



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Pedestrian Level Crossing Safety on the East West Line of Addis Ababa Light Rail Transit

**A thesis submitted to the graduate school of Addis Ababa University in partial fulfillment
of the requirements for the degree of Masters of Science**

In

Rolling Stock Engineering

Prepared by:

Habtamu Seid

Advisor: Dr. –Ir. Eshetie Berhan

June 2015

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DECLARATION

I hereby declare that the thesis entitled “*Pedestrian Level Crossing Safety on the East-West line of Addis Ababa Light Rail Transit*” is original and has not been submitted for other degrees or the like in this university or any other institutes. It does not contain any material, partly or wholly, published or written by others, except those references quoted in the text.

Habtamu Seid Ali

Name

Signature

Date

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First of all thanks to the Almighty God [Leul Egziabher] for his blessing and opportunity for me to finish My MSc. Research.

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Last but not least, I want to write something about the contribution of my parents in completion of this work and my education, but unluckily, all words in my vocabulary are insufficient to fully state my feelings for them.

ABSTRACT

In recent years, Railway level crossing (RLC) accidents is one of the major contributing factors of railway related fatality problems in many countries. A fundamental requirement in pedestrians safety planning is the isolation of level crossings along the railway. This is normally assisted by precautions which are used to give information for every group of pedestrians. The study was done by direct observation and Census (random sampling technique by taking 15 minutes duration) to examine the flow of pedestrians and trains along the level crossings (Stations) of the newly build East-West line of Addis Ababa Light Rail Transit.

From the collected data; by calculating the train pedestrian value and pedestrian category, the necessity of precautions (road markings, audible warnings, pedestrian signals, tactile threshold and guard rails) is analyzed. And also by taking the flow of pedestrians from the graph, the necessity of grade separation is analyzed.

The result of the reasearch is that; Road markings, audible warnings and pedestrian signals are necessary in all stations. Since the necessity of tactile threshold is dependent on the alignment of crossings and adjacent footways, 8 out of 14 stations are isolated to construct a tactile threshold. And also the location of all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail in every station.

In some areas, there is a crowded flow of pedestrians and due to that reason pedestrians are trying to use vehicle crossings as a crossing. It may create a collision between pedestrians and road vehicles due to the congestion. This study recommends the necessity of grade separations (Bridges or Tunnels) in order to avoid those accidents.

Key words: *Railway Level Crossing, Stations, Train Pedestrian Value, Pedestrian Category, Precautions, Grade separations.*

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CHAPTER ONE: INTRODUCTION

1.1. BACKGROUND

Railway level crossing (RLC) is a location where a public or private roadway, footpath, or both, crosses one or more railway/ tramway tracks. It provides a means for vehicles, pedestrians and animals to cross over railway lines. They exist in countries all over the world and in many different forms. The layout, configuration and use of level crossings vary from location to location, so each one is essentially unique [1].

Railway level crossing accidents is one of the major contributing factors of railway related fatality problems in many countries. RLC is considered as a unique intersection as systems are complex and dealing with at least two mode of transport [2]. Therefore collision between motor vehicles, pedestrians and trains is likely to happen at RLC and cause catastrophic consequences.

Safety and the operational problems at RLC can be further classified into highway and railway. The highway component comprises drivers, pedestrians, vehicles and roadway segments, whereas the train component is classified into train and track at crossing locations. The functions and characteristics of the two components and their corresponding elements represent the risk at RLC locations. Various studies have been conducted in many countries, based on a range of issues associated with safety level at RLC [1]. Accident at RLC may be caused by a single factor or by the combination of many other factors.

Most of the time, pedestrians are tends to be blamed in consequences of accidents at RLC. It is due to the verity that road user is likely to have defined traffic control devices, rules and traffic laws when crossing. Therefore engineers of highway and railway should also take into consideration the road user factors in order to plan and to design control devices or making any improvements at RLC. They should be aware of road user characteristics, capabilities, requirements, needs and obligations of road users.

Railway safety is a crucial aspect of rail operation in all over the world. Railway level crossings (RLC) are the interface between roads and railway tracks, and as such are the potential site for vehicle, pedestrian and train collisions and incidents [1].

Nevertheless, the high rates of economic growth experienced in the world, coupled with the growth in personal disposable incomes and the related growth in motor vehicle populations have stressed the need for attitudinal change as far as personal safety is concerned [2].

Railroad trains have a much larger mass relative to their braking capability, and thus a far longer stopping distance than road vehicles. In general, trains do not stop at level crossings but rely on vehicles and pedestrians to clear the tracks in advance. Level crossings constitute a significant safety concern internationally. On average, each year 400 people are killed in the European Union and over 300 in the United State in level crossing accidents. Collisions can occur with vehicles as well as pedestrians; pedestrian collisions are more likely to result in a fatality. Among pedestrians, young people (5–19 years), older people (60 years and over) and males are considered to be high risk users.

The most effective way to improve traffic safety at railroad level crossings is to put precautions at the level crossing [12]. In terms of warning systems, level crossings are either passive crossings which have warnings such as signs, or active crossings which have automatic warning devices such as boom gates, flashing lights and warning tones. Fewer collisions take place at level crossings with active warning systems [6].

The East-West line project of Addis Ababa Light Rail Transit (AA-LRT) starts from Ayat and ends at Torhailoch with a total length of 17.4km; there are totally 22 stations, in which 15 ground station and 7 sky station are contained [5]. The stations are used as a crossing for pedestrians and the necessity of precautions and grade separations is calculated on the paper.

1.2. PROBLEM STATEMENT

Railway level crossing (RLC) accidents is one of the major contributing factors of railway related fatality problems in many countries [1]. Railway Level Crossing systems are complex and dealing with at least two mode of transport. Therefore collision between Pedestrians, motor vehicles and trains is likely to happen at Railway Level Crossings and cause catastrophic consequences [7].

The East-West line project of AA-LRT starts from Ayat and ends at Torhailoch. The total length of main line (East-West line, 1st phase) is 17.4km; there are totally 22 stations, in which 15 ground station and 7 sky station are contained.

According to current social-economic situation, passenger flow, development tendency and integrated with population and employment current situation and development tendency along the line, as well as passenger flow documentations and other relevant study results, it is necessary to do safety management system on the line [10].

The AA-LRT project is well underway; nevertheless, the issue of pedestrian and car crossings seems yet to have been dealt with. People either jump over inconvenient barriers or walk a long way to cross over the rails. From the beginning, its causing some problems and accidents on pedestrians safety [11].

In the design of the new AA-LRT project, pedestrians' level crossings are not considered. It creates some problems on the users which crosses the railroad. In addition to that; eventhough the railroad is new for the city, awareness creation on the pedestrians is not done.

“When the Ethiopian Railway Corporation (ERC) brought the design of the railway, it had no pedestrian crossings and vehicle turn routes,” said Fekade Haile (Eng.), head of Addis Ababa City Roads Authority (AACRA). “So, we discussed with them several times and asked them to redesign it by including both pedestrian and vehicle crossings and turning routes [11].”

In the New Addis Ababa Light Rail Transit pedestrians are forced to use only *Stations* and *Squares* to cross from one end to the other. Due to this, pedestrian either jump over inconvenient

barriers or walk a long way to cross over the rails. The design of Grade Separation and installation of precautions which gives information for the pedestrian is not considered.



Figure 1: Pedestrians attempting to cross the newly built tracks with difficulty.

By considering different countries experience and current situations on level crossings, it is easy to predict that there will be accidents on these crossings. So, in order to avoid these accidents and keep the Railway Level Crossing safe, there must be a design of pedestrians' level crossing safety.

Our Basic research questions are:

1. How can we create a safe pedestrians level crossing system in AA-LRT?
2. Which type of precautions should provide for the pedestrians at railway level crossings?
3. Which area of AA-LRT needs a Grade Separation??
4. Which parts of the AA-LRT project needs recommendations and suggestions?

1.3. OBJECTIVE OF THE STUDY

1.3.1. General objective

The Main objective of the study is to create a Safe Pedestrian Level crossing system in the East-West Line of Addis Ababa Light Rail Transit.

1.3.2. Specific objective

- To provide precautions for the pedestrians at a railway level crossings.
- To select a suitable grade separation system at level crossings.
- To give some suggestions and recommendation for the body who govern the light rail transit.

1.4. SIGNIFICANCE OF THE RESEARCH

Railway level crossing (RLC) accidents is one of the major contributing factors of railway related fatality problems in many countries. Level crossings constitute a significant safety concern internationally. Taking the experience of other countries, we have to build a safe pedestrian level crossing safety system on the new Addis Ababa Light Rail Transit. So, designing a safe railway level crossing has a great significance in terms of;

- Reducing the fatality rate on level crossings.
- Reducing the loss of infrastructures and material costs.
- Creating a safe and reliable traffic system.

1.5. SCOPE OF THE STUDY

This study cover each crossings which are found on the East-West part of the newly building Addis Ababa Light Rail Transit. The research will have a Scope of;

- Deciding the necessity of precautions at each level crossing.
- Selecting a reliable Grade separation system.
- Giving some suggestions and recommendation for the body who govern the AA-LRT.

1.6. ORGANIZATION OF THE PAPER

In the first Chapter; Introduction about Railway Level Crossings, Problem statement of the research and Objective, significance, scope and limitation of the paper are included. The second chapter consist literatures from different articles which are worked on the railway level crossing safety. The methodology of the research is described in the third chapter. Next to the methodology part; data collection, data analysis and data presentation of the research is included in chapter four. Chapter five includes the main findings, result and conclusion of the research. Recommendation about the AA-LRT project is described in chapter six.

