenagna Side)	15090	113.89	147.91	0.00909	0.00265	1.04	0.39	62%
		14149	111.74	144.97	0.00909	0.00265	1.02	0.38	62%
5	Office of Ministry of Mines U-turn	5382	83.99	107.27	0.00909	0.00265	0.76	0.28	63%
N-S Line									
6	VOLVO Company U-Turn	4680	80.60	102.70	0.00909	0.00265	0.73	0.27	63%
7	Adey Ababa Junction	15510	114.81	149.18	0.01023	0.00293	1.17	0.44	65%
8	Meshualekiya RA (Kality & Meskel Sq. Side)	608	44.12	54.38	0.00909	0.00265	0.40	0.14	64%
		2884	69.86	88.31	0.00909	0.00265	0.63	0.23	63%
9	Sebategna Junction	9916	100.61	129.77	0.00909	0.00265	0.91	0.34	62%

II. Accident History Formula

$$B = \frac{T_o}{T_o + T}(a) + \frac{T_o}{T_o + T}\left(\frac{N}{T}\right)$$

Where:

a = initial collision prediction from basic formula, collisions per year at the crossing

B = second collision prediction, collisions per year at the crossing

$\frac{N}{T}$ = Collision history prediction,

As AALRT is operated recently no significant accident history is recorded. Hence the value of $\frac{N}{T}$ and T in the above formula is one year.

T_o is formula weighting factor $\frac{1}{(0.05+a)}$ determined for each crossings.

Hence b becomes

$$B = \left(\frac{\frac{1}{(0.05 + a\,)}}{\frac{1}{(0.05 + a)} + 1}\right)(a) = \left(\frac{1}{(1.05 + a\,)}\right)(a) = \frac{a}{(1.05 + a\,)}$$

III. Normalizing Equation

This third equation of US DOT accident prediction model adds a normalizing constant, which adjust expected accidents per year from the above two formulas matches with current collision trends. Since collision trends are unavailable at this time a normalizing constant of one is used for level crossings of AALRT. This results final accident prediction to be the same as second accident prediction.

The final accident prediction in number of accident per year at the level crossings of AALRT is calculated in the table 4-10 below.

Table 4-10 Final Collision/year at AALRT level crossings from US DOT Model

S.N.	Crossing Name	Crossing AADT in Vech/day	Initial Collision/year a		Final Collision/year A = a/(1.05+a)		Percent of accident reduction due to Type G control system
			Type F	Type G	Type F	Type G	
E-W Line							
1	Ayat Village Entrance U-Turn	2742	0.63	0.23	0.37	0.18	52%
2	Tsehay Realestate RA (Ayat & Megenagna Side)	10503	0.93	0.35	0.47	0.25	47%
		5947	0.79	0.29	0.43	0.22	49%
3	CMC Mikael U-Turn	5548	0.77	0.29	0.42	0.21	49%
4	Salitemihiret RA (Ayat & Megenagna Side)	15090	1.04	0.39	0.50	0.27	45%
		14149	1.02	0.38	0.49	0.27	45%
5	Office of Ministry of Mines U-turn	5382	0.76	0.28	0.42	0.21	49%
N-S Line							
6	VOLVO Company U-Turn	4680	0.73	0.27	0.41	0.21	50%
7	Adey Ababa Junction	15510	1.17	0.44	0.53	0.29	43%
8	Meshualekiya RA (Kality & Meskel Sq. Side)	608	0.40	0.14	0.28	0.12	56%
		2884	0.63	0.23	0.38	0.18	52%
9	Sebategna Junction	9916	0.91	0.34	0.47	0.25	47%

2. Expected Accident Frequency Model

The result of US DOT accident prediction is counter checked using EAF model. The number of crashes per year at level crossings of AALRT calculated by

$$EAF = A * B * R$$

Where

A = vehicular traffic factor determined by

$$A = 1.35135 * 10^{-6} * (2 * 10^{-10} * ADT^3 - 10^{-5} * ADT^2 + ADT - 67)$$

B = factor based on existing warning device

For Crossbucks (Type S) B = 3.06
For Crossbuck + Flashing lights (Type F), B = 0.23 and
For Crossbuck + Flashing lights + Gates (Type G), B = 0.08