1.7. LIMITATION OF THE STUDY

The research has the following limitations:

- Since the light railway construction is new for the city, there are some limitations on getting previous accident data which would help us on designing a safe railway level crossing. Therefore, our research is limited only on the fore coming analyses.
- This paper has limitations on giving a detail explanation on how to construct grade separation bridges and tunnels since it needs another Civil Engineering principles and specialists.
- The effect of “performance of Operators” which controls the precaution system on the RLC safety is not included. Because, the project is still under construction.

CHAPTER TWO: LITERATURE REVIEW

2.1. INTRODUCTION

Railway level crossing is a location where a public or private roadway, footpath, or both, crosses one or more railway/ tramway tracks. It provides a means for vehicles, pedestrians and animals to cross over railway lines. They exist in countries all over the world and in many different forms. The layout, configuration and use of level crossings vary from location to location, so each one is essentially unique [1].

Railway level crossing (RLC) accidents is one of the major contributing factors of railway related fatality problems in many countries. RLC is considered as a unique intersection as systems are complex and dealing with at least two mode of transport [2]. Therefore collision between motor vehicles and trains is likely to happen at RLC and cause catastrophic consequences.

Safety and the operational problems at RLC can be further classified into highway and railway. The highway component comprises drivers, pedestrians, vehicles and roadway segments, whereas the train component is classified into train and track at crossing locations. The functions and characteristics of the two components and their corresponding elements represent the risk at RLC locations. Various studies have been conducted in many countries, based on a range of issues associated with safety level at RLC [1]. Accident at RLC may be caused by a single factor or by the combination of many other factors.

Most of the time, pedestrians are tends to be blamed in consequences of accidents at RLC. It is due to the verity that road user is likely to have defined traffic control devices, rules and traffic laws when crossing. Therefore engineers of highway and railway should also take into consideration the road user factors in order to plan and to design control devices or making any improvements at RLC. They should be aware of road user characteristics, capabilities, requirements, needs and obligations of road users.

Railway safety is a crucial aspect of rail operation in all over the world. Railway level crossings (RLC) are the interface between roads and railway tracks, and as such are the potential site for vehicle-train collisions and incidents [1].

Nevertheless, the high rates of economic growth experienced in the world, coupled with the growth in personal disposable incomes and the related growth in motor vehicle populations have stressed the need for attitudinal change as far as personal safety is concerned [2].

Railroad trains have a much larger mass relative to their braking capability, and thus a far longer stopping distance than road vehicles. In general, trains do not stop at level crossings but rely on vehicles and pedestrians to clear the tracks in advance. Level crossings constitute a significant safety concern internationally. On average, each year 400 people are killed in the European Union and over 300 in the United State in level crossing accidents. Collisions can occur with vehicles as well as pedestrians; pedestrian collisions are more likely to result in a fatality. Among pedestrians, young people (5–19 years), older people (60 years and over) and males are considered to be high risk users.

The most effective way to improve traffic safety at railroad level crossings is to put precautions at the level crossing [12].

In terms of warning systems, level crossings are either passive crossings which have warnings such as signs, or active crossings which have automatic warning devices such as boom gates, flashing lights and warning tones. Fewer collisions take place at level crossings with active warning systems [6].

The East-West line project of Addis Ababa Light Rail Transit (AA-LRT) starts from Ayat and ends at Torhailoch with a total length of 17.4km; there are totally 22 stations, in which 15 ground station and 7 sky station are contained [5]. The stations are used as a crossing for pedestrians and the necessity of precautions and grade separations is calculated on the paper.

2.2. DIFFERENT COUNTRIES' EXPERIENCE

A major concern in rail industry worldwide is to ensure safety in railway operations in general and at road/rail level crossings in particular where the number of fatal accidents has been significantly increasing over the years.

Accidents at level crossings are the result of complex interactions between factors arising from the design and operations of level crossings. An important first step towards eliminating the causes of these accidents is through understanding and assessing the risks associated with a given level crossing and acting on them [14]. The crashes at railway level crossings represent a significant part of casualties in railway traffic. Having two different traffic modes meeting each other at level is always a challenge for traffic safety. Legally the train has always right-of-way at railway level crossings in all countries [12].

Safety at railway level crossings is an important issue for road users, train passengers, train drivers and their crew. Every year in *Australia*, an average of 37 road users, vehicle occupants and pedestrians, die as a result of collisions with trains at railway level crossings [15].

According to statistics, accidents related to pedestrians directly make up approximately one-third of the total number of *Chinese* road traffic accidents. The death toll of pedestrian traffic accidents accounts for 27% of the total death toll from traffic accidents. Most pedestrians in China have a low likelihood of obeying traffic laws, with many breaking the traffic rules when crossing the street every day. In recent years, the “Chinese style of crossing roads” has led to many serious traffic accidents. The growing death toll caused by pedestrians’ unsafe behavior when crossing the street is drawing more and more attention. How the safety of pedestrians when crossing the street can be assured and how casualties can be reduced has become a sensitive and thorny issue for road traffic safety experts [16].

Canada has 48,000 kilometers of track that provides a reliable and affordable way for movement of people and goods across Canada and from/to the United States of America [26]. There are Approximately 37,000 public, private, and pedestrian highway-railways crossings in Canada [24].

According to Transport Safety Board between 2003 and 2012 there was 2165 crossing collisions in Canada resulted in 267 crossing fatalities [25]. Six percent of the total collisions involved pedestrians, resulted in 59 percentage fatality. Vulnerable road user collisions at grade crossings, while less common than other forms of vulnerable road user collisions, are more likely to result in death or irreparable injury. [17].

This list is not a definitive list of the world's worst accidents. It simply shows some selective accidents around the world. [7].

Table 1: Selected level crossing accidents around the world

No.	ACCIDENT	DEATH	COUNTRY	YEAR
1	Langenweddingen level crossing disaster	94	Germany	1967
2	Manfalut train accident	51	Egypt	2012
3	Nagpur level crossing disaster	55	India	2005
4	Marhanets train and bus collision	45	Ukraine	2010
5	Villa Soldati level crossing tragedy	42	Argentina	1962
6	Polgahawela level crossing accident	35	Sri Lanka	2005
7	Dorion level crossing accident	19	Canada	1966
8	2009 Slovak coach and train collision	12	Slovakia	2009
9	Flores rail crash	11	Argentina	2011
10	Bourbonnais train accident	11	United states	1999
11	Hixon rail crash	11	United kingdom	1968
12	Kerang rail accident	11	Australia	2007
13	Glendale train crash	11	United states	2005
14	Lockington rail crash	9	United kingdom	1986
15	Gerogery level crossing accident	5	Australia	2001
16	Fox River Grove level crossing accident	7	United states	1995
17	Ufton Nervet rail crash	7	United kingdom	2004
18	Ottawa bus-train crash	6	Canada	2013

2.3. PRECAUTIONS FOR PEDESTRIANS AT RLCs

Pedestrian collisions at at-grade railway crossings are more likely to result in death or irreparable injury. These tragic rare events have significant adverse effects on communities with at-grade crossings. To improve pedestrian safety at at-grade crossings, a study to develop guidelines for the safety assessment of railway crossings for pedestrians should be done [17].

In Sweden and Norway they have used a simple warning signal at the level crossings with one track and very low volume private road. There is a normal light bulb at the level crossing and the light is on when the train is not approaching the level crossing. If the light is off the train is approaching or the bulb is broken [12].

In Canada, USA, Australia, and Europe treatments have been used to enhance vulnerable road user safety at grade crossings [17].

Passive treatments include traffic control devices that provide a static message of warning and guidance at grade crossings. They are intended to work as a system to permit safe and efficient operations at grade crossings. Passive treatments do not change their appearance or position. Passive treatments includes; Traffic Signs, Pavement markings, Surface treatments and Barriers.

Active treatments are treatments that are only in operation when a train is approaching. These treatments either provide a visual or auditory warning (or both) or they discourage a vulnerable road user from crossing at a location (either by a gate closing or an arm lowering).

Appropriate provision should be made for pedestrians, taking account of the number and frequency of pedestrians and trains, at all public vehicular level crossings. There should be sufficient space, taking into account the volume and nature of the users. Allowance should be made for the needs of those with pushchairs and in wheelchairs [5].

The Main pasive and active pedestrian precautions include the following groups:

2.3.1. Road markings

Road markings are a special type of traffic signs which are marked on the surface of the road. Like traffic signs they can give orders, warning or information. Sometimes they are used with traffic signs [22].

It is any kind of device or material that is used on a road surface in order to convey official information. They can also be applied in other facilities used by vehicles to mark parking spaces or designate areas for other uses. Road surface markings are used on paved roadways to provide guidance and information to drivers and pedestrians [23].

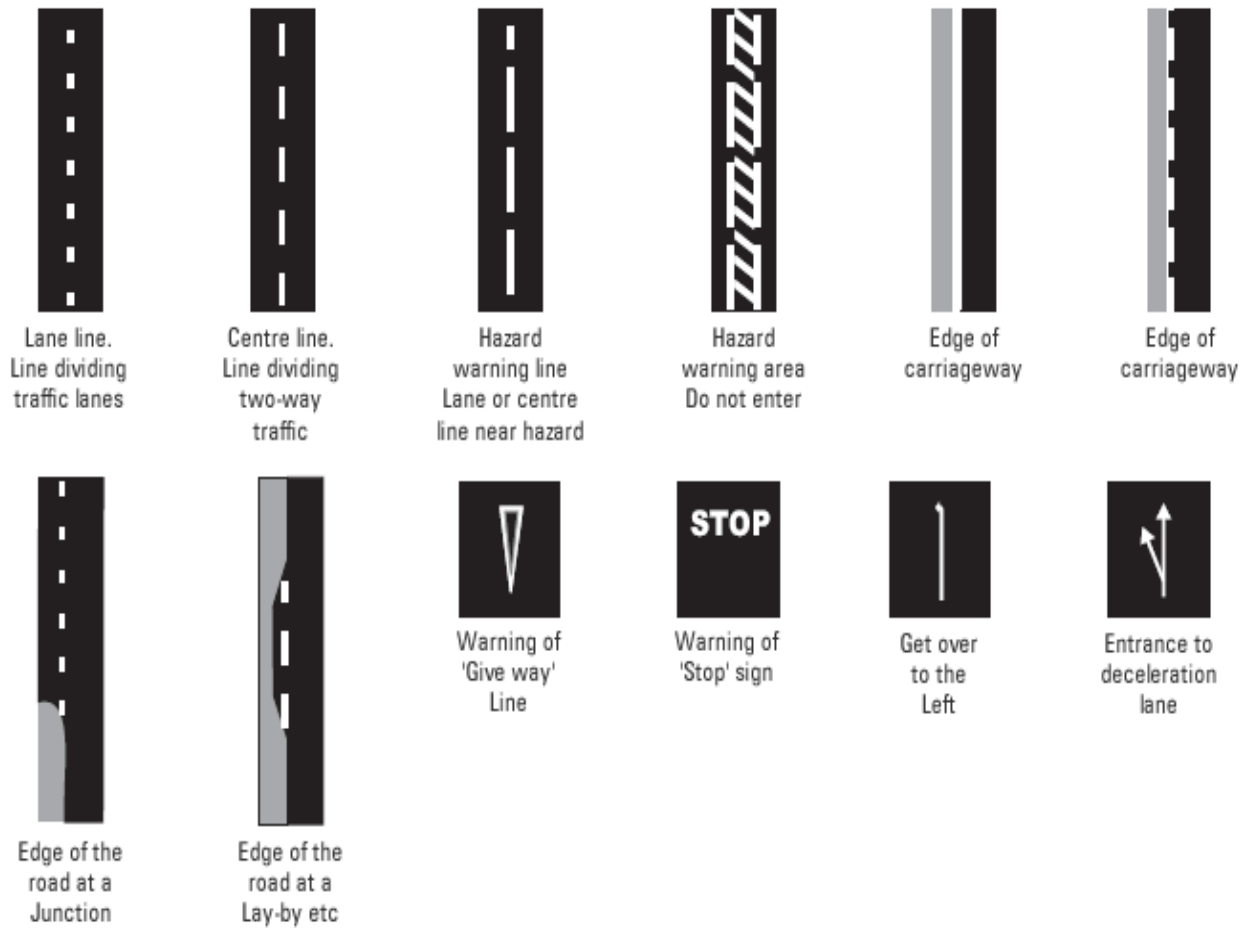


Figure 2: Road markings giving warning and information

2.3.2. Audible warnings

This are used in conjunction with mechanized swing gate assemblies and fitted inside the gate mechanism or mounted near the gate mechanism. The audible warning may either produce a different tone in this situation, or stop when the first train passes and resume when the second train approaches [17].



Figure 3: Audible warnings

Where road traffic light signals are provided, the warning sound should begin when the amber lights first show. At all automatic open or half barrier crossings, the warning sound continues until the intermittent red lights are extinguished. At barrier crossings operated by railway staff, the warning sound stops when the barriers are fully lowered.

At automatic open or half barrier crossings where two trains can arrive at the crossing without providing the minimum road open time, the character of the warning sound should change distinctively after the first of the trains arrives at the crossing. At simple, un-automated, open crossings, the audible warning may be provided by horns from approaching trains [5].

2.3.3. Pedestrian signals

This are visual warning treatments which Uses flashing lights or countdown timers to warn vulnerable road users of approaching trains or specifically warn of a second train [17].



Figure 4: pedestrian signals

Traffic signals for pedestrians may be provided at crossings particularly where the volume of pedestrians is high or vulnerable groups use the crossing regularly. The pedestrian traffic signal may be especially helpful at skewed automatic half barrier crossings, at full barrier crossings on one way streets and at auto-lower full barrier crossings [5].

Pedestrian signals should face outwards from the crossing towards approaching pedestrians. Pedestrian signals are not normally considered necessary at gated crossings operated by railway staff.

2.3.4. Tactile thresholds

It is an area of tactile paving slabs laid in a specific pattern for the guidance of visually-impaired pedestrians. When moving around the pedestrian environment, visually impaired people will actively seek and make use of tactile information underfoot, particularly detectable contrasts in surface texture. Tactile thresholds are not required on roads where there is no footway [5].

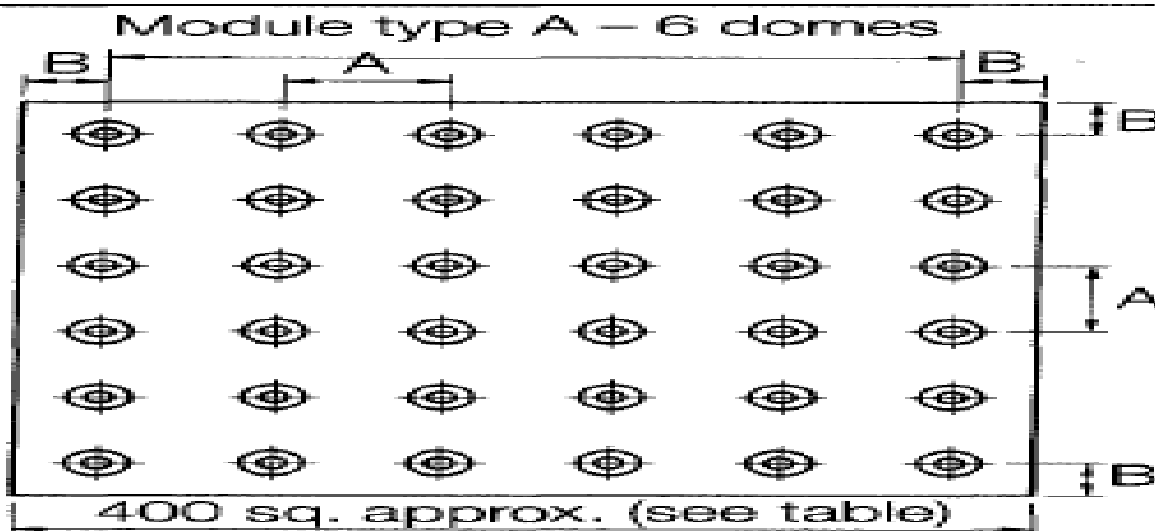
Tactile paving surfaces can be used to convey important information to visually impaired pedestrians about their environment, for example, hazard warning, directional guidance, or the presence of an amenity. Research has determined that visually impaired people can reliably detect, distinguish and remember a limited number of different tactile paving surfaces and the distinct meanings assigned to them [21].



Figure 5: Tactile threshold

The installation of tactile paving surfaces should be considered as part of a wider package of measures to assist visually impaired people. The installation process should involve an assessment of the surrounding environment. In particular, the condition of the surrounding footway should be examined.

The profile of the blister surface comprises rows of flat-topped ‘blisters’; 5mm ($\pm 0.5\text{mm}$) high. The blister surface can be made of any material suitable for footway pavements. It is most commonly supplied in 400mm sq. concrete slabs or smaller block paviors [21].



Module Type	Size	Pitch Dimensions	
		A	B
A	400 sq.	66.8	33
B	450 sq.	64	33
C	200x133	67	33

Figure 6: profile and figure of blister surface

Before installing a tactile threshold, it is essential to:

1. Understand the mobility needs of visually impaired people.
2. Recognize that schemes which result in carriageways and adjacent footways at the same level, as in partially pedestrianized areas, can be hazardous to visually impaired people.
3. Consider the surrounding environment, taking into account the arrangement of crossing facilities [21].

2.3.5. Guard rails

Where vulnerable or large numbers of pedestrians regularly use a crossing, consider appropriate means to deter them from walking on the carriageway such as guard rails on approach. Guard rails should be provided only where the footway is sufficiently wide and does not create a bottleneck.

Where pedestrians in significantly large numbers cross from one side of the road to the other while the road is closed to allow a train to pass over the crossing, consider providing a double row of non-reflecting road studs to indicate the safe place to cross [5].



Figure 7: Guard rails

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. The TPV is the product of the maximum number of pedestrians and the number of trains passing over the crossing within a period of 15 minutes. [5].

$$\text{TPV} = \text{No. of trains} \times \text{No. of pedestrians} \dots\dots\dots (1)$$

After calculating the train pedestrian value the Pedestrian categories are taken from the given Table below.

Table 2: pedestrian categories

Pedestrian Category	Train Pedestrian Value (TPV)
A	More than 450
B	151 – 450
C	150 or less

As with all aspects of level crossing risk, the precautions for pedestrians should be determined by risk assessment. To guide that process Table 3 suggests precautions which may be appropriate for these pedestrian categories.