R = average daily train traffic on AALRT = 122 trains/day

The predicted accident per year at level crossings of AALRT based on two cases of warning system presented in the table 4-11 below

Table 4-11 Expected number of accident per year at AALRT level crossings from EAF model

S.N.	Crossing Name	Crossing ADT in Vech/day	ADT Factor A	Number of Accident Per year EAF		Percent of accident reduction due to Type G control system
				Type F	Type G	
E-W Line						
1	Ayat Village Entrance U-Turn	2742	0.00352	0.10	0.03	65%
2	Tsehay Realestate RA (Ayat & Megenagna Side)	10503	0.01293	0.36	0.13	65%
		5947	0.00753	0.21	0.07	65%
3	CMC Mikael U-Turn	5548	0.00704	0.20	0.07	65%
4	Salitemihiret RA (Ayat & Megenagna Side)	15090	0.01815	0.51	0.18	65%
		14149	0.01709	0.48	0.17	65%
5	Office of Ministry of Mines U-turn	5382	0.00683	0.19	0.07	65%
N-S Line						
6	VOLVO Company U-Turn	4680	0.00597	0.17	0.06	65%
7	Adey Ababa Junction	15510	0.01863	0.52	0.18	65%
8	Meshualekiya RA (Kality & Meskel Sq. Side)	608	0.00073	0.02	0.01	65%
		2884	0.00370	0.10	0.04	65%
9	Sebategna Junction	9916	0.01224	0.34	0.12	65%

CHAPTER 5 RESULT AND DISCUSSION

5.1 Evaluation of AALRT Level Crossings Based Design Standards and Guidelines

Almost all of the fundamental requirements of The American Railway Engineering and Maintenance-of-Way Association (AREMA) and Chinese standard (GB50090-2006 PRC) for design of highway-railroad level crossing are satisfied by level crossings of AALRT. Therefore level crossings along Addis Ababa Light Rail transit could be considered as safe from infrastructural point of view. But the provision of traffic control systems outlined by Manual on Uniform Traffic Control Devices (MUTCD) are case specific. One crossbuck sign is used on each highway approach in combination with four quadrant gate system and traffic signal at all highway-railroad level crossings of AALRT. Since the train speed at level crossings is less than 60km/hr, traffic signals are used instead of flashing lights. But the traffic volume on most of AALRT level crossings is high, traffic signals are coupled with four quadrant gate system as recommended by MUTCD. These traffic control system could be considered as enough according to MUTCD specifications. With such active traffic control system, parallel orientation of highways to AALRT lines and frequent train operation (15-20 min headway), Stop (R1-1) or Yield (R1-2) and Advance warning signs (W10 series) are not applicable to AALRT level crossings. Pavement markings shall not be required at highway-rail grade crossings in urban area, hence it isn't used

5.2 Relative Accident at Level Crossings along AALRT

Result of New Hampshire model identifies AALRT level crossings at Adey Ababa junction, Salitemihiret and Tsehay Realestate roundabout and Sebategna junction are most hazardous. These crossings are also the most congested crossings with an average annual daily traffic more than 10000 vehicles. The protection factor and number of train per day used in New Hampshire model are the same for all AALRT level crossings. Therefore as the number of highway traffic increases the accident level at those crossings also increases as shown in the figure 5-1 below.

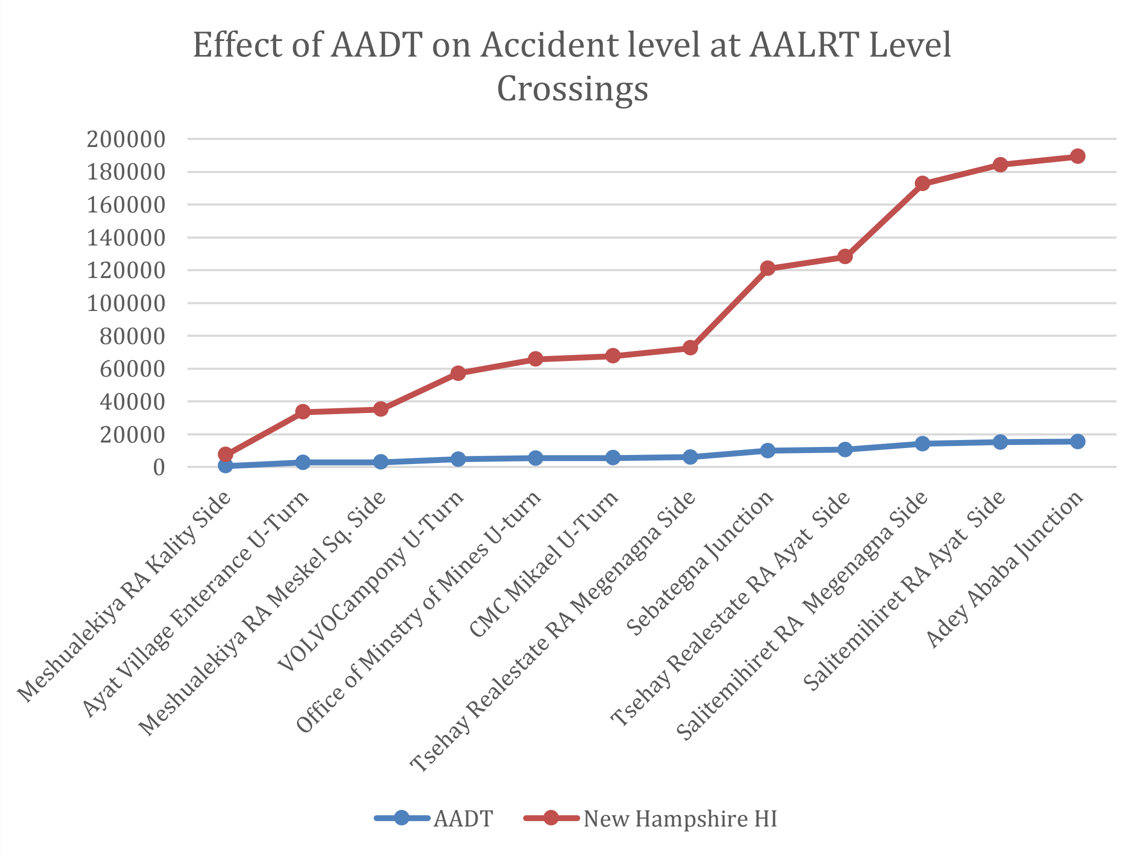

Figure 5-1 Effect of AADT on Accident level at AALRT Level Crossings

In New Hampshire model effects of train length and speed, geometry of crossing such as number of traffic lane, crossing width and crossing angle are not considered. However Contra Costa model considers the effect of number of traffic lane on accident level directly in the model. The effect of other parameters like train length and speed, crossing width and angle are considered indirectly through the calculation of crossing blockage time. For a given number of train per day, number of vehicle per day and number of traffic lanes, as the crossing blockage time increases the hazard index from Contra Costa model also increases. The crossing blockage time in turn increases with an increases in the width of a crossing. Skewedness of crossing increase the crossing width. Therefore crossings with wider width like Adey Ababa level crossing are expected to have higher accident level. From both models level crossing at Adey Ababa junction has the highest probability of accident. The highest highway traffic volume and geometrical condition makes this crossing more vulnerable to accident.

5.3 Expected Accidents at Level Crossings along AALRT

Both US DOT and EAF models identified level crossings at Adey Ababa junction, Salitemihiret and Tsehay Realestate roundabout and Sebategna junction are most hazardous. This result also conforms the output of hazard index models. In both models the expected accident at the crossings will decrease by more than 50% if the gates start operation. The US DOT accident prediction model gives higher expected accident number than EAF model as shown in the figure 5-2 below. This is due to US DOT model gives more weight to the effect of highway traffic on level crossing safety through exposure index than EAF model by vehicular traffic factor A