Table 3: appropriate pedestrian precautions

Pedestrian category	Width of footway	Road markings	Audible warnings [#]	Pedestrian signals	Tactile threshold [#]	Guard rails
A	2 or more	Yes	Yes	Yes	Yes	**
B	1.8 or more	Yes	Yes	**	Yes	**
C	1.5 or more *	Yes	Yes	**	**	**

[#] not required at gated crossings operated by railway staff

* A reduced width of 1 m or lack of approach funnel is normally restricted to those crossings with a daily pedestrian usage of less than about 25

** Yes if necessary

2.4. GRADE SEPARATIONS AT LEVEL CROSSINGS

Grade separation is the method of aligning a junction of two or more surface transport axes at different heights (grades) so that they will not disrupt the traffic flow on other transit routes when they cross each other. The composition of such transport axes do not have to be uniform. It can consist of a mixture of roads, footpaths, railways, canals, or airport runways [12].

Bridges (overpass or fly overs), tunnels (or underpasses) or a combination of both can be built at a junction to achieve the needed grade separation [13].

In railway construction, grade separation also means the avoidance of level crossings by making any roads crossing the line either pass under or over the railway on bridges. This greatly improves safety and is crucial to the safe operation of high speed lines. It is possible that the grade-separated crossing is situated in a different place than a level crossing. In that case a new road connection must be built.

In *Finland*, if there is high-speed traffic (speed more than 140 km/h) on the track no level crossings are allowed. In long-term plans in many countries railroad level crossings are going to be closed and grade separated crossings built instead [12].

Lincoln high street crossing was one of the "worst level crossing for instances of misuse" in Lincoln and it is hoped the footbridge over the railway line on Lincoln High Street will improve safety and ease congestion at the crossing. The High Street footbridge will allow pedestrians and cyclists to cross at all times even when trains are passing. Currently trains stop traffic regularly on a daily basis [18].

On the Lincoln high street there is a high pedestrian demand to cross a freeway and there is a traffic conflict that is encountered by pedestrians. (Such as on wide streets with high pedestrian volumes combined with high-speed traffic). And also there are documented collisions or close calls involving pedestrians and vehicles. [18].



Figure 8: Lincoln High Street Footbridge Application Design

A grade-separated crossing is considered for *Lincoln High Street* due to the following reasons:

- There is moderate to high pedestrian demand to cross a freeway or expressway.
- The distance between 2 consecutive crossings is high.
- There are large numbers of young children, particularly on school routes, who regularly cross high-speed or high-volume roadways.
- There are documented collisions or close calls involving pedestrians and vehicles.
- One or more of the conditions stated above exists in conjunction with a well-defined pedestrian origin and destination (such as a residential neighborhood across a busy street from a school) [19].

2.4.1. Pedestrian Bridges

Pedestrian grade-separation bridges are more effective when the roadway is below the natural ground line, as in a cut section. Elevated grade separations in cut sections, where pedestrians climb stairs or use long approach ramps, tend to be underused. Pedestrian bridges need adequate right of way to accommodate accessible ramp approaches leading up to and off of the structure.

The height of the structure can affect the length of the pedestrian ramp approaches to the structure. When access ramps are not feasible, provide both elevators and stairways. The minimum clear width for pedestrian bridges is 8 feet. Consider a clear width of 14 feet where a pedestrian bridge is enclosed or shared with bicyclists, or equestrians, or if maintenance or emergency vehicles will need to access [19].



Figure 9: pedestrian bridges

2.4.2. Pedestrian Tunnels

Tunnels are an effective method of providing crossings for roadways located in embankment sections. Well-designed tunnels can be a desirable crossing for pedestrians. People may be reluctant to enter a tunnel with a depressed profile because they are unable to see whether the tunnel is occupied.

The minimum overhead clearance for a pedestrian tunnel is 10 feet. The minimum width for a pedestrian tunnel is 12 feet. Consider a tunnel width between 14 and 18 feet depending on usage and the length of the tunnel [19].



Figure 10: pedestrians' tunnel

2.5. ADDIS ABABA LIGHT RAIL TRANSIT

The Addis Ababa Light Rail Transit project is located in Addis Ababa, the capital of Ethiopia, which was the location of the head office of African Union. The altitude of the plateau is 2,400m. With an urban population of over 4,000,000, it takes 5% of the total population of Ethiopia. The urban area is 530.14 km², and the density reached 5,607.96/km². To effectively solve the problem of urban transportation, esp. that of the downtown area, the government of Ethiopia decides to build a light rail in the city of Addis Ababa. Currently this project has planned two lines, the east-west line and the south-north line. About 3 km is the sharing section for both E-W route and N-S route, which has the greatest passenger current [5].

Line E-W goes along the important E-W transportation corridor in Addis Ababa. This line goes through city center, and is one of the most important contacting lines between city center and

city western parts and western suburbs. The eastern and central parts of this line go through highly populated areas, the busiest commercial areas and Ayat residential area with large traffic flow; the western part of the line goes through western city and western suburbs.



Figure 11: the Testing of Addis Ababa Light Rail Transit

According to current social-economic situation, passenger flow, development tendency and integrated with population and employment current situation and development tendency along the line, as well as passenger flow documentations and other relevant study results, it is forecasted that the maximum unidirectional section passenger flow of Line E-W in peak hours will take place in the road section from Lideta Light to La Gare shared with Line N-S. The total unidirectional section passenger flows in initial stage, short-term and long-term are 38462 persons/day, 70308 persons/day and 115385 persons/day respectively. The maximum passenger flows of initial stage, short-term and long-term in peak hours are 5000 persons/hour, 9140 persons/hour and 15000 persons/hour respectively [5].

LRT E-W route is the most important corridor in Addis Ababa. The rail is laid along the center of the roads. The situations of different sections are as follows:

- The width of this road section from Ayat area to Megenagna (Adwa Square) is planned to be 50 meters. The line will extend further to eastern city in the future to connect Ayat and Legetafo.
- The width of this road section from (Megenagna) Adwa Square to Torhailoch Square is planned to be 40 meters.
- The width of this road section from Torhailoch Square to Ayer Tena area (Jimma junction) is planned to be 30-40 meters. This line will extend westward further to Sebeta area. A future railway hub will be built here.

Twenty-two LRT stations are placed in phase one of E-W route project, five of which are shared with N-S route. Average interval between two adjacent stations is 815 meters. The longest interval is 1210 meters and the shortest interval is 525 meters.

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Addis Ababa Light Rail Transit (LRT)

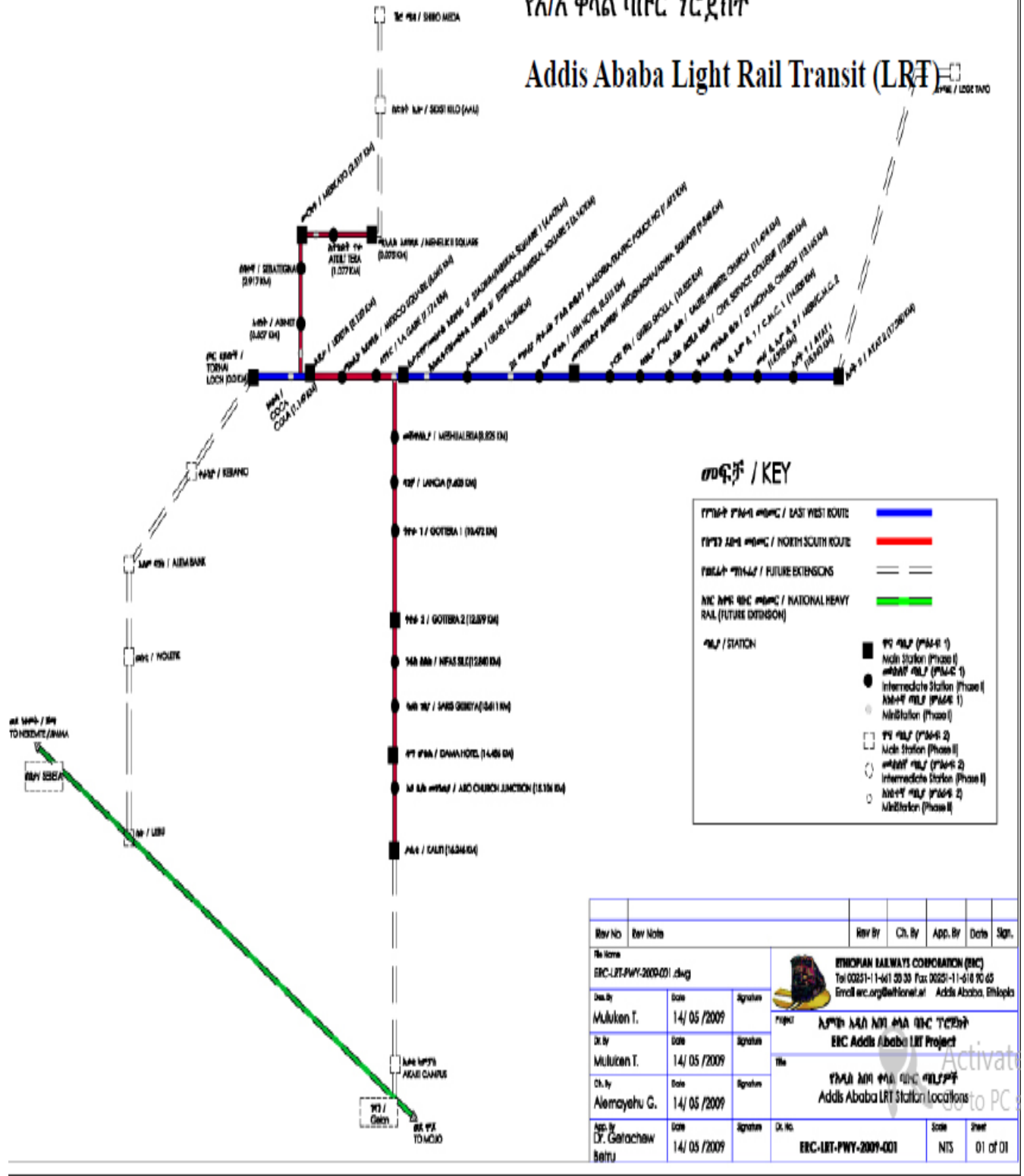


Figure 12: the Design of Addis Ababa Light Rail Transit

CHAPTER THREE: METHODOLOGY

3.1. STUDY AREA

The study was conducted in the East-West line of Addis Ababa Light Rail Transit. The Addis Ababa Light Rail Transit project is located in Addis Ababa, the capital of Ethiopia, which was the location of the head office of African Union. The altitude of the plateau is 2,400m. With an urban population of over 4,000,000, it takes 2.4% of the total population of Ethiopia. The urban area is 530.14 km², and the density reached 5,607.96/km².