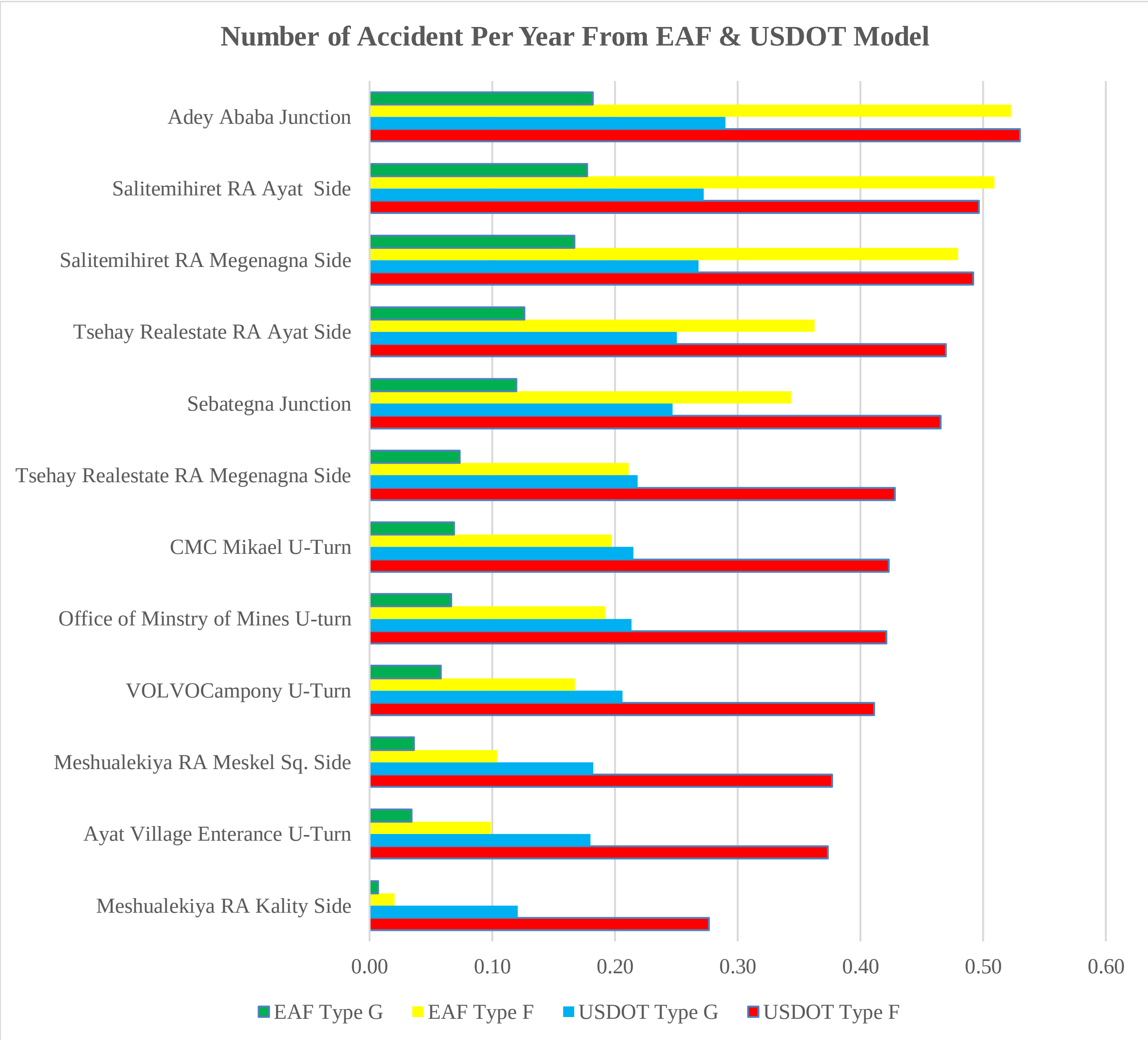

Figure 5-2 Expected accident per year at AALRT level crossings

Highway-railroad level crossings along AALRT are located around commercial areas serving 116 commercial trains and more than 2000 average daily traffic. Such conditions call for the use of automatic gates (type 'G' control system) at level crossings. Besides to these, for type 'F' traffic control system the minimum expected accident number per year from US DOT accident prediction model is 0.28 found at Kality side level crossing of Meshualekiya roundabout. This value is greater than 0.075 accident/year which is a threshold value for the start of type 'G' traffic control system.

The passenger train exposure is the product of passenger train per day and AADT. This product is below 400,000 at Ayat village entrance and Meshualekiya roundabout level crossings for type 'G' traffic control system. The US DOT expected accident numbers per year at these crossings are below 0.2 from US DOT model which is a threshold value for consideration of grade separation based on economic feasibility. Therefore Ayat village entrance and Meshualekiya roundabout level crossings do not need grade separation.

But on the other level crossings of AALRT the expected accident numbers per year are significantly greater than 0.2. Also the exposure index exceeds 400,000 as shown in the table 5-1below.

Table 5-1 The passenger train exposure at AALRT level crossings

S.N.	Crossing Name	AADT (V)	Train Volume (R) in Train/day	Crossing Exposure =V*R
1	Ayat Village Entrance U-Turn	2742	122	334,541
2	Tsehay Realestate RA Ayat Side	10503	122	1,281,425
	Tsehay Realestate RA Megenagna Side	5947		725,554
3	CMC Mikael U-Turn	5548	122	676,890
4	Salitemihiret RA Ayat Side	15090	122	1,840,990
	Salitemihiret RA Megenagna Side	14149		1,726,209
5	Office of Ministry of Mines U-turn	5382	122	656,554
6	VOLVO Company U-Turn	4680	122	570,998
7	Adey Ababa Junction	15510	122	1,892,208
8	Meshualekiya RA Kality Side	608	122	74,220
	Meshualekiya RA Meskel Sq. Side	2884		351,791
9	Sebategna Junction	9916	122	1,209,808

CHAPTER 6 CONCLUSIONS AND RECCOMENDATIONS

This study assessed major safety issues on highway-railroad level crossings along the Addis Ababa Light Rail Transit (AALRT) using relevant design standards and accident rating models.

The level crossings along AALRT are found to be conformant to the guidelines and design standards of American Railway Engineering and Maintenance-Of-Way Association AREMA manual, Chinese standard GB50090, and manual on uniform traffic control devices MUTCDS.

Despite this, level crossings at Tsehay Realestate roundabout, Salitemihiret roundabout, Adey Ababa and Sebategna junction shows highest accident frequency.

From result and discussion the following points can be concluded.

- Geometry of crossing and traffic volume are found to be the reasons for high accident frequency at Tsehay Realestate roundabout, Salitemihiret roundabout, Adey Ababa and Sebategna junction level crossings.
- For type ‘F’ traffic control system the threshold value (0.075) for gate operation is exceeded by all level crossings of AALRT from US DOT model. This indicates the gates at the crossings should start operation.
- When gates are operational, level crossings at Tsehay Realestate roundabout, Salitemihiret roundabout, Adey Ababa junction, Sebategna junction, CMC Mikael U-turn, Office of Ministry of Mines U-turn and VOLVO Company U-turn recorded US DOT accident frequency greater than 0.2 which is higher than the threshold value. Therefore these crossings should be considered for grade separation if the cost of grade separation can be economically justified based on fully allocated life-cycle costs.
- Ayat village entrance and Meshualekiya roundabout level crossings have accident frequency below 0.2 and crossing exposure is also lower than 400,000. Therefore the level crossings can operate safely without grade separation.

Findings from this research can be used as starting platform for further study in the following areas of highway-railroad level crossing.

- As presented in literature review part, not all the factors and their effects are treated in this study directly. Therefore further analysis of the effects of highway gradient, illumination, distractive influences, visibility and vehicle driver-related factors on the accident potential and the hazard index is highly recommended. Increased understanding of the impact of these factors would improve the ability to identify and rank the hazardous crossings.
- The analyses performed in this study are without accident history using models developed in other country particularly United States of America that decrease the accuracy. Adaptation and applicability of these models for Ethiopian context could also be one study area
- During data collection the Author observed plenty of old cars operating on the streets of Addis Ababa. The adverse effect of old cars on Highway-railroad level crossing safety is also recommended for further research.
- Critical investigation of accidents may yield valuable information regarding driver behavior. Study concerning driver behavior around Highway-railroad level crossing would permit better community education and awareness programming
- Performance evaluation of traffic control system used at Highway-railroad level crossing is helpful in economic evaluation of warning system upgrading.