3.2. STUDY POPULATION

The study was conducted in each level crossing across the East-West line of Addis Ababa Light Rail Transit. The East-West line of Addis Ababa Light Rail Transit has 22 stations which are used as a level crossing for pedestrians and passengers. During the census the flow of pedestrians which cross the level crossing (stations) are taken.

3.3. STUDY DESIGN

The study was done by direct observation and Census (random sampling technique by taking a 15 minutes duration), which was conducted from November 2014 to March 2015 to examine the flow of pedestrians and trains along the level crossings of the newly build East-West line of Addis Ababa Light Rail Transit.

The number of pedestrians and train which passes along each level crossing is collected within 4 different time intervals. 2 from morning peak hours and 2 from afternoon peak hours. And then the maximum pedestrians and train flow is taken to calculate the Train Pedestrian Value (See Appendix 9.1).

3.4. STUDY METHODOLOGY

The study was conducted in each level crossing across the East-West line of Addis Ababa Light Rail Transit. The East-West line of Addis Ababa Light Rail Transit has 22 stations which are used as a level crossing for pedestrians and passengers. From 22 stations 14 stations are ground stations, 1 station is under ground and the remaining 6 stations are built on the bridge (Sky stations). Pedestrians don't use underground and sky stations as a level crossing. Therefore, during the census Pedestrians and train flow data collection is not done and those 7 stations are *safe*.

There must be precautions for the pedestrians' in order to avoid accidents which happen on the RLC. The main parameter we are going use to provide precautions is pedestrian categories. The volume of pedestrian and train flow is determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories [5].

TPV is the product of the maximum number of pedestrians and the number of trains passing over the crossing within a period of 15 minutes. A detailed method of Train Pedestrian Value (TPV) calculation can be found in Appendix 9.1.

TPV= No. of pedestrians X No. of trains (Within 15 minutes)

After calculating the train pedestrian value the Pedestrian categories are taken from the given Table below [5].

Pedestrian Category	Train Pedestrian Value (TPV)
A	More than 450
B	151 – 450
C	150 or Less

As with all aspects of level crossing risk, the Precautions for pedestrians is determined by risk assessment. To guide that process, Table 3 suggests precautions which may be appropriate for these pedestrian categories. The precautions are:

1. Road markings
2. Audible warnings
3. Pedestrian signals
4. Tactile thresholds
5. Guard rails

In designing safe pedestrian level crossings, some assumptions are also taken.

1. The flow of pedestrians at Peak hours is chosen. Because, our design should have a factor of safety by considering the maximum flow of pedestrians.
2. At the moment, there is no flow of pedestrians at some stations due to the construction process. Therefore the flow of pedestrians is taken by comparing the flow of other ground stations.
3. At the moment the number of trains which cross the level crossing are not on work. Therefore an information which is given by the governing body of the Ethiopian railway corporation is used. Which is:
 - At least 1 train crosses each level crossings in each 6 minutes.
 - It means in 15 minutes atleast 5 trains will cross the level crossing in each lines.

After deciding the necessity of precautions at each station and the flow of pedestrians along the level crossing, further decisions will be made on the significance of grade separations (Bridge or tunnel) in some locations by using the *graph of the flow of pedestrians*.

CHAPTER FOUR: DATA COLLECTION, PRESENTATION AND ANALYSIS

1. Torhailoch Station (EW 22): It is the first station in the east-west direction of Addis Ababa Light Rail Transit. It's found near to the Torhailoch square and has a much amount of passenger and pedestrian flow from four different directions. Since this area is the starting point for the railway transport, high demand of rail transport is registered in this area.

The data is collected on Wednesday, february 18, 2015 and Friday, february 20, 2015. The flow of pedestrians in each minute is summarized on the following graph.

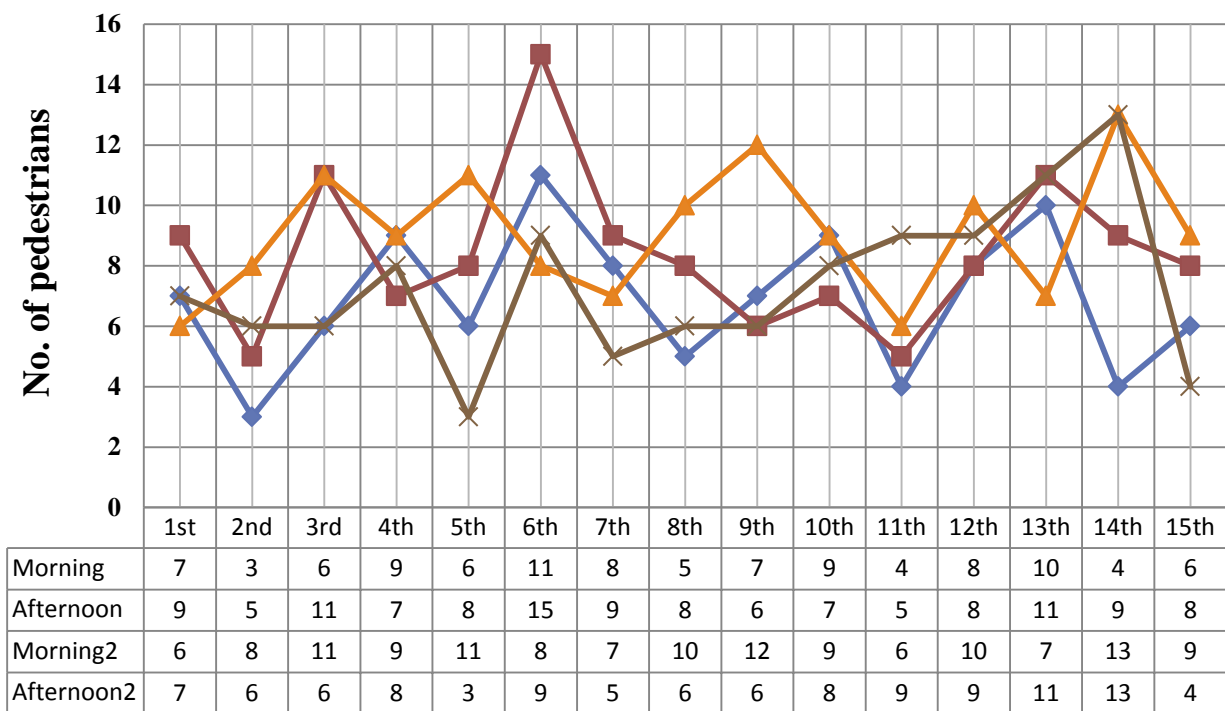


Figure 13: the flow of pedestrians at Torhailoch station

As shown in the graph, the Total maximum pedestrian flow is registered at the 3rd Census (Morning 2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 136.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 136 \times 5 = \underline{680}$$

Since the train pedestrian value is greater than 450 [680>450], the pedestrian category for this station is category “A” according to table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Torhailoch station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian stop markings across the footway on approach to the crossing. According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

As shown in figure 13, there is a uniform High pedestrian flow across the station. The area is the starting point of the rail transit (EW22) and also Origin and Destination of other forms of Transports (Bus, Mini Bus). Therefore, Grade separation system should be considered at this station.

2. **Coca Cola Station (EW 21):** this station found with in a 300m gap from the Torhailoch station and its located 1.8 meter above from the ground. The passengers and pedestrians who cross this station will use a stair to reach in to the upper part of the railway.

The data is collected on Thursday, February 19, 2015 and Saturday, February 21, 2015. The flow of pedestrians is summarized on the following graph.