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APPENDIXES A

Crossing Inventory Form

Part 1: Location and Classification

1. Railroad Line name	2. Number of garde crossing along this railroad line	3. Grade Crossing name

4. Crossing Type

☐ U-turn grade crossing ☐ Roundabout grade crossing ☐ X-garde crossing

Part II: Railroad Information

1. Number of Daily Train Movments

1.A. Total Trains	1.B. Total Daylight Thru Trains (6AM to 6PM)

2. Speed of Trains at Crossing

2.A. Max Time Table Speed (Km/hr) ___________________

2.B. Typical Speed Range over crossing from_____________to___________

3. Type and Number of Tracks

Main______________ Other______________ If other, Specify ____________________

Part III: Traffic Control Device Information

1. No Signs or Signals	2.Type of warning Devices at crossing - Signs (sprcify number of each)		
☐ Check if correct	2.A. Crossbucks	2.B. Highway Stop Signs(R1-1)	2.C.RR Advance warning Signs (W10-1) ☐ yes ☐ No

2.D. Pavement Markings	2.E. Other Signs: (Specify MUTCD type)
☐ Stoplines ☐ RR xing Symbols ☐ None	Number ____________ Specify Type Number ____________ Specify Type

3. Types of Warning Devices at Crossing - Train Activated Devices (specify number of each)

3.A. Gates	3.B. Four-quadrant (or full barrier) gates	3.C. Cantilevered (or Bridged) Flashing lights:
	☐ yes ☐ No	Over traffic lanes (number)___________ Not over traffic lanes (number)________

3.D. Mast Mounted Flashing Lights (number)	3.E. Highway Traffic Signals (number)	3.F. Bells

Part IV: Physical Characteristics

1. Type of development

☐ Open Space ☐ Residential ☐ Commercial ☐ Industrial ☐ Institutional

2.Smallest Crossing Angle	3. Number of Traffic Lanes crossing Railroad
☐ 0-29 degree ☐ 30-59 degree ☐ 60-90 degree	

4.Is Highway Paved?	5. Is Crossing Illuminated (Street lights within 15m range from nearest rail)	6. Is Rail CWR or Jointed?
☐ yes ☐ No	☐ yes ☐ No	☐ CWR ☐ Jointed

7.Is Rail plated	8. Is rail double shoulder tied	9. Flangeway at level crossing
☐ yes ☐ No	☐ yes ☐ No	9.A. width (mm)__________ 9.B. Depth (mm)__________

10. Crossing Surface

☐ 1. Timber ☐ 2. Asphalt ☐ 3. Rubber ☐ 4. Concrete ☐ 5. Concrete and Rubber

☐ 6. Metal ☐ 7. Other (Specify)______________________________

11. The length of level roadway surface to top of the rails beyond the outer rail of the outermost track in each direction

☐ < 0.6m ☐ 0.6m to 2m ☐ ≥ 2m

Part V: Highway Information

1. Functional Classification of Road at Crossing	2. Posted Highway Speed	3. Crossing AADT
☐ Primary Aertrial Streets (PAS) ☐ Collector Streets (CS) ☐ Secondary Aertrial Streets (SA ☐ Feeder Streets (FS)		

APPENDIX B

Vehicle Count Summary

AALRT Level Crossing______________________ **Date:** __________________________________

Enumerator: _________________________________ **Count Duration:** ________**to** ___________

HOUR	CARS			LIGHT		MEDIUM	HEAVY	ARTICULATED	Total
	Standard Car	Wagon & Pickup	Minibus & Van	Large Bus	Single Rear Axle Trucks	Dual Rear Axle Trucks	4 Axle Trucks	Large Trucks	
12:30 1:30									
1:30-2:30									
2:30-3:30									
3:30-4:30									
4:30-5:30									
5:30-6:30									
6:30-7:30									
7:30-8:30									
8:30-9:30									
9:30-10:30									
10:30-11:30									
11;30-12:30									
Total									