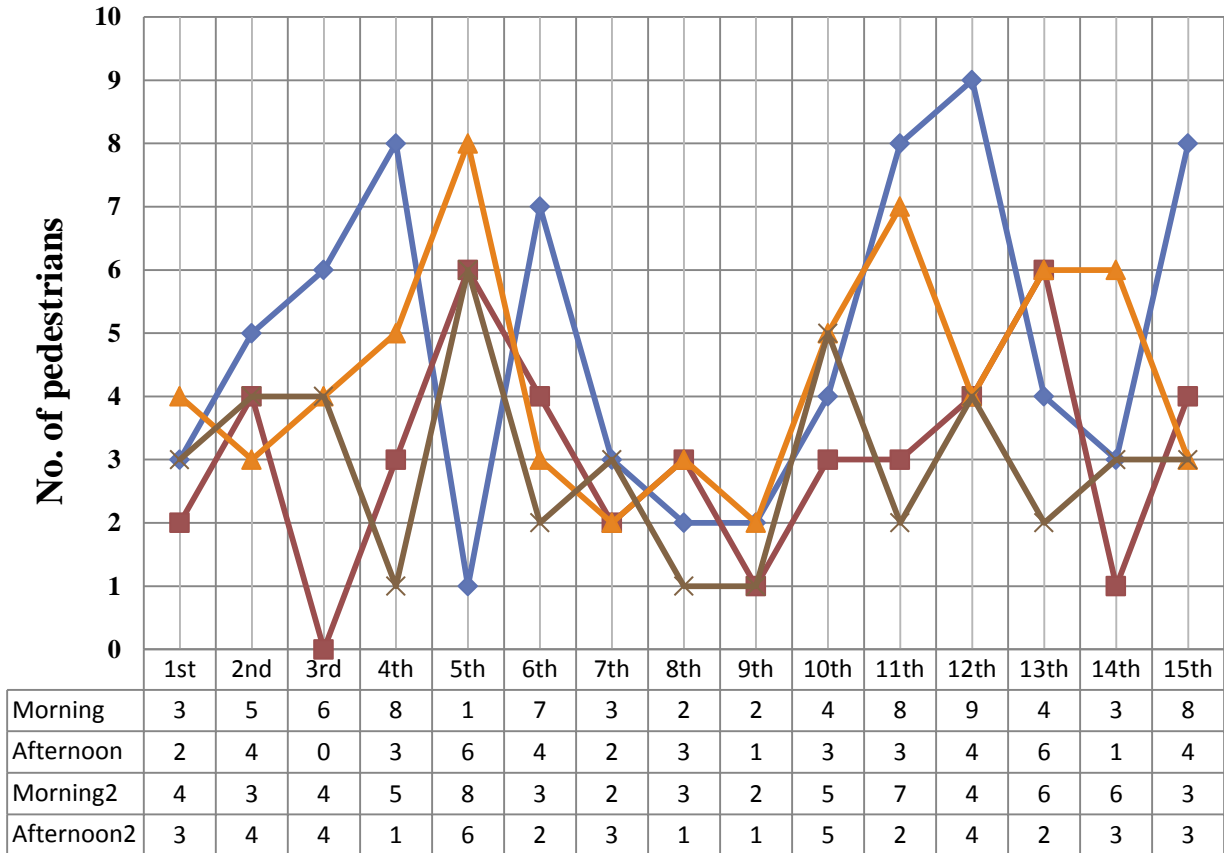


Figure 14: the flow of pedestrians at Coca Cola station

As shown in the graph, the Total maximum pedestrian flow is registered at the 1st Census (Morning 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 73.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 73 \times 5 = \underline{365}$$

Since the train pedestrian value is between 151 and 450 [$151 < 365 < 450$], the pedestrian category for this station is category “B” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 1.8 or more meter.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). So that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

As shown on the above Graph, The flow of pedestrians across the station is very Low and fluctuated at every minutes. This area is not Origin and Destination of other forms of Transports (Bus, Mini Bus). Therefore, No Need of grade separation system at this station.

As this station, the crossings and adjacent footways are not at the same level. Therefore, the tactile thresholds should not be placed. According to the Train Pedestrian Value Calculation, No need to construct guard rails too.

3. Yordanos Hotel Station (EW 13): this station is built 150m far from the Urael Church. In its basic design the station was proposed to build underground. But, Ground stations are less investment and less inconvenience comparing to the underground station design. This station is used by so many pedestrians who flow from Bambis and Kazanchis.

The data is collected on Wednesday, February 18, 2015 and Monday, February 23, 2015. The flow of pedestrians is summarized on the following graph.

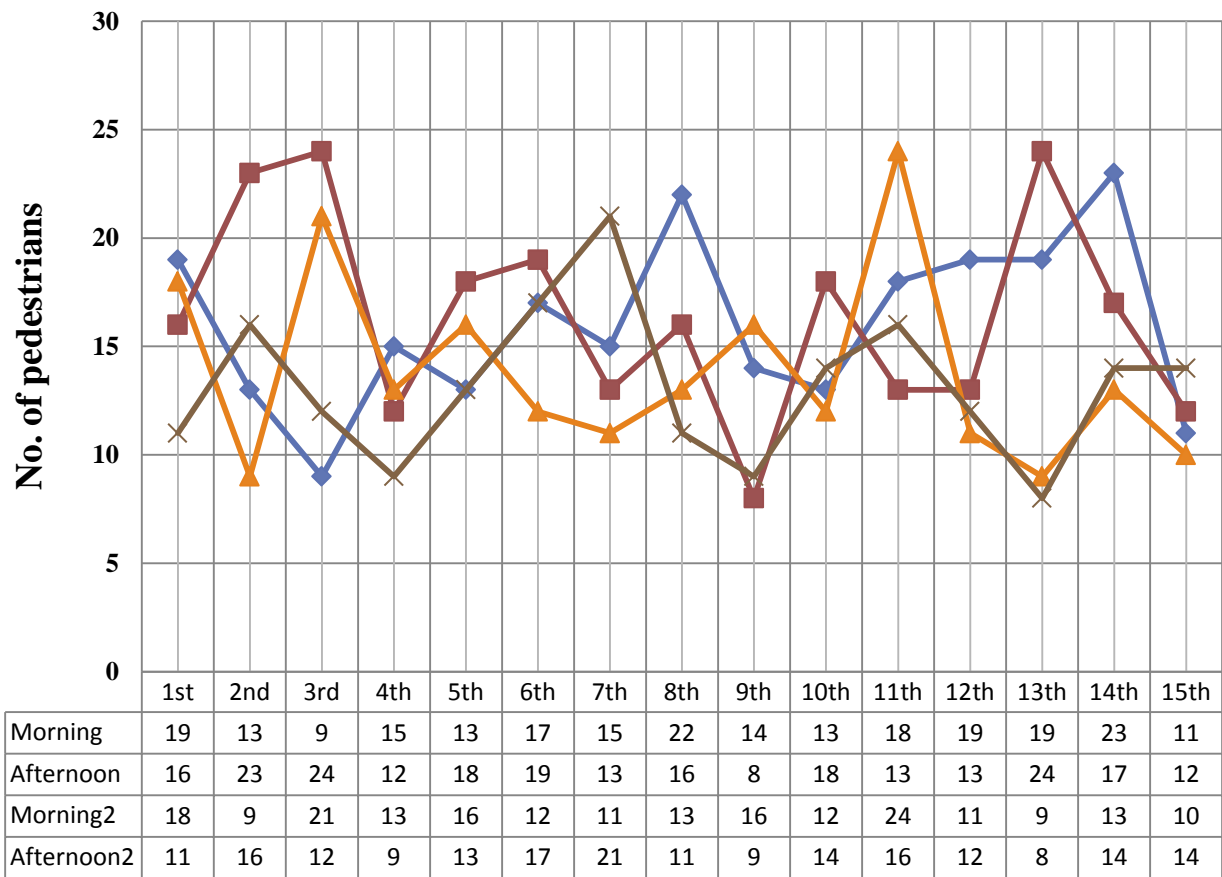


Figure 15: the flow of pedestrians at Yordanos station

As shown in the graph, the Total maximum pedestrian flow is registered at the 2nd Census (Afternoon 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 246.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

Train pedestrian value = No. Of pedestrians X No. Of trains

$$TPV = 246 \times 5 = \underline{1230}$$

Since the train pedestrian value is >1230 [$1230 > 450$], the pedestrian category for this station is category "A" according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Yordanos Hotel station, the crossings and adjacent footways are at the same level as shown in the figure below. Therefore, the tactile thresholds should be placed. According to the Train Pedestrian Value Calculation, No need to construct guard rails.

Urael Square is found within 150 meters gap from this station & pedestrians use it as a crossing. Therefore, there is no need to build a grade separation at this area.

4. Chemical Corporation Station (EW 12): Nowadays this place has high flow of pedestrians and vehicles due to the existence of so many business centers, markets, schools and governmental offices. The station is found on the ground and it is as easy to use as a crossing for so many pedestrians.

The data is collected on Friday, February 20, 2015 and Monday, February 23, 2015. The flow of pedestrians is summarized on the following graph.