APPENDIX C

Appendix C-1 Ayat Village Enterance AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	2211	2327	2365	2272	2312	1657	1410	548	282	1.20	2504.01	91.3%	2504.01
Light Vehicle	154	163	167	157	154	145	77	38	26	1.21	175.32	6.4%	175.32
Medium Vehicle	40	77	51	59	31	48	12	13	14	1.23	55.63	2.0%	55.63
Heavy Vehicle	3	1	3	4	3	5	0	0	1	1.10	3.04	0.1%	3.04
Articulated	3	7	0	11	0	7	1	0	0	1.00	4.14	0.2%	4.14
												TOTAL AADT	**2742**

Appendix C-2 Tsehay Realestate Roundabout (Ayat Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	7879	7643	7492	7421	6657	7601	7136	2280	2602	1.32	9775.69	93.1%	9775.69
Light Vehicle	442	606	377	427	388	316	183	104	84	1.22	474.92	4.5%	474.92
Medium Vehicle	243	213	199	244	212	159	112	27	33	1.17	230.12	2.2%	230.12
Heavy Vehicle	17	16	12	7	12	4	6	3	3	1.47	15.04	0.1%	15.04
Articulated	7	15	1	12	4	5	10	0	0	1.00	7.71	0.1%	7.71
												TOTAL AADT	**10503**

Appendix C-3 Tsehay Realestat Roundabout (Megenagna Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	4681	4536	4406	4422	4318	4016	3837	948	915	1.22	5258.68	88.4%	5258.68
Light Vehicle	333	323	302	397	399	277	300	86	46	1.22	405.31	6.8%	405.31
Medium Vehicle	254	261	258	279	302	206	106	33	19	1.11	264.16	4.4%	264.16
Heavy Vehicle	12	7	18	7	0	4	5	2	1	1.27	9.61	0.2%	9.61
Articulated	12	7	11	10	6	8	1	1	2	1.20	9.41	0.2%	9.41
												TOTAL AADT	**5947**

Appendix C-4 CMC-Mikael U-Turn AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	4115	4010	4261	4137	4080	3306	2745	1269	1322	1.36	5167.32	93.1%	5167.32
Light Vehicle	293	236	284	297	221	191	84	49	54	1.25	285.44	5.1%	285.44
Medium Vehicle	77	111	81	103	87	103	70	4	3	1.03	93.23	1.7%	93.23
Heavy Vehicle	1	1	0	2	5	2	3	0	0	1.00	2.00	0.0%	2.00
Articulated	0	1	0	1	0	0	0	0	0	1.00	0.29	0.0%	0.29
												TOTAL AADT	**5548**

Appendix C-5 Salitemihret Roundabout (Ayat Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	11175	11133	12086	11777	11278	10177	8772	3457	2840	1.29	14133.48	93.7%	14133.48
Light Vehicle	688	629	737	839	719	493	316	82	54	1.12	707.53	4.7%	707.53
Medium Vehicle	139	191	204	226	187	240	146	30	33	1.15	218.41	1.4%	218.41
Heavy Vehicle	18	5	13	18	14	1	9	3	1	1.80	19.94	0.1%	19.94
Articulated	15	14	15	11	9	8	3	0	0	1.00	10.71	0.1%	10.71
												TOTAL AADT	**15090**

Appendix C-6 Salitemihret Roundabout (Megenagna Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	9815	10432	9857	9690	9451	8399	9691	3968	2364	1.33	12816.82	90.6%	12816.82
Light Vehicle	887	998	962	1028	950	699	457	227	90	1.18	1008.71	7.1%	1008.71
Medium Vehicle	227	285	270	283	294	226	121	39	43	1.16	283.35	2.0%	283.35
Heavy Vehicle	14	2	20	19	21	16	4	4	1	2.03	25.92	0.2%	25.92
Articulated	9	16	16	17	20	12	5	2	0	1.06	14.46	0.1%	14.46
												TOTAL AADT	**14149**