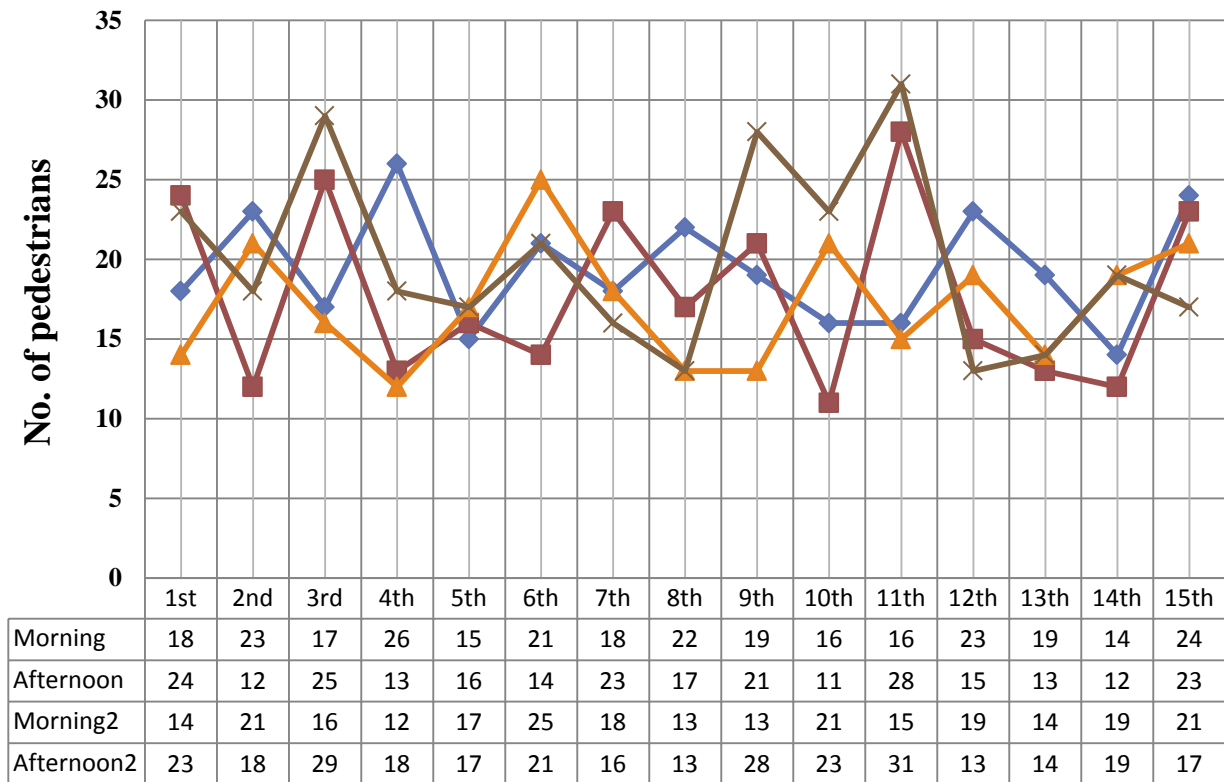


Figure 16: the flow of pedestrians at Chemical Corporation station

As shown in the graph, the Total maximum pedestrian flow is registered at the 4th Census (Afternoon 2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 300.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 300 \times 5 = \underline{1500}$$

Since the train pedestrian value is >450 [$1500 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing.

As shown in the figure below, At the Chemical Corporation station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

Next to this station, there is a big square which is 120 meter far. Since, pedestrians uses this station as a crossing, there is no need to build another grade separation system.

5. Mazoria (traffic police HQ) Station (EW 11): another ground station which is found next to chemical corporation station is 22 Mazoria (traffic police HQ) Station. The flow of pedestrians along this station is also very high.

The data is collected on Thursday, February 19, 2015 and Friday, February 20, 2015. The flow of pedestrians is summarized on the following graph.

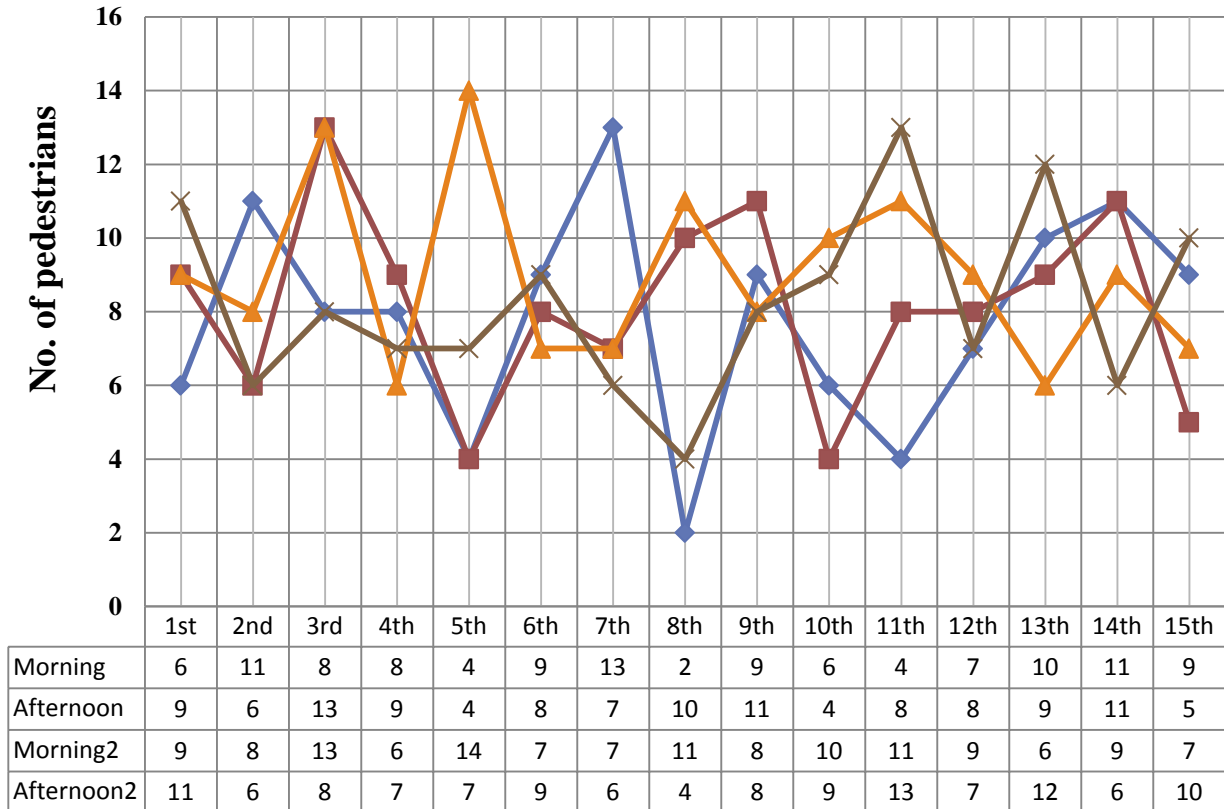


Figure 17: the flow of pedestrians at 22 Mazoria (Traffic Police HQ Office) station

As shown in the graph, the Total maximum pedestrian flow is registered at the 3rd Census (Morning 2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 135.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 135 \times 5 = \underline{675}$$

Since the train pedestrian value is >450 [$675 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be >2 meter.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing.

Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Mazoria station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian stop markings across the footway on approach to the crossing. According to the Train Pedestrian Value Calculation, No need to construct guard rails.

As shown on the above Graph, There is a uniform High pedestrian flow across the station. But there is also another means of crossing at 22 square and pedestrians also use this square as an alternative. Therefore there is no need to build another grade separation.

6. Lem Hotel Station (EW 10): as the name indicates, this station is found in front of Lem hotel which is a center place for Sholla and Megenagna paths. Since the distance between 22 mazoria and Lem hotel station is very long, pedestrians are obligated to cross along this station.

The data is collected on Friday, February 20, 2015 and Monday, February 23, 2015. The flow of pedestrians is summarized on the following graph.

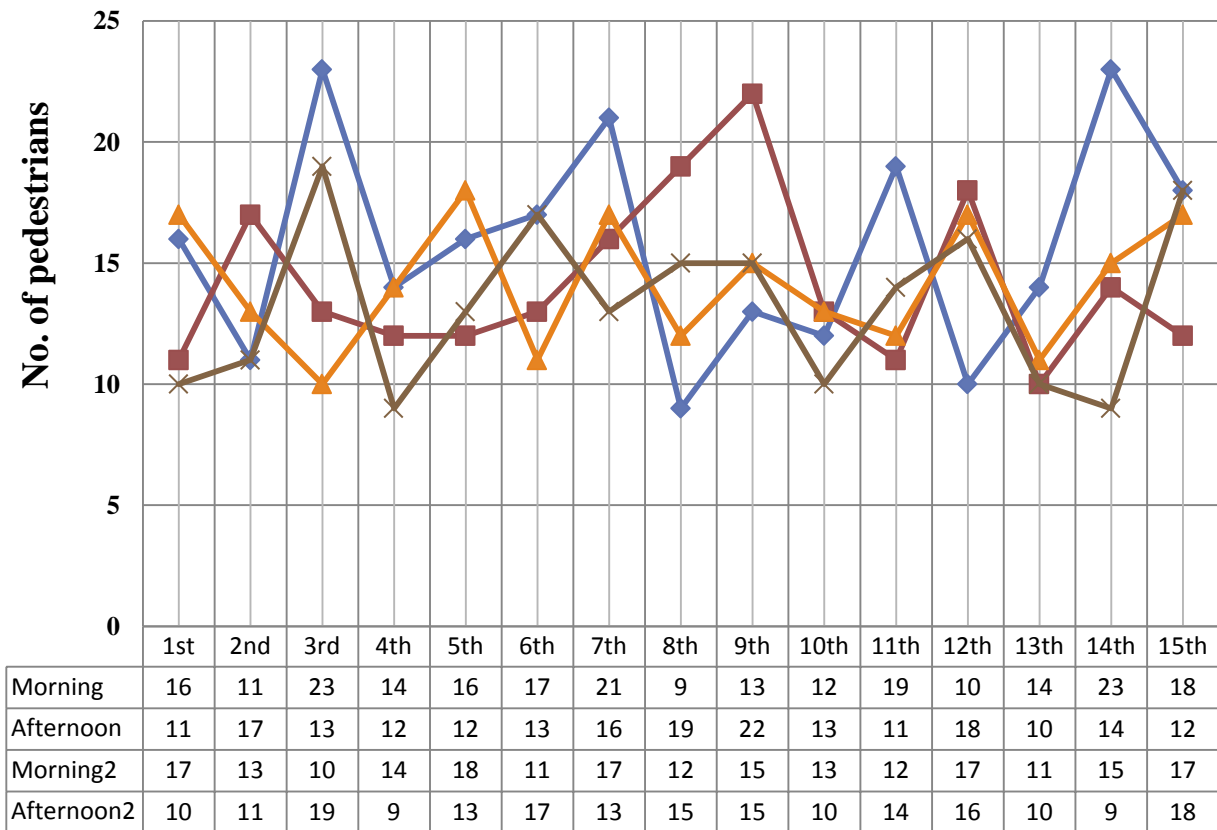


Figure 18: the flow of pedestrians at Lem Hotel station

As shown in the graph, the Total maximum pedestrian flow is registered at the 1st Census (Morning 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 236.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 236 \times 5 = \underline{1180}$$

Since the train pedestrian value is >450 [$1180 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station(See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Lem Hotel station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

7. **Megenagna Adwa square Station (EW 9)** : it is the biggest station of the East West Line of Addis Ababa Light Rail Transit. The flow of pedestrians along this station is very high. The station is built 150 meters far from the Adwa Square due to sophisticated construction of bridges and high way in the surrounding.