Appendix C-7 Gurd Shola Ministry of Mines U-Turn AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	4121	3853	3867	3835	3903	2983	3204	1330	1138	1.36	5016.00	93.2%	5016.00
Light Vehicle	296	326	328	328	294	167	151	52	24	1.15	311.11	5.8%	311.11
Medium Vehicle	61	53	47	36	51	32	30	10	4	1.16	51.33	1.0%	51.33
Heavy Vehicle	2	1	1	3	4	1	0	0	0	1.00	1.71	0.0%	1.71
Articulated	1	1	0	2	0	2	4	0	0	1.00	1.43	0.0%	1.43
												TOTAL AADT	**5382**

Appendix C-8 VOLVO Company U-Turn AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	3797	2789	3801	3357	3408	3354	1875	768	762	1.25	3998.75	85.4%	3998.75
Light Vehicle	357	336	430	371	435	346	174	116	105	1.32	463.30	9.9%	463.30
Medium Vehicle	110	103	89	100	107	85	48	16	25	1.22	112.15	2.4%	112.15
Heavy Vehicle	39	48	35	43	50	68	28	7	0	1.07	47.46	1.0%	47.46
Articulated	51	100	34	46	41	64	43	10	0	1.10	58.64	1.3%	58.64
												TOTAL AADT	**4680**

Appendix C-9 AdeyAbaba Junction AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	11782	10870	7917	10423	10820	9788	9242	3609	3906	1.37	13814.45	89.1%	13814.45
Light Vehicle	745	880	523	5914	714	495	312	153	131	1.22	1666.66	10.7%	1666.66
Medium Vehicle	4	6	19	3	1	25	18	10	33	2.49	26.60	0.2%	26.60
Heavy Vehicle	0	2	1	0	1	3	0	0	1	1.17	1.19	0.0%	1.19
Articulated	3	1	2	0	0	1	0	0	0	1.00	1.00	0.0%	1.00
												TOTAL AADT	**15510**

Appendix C-10 Meshualekia Roundabout (Kality Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	486	491	526	556	529	384	304	143	82	1.25	586.71	96.4%	586.71
Light Vehicle	18	18	12	17	13	15	3	10	5	1.44	19.86	3.3%	19.86
Medium Vehicle	0	1	0	2	3	2	0	0	2	1.50	1.79	0.3%	1.79
Heavy Vehicle	0	0	0	0	0	0	0	0	0	-	-	0.0%	-
Articulated	0	0	2	0	0	0	0	0	0	-	-	0.0%	-
												TOTAL AADT	**608**

Appendix C-11 Meshualekia Roundabout (Meskel Square Side) AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	2279	2513	2424	2131	2161	2389	1359	705	647	1.28	2780.35	96.4%	2780.35
Light Vehicle	101	109	106	87	79	65	70	4	5	1.06	93.02	3.2%	93.02
Medium Vehicle	3	10	14	7	11	4	1	2	2	1.35	9.51	0.3%	9.51
Heavy Vehicle	0	0	0	0	0	0	0	0	0	-	-	0.0%	-
Articulated	1	1	0	0	0	1	0	1	0	1.50	0.64	0.0%	0.64
												TOTAL AADT	**2884**

Appendix C-12 Sebategna Junction AALRT Level Crossing AADT

Vehicle Class	Monday May 23,2016	Tuesday May 24,2016	Wednesday May 25,2016	Thursday May 26,2016	Friday May 27,2016	Saturday May 28,2016	Sunday May 29,2016	Tuesday May 24,2016 Night	Saturday May 28,2016 Night	Avg. Night Time Factor	ADT	Percent of Composition	AADT
Car	7987	6452	6842	7194	5974	6416	3334	2895	1416	1.33	8428.06	85.0%	8428.06
Light Vehicle	1496	1326	1305	1271	1328	1116	586	451	70	1.20	1450.67	14.6%	1450.67
Medium Vehicle	28	8	13	11	26	23	24	3	9	1.38	26.30	0.3%	26.30
Heavy Vehicle	8	23	7	3	5	24	0	0	0	1.00	10.00	0.1%	10.00
Articulated	4	1	0	0	0	4	1	0	0	1.00	1.43	0.0%	1.43
												TOTAL AADT	**9916**