The data is collected on Wednesday, February 18, 2015 and Thursday, February 18, 2015. The flow of pedestrians is summarized on the following graph.

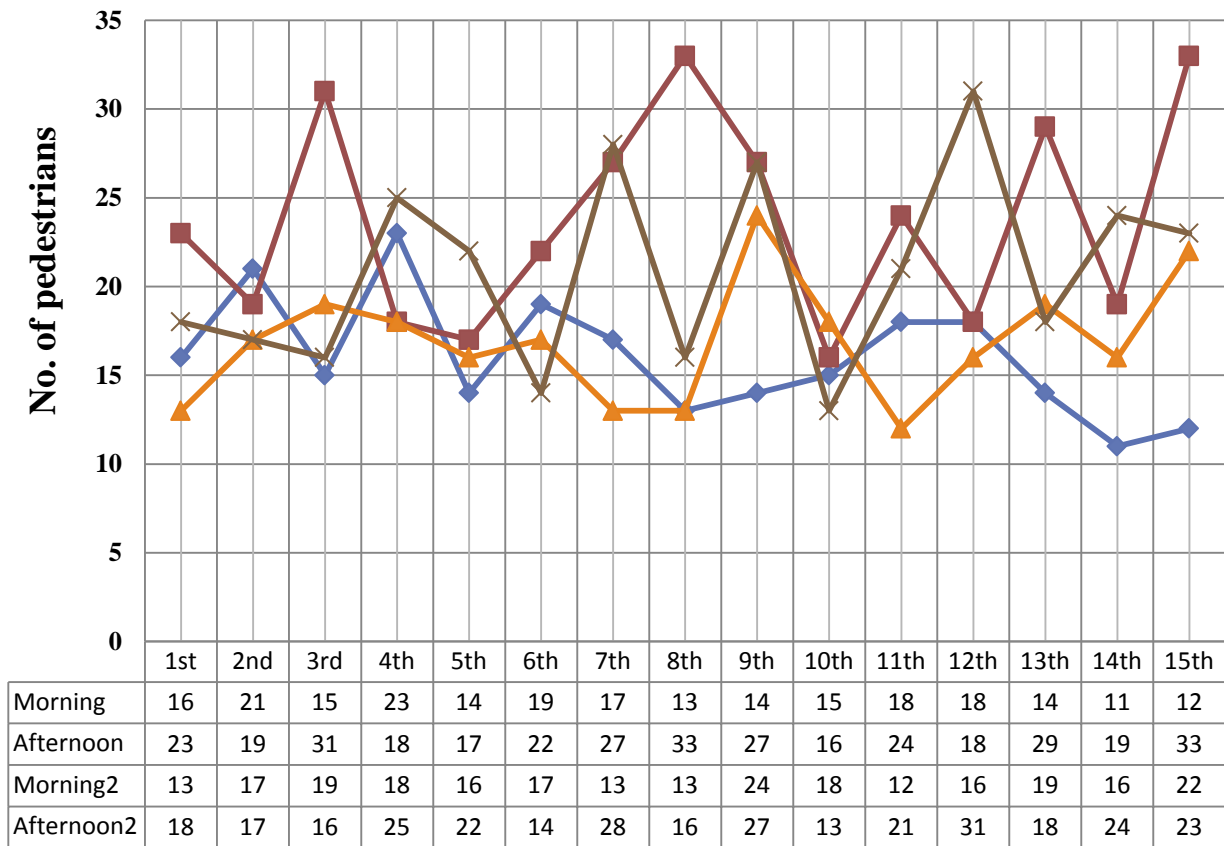


Figure 19: the flow of pedestrians at Megenagna Adwa square station

As shown in the graph, the Total maximum pedestrian flow is registered at the 2nd Census (Afternoon 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 356.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 356 \times 5 = \underline{1780}$$

Since the train pedestrian value is >450 [$1780 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Megenagna station, the crossings and adjacent footways are not at the same level. Therefore, the tactile thresholds should not be placed. According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

As shown on the above Graph, There is a uniform High pedestrian flow across the station. . The area is the starting point of the rail transit and also Origin and Destination of other forms of Transports (Bus, Mini Bus). Therefore, grade separation system should be considered at this station.

8. Gurd shola Station (EW 8): : it is the 8th station from the east west direction. The station is found on the ground and it has ramps for pedestrians passage to the railway platform. The flow of pedestrians at this station is moderate.

The data is collected on Tuesday, February 24, 2015 and Thursday, February 26, 2015. The flow of pedestrians is summarized on the following graph.

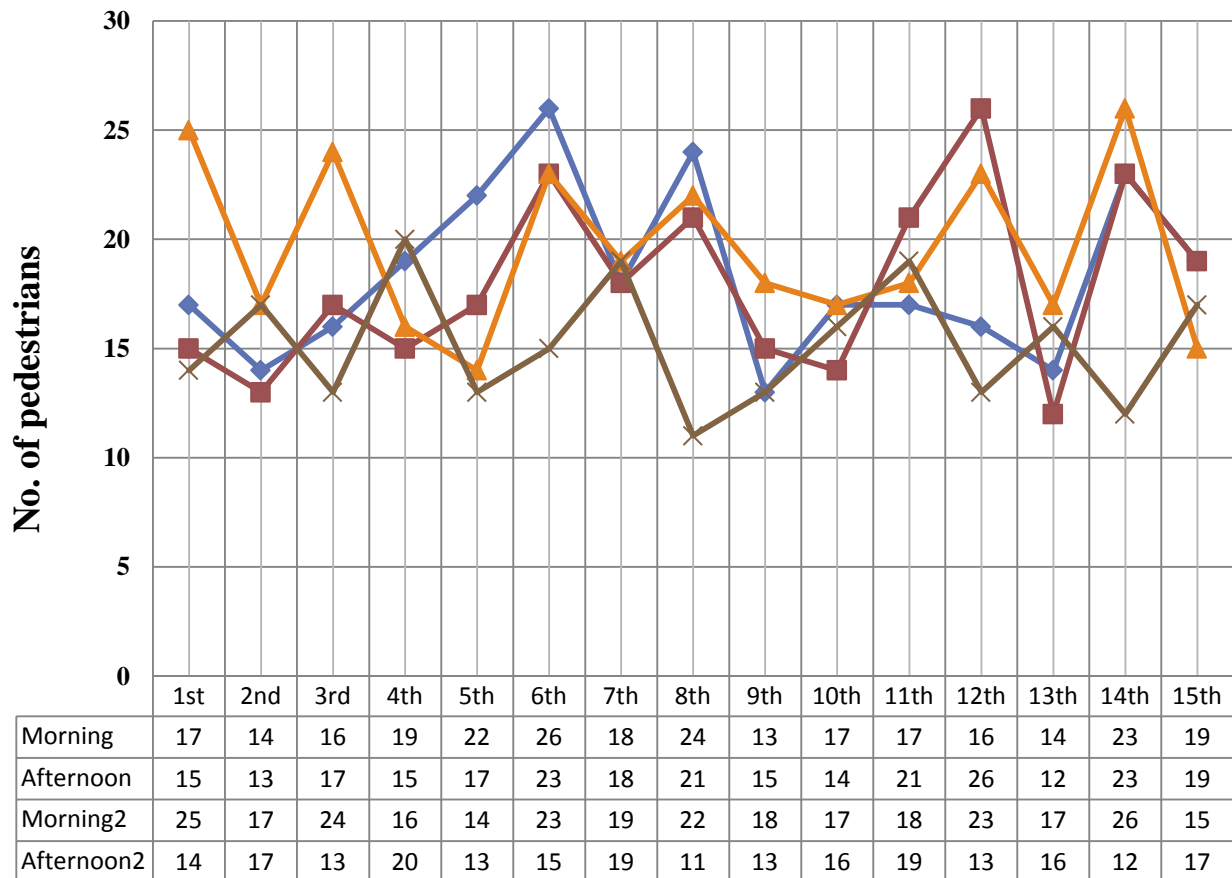


Figure 20: the flow of pedestrians at Gurd Shola station

As shown in the graph, the Total maximum pedestrian flow is registered at the 3rd Census (Morning 2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 294.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 294 \times 5 = \underline{1470}$$

Since the train pedestrian value is >450 [$1470 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Gurd Shola station, the crossings and adjacent footways are at not the same level. Therefore, the tactile thresholds should not be placed.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

9. Salite Meheret Church Station (EW 7): this station is found in front of Salite mehret church and the station is found on the same level with that of a roadway. This station is easily reachable to cross by pedestrians because of its flatness. The flow of pedestrians along this station is very low compared to other stations.

The data is collected on Wednesday, February 25, 2015 and Friday, February 27, 2015. The flow of pedestrians is summarized on the following graph.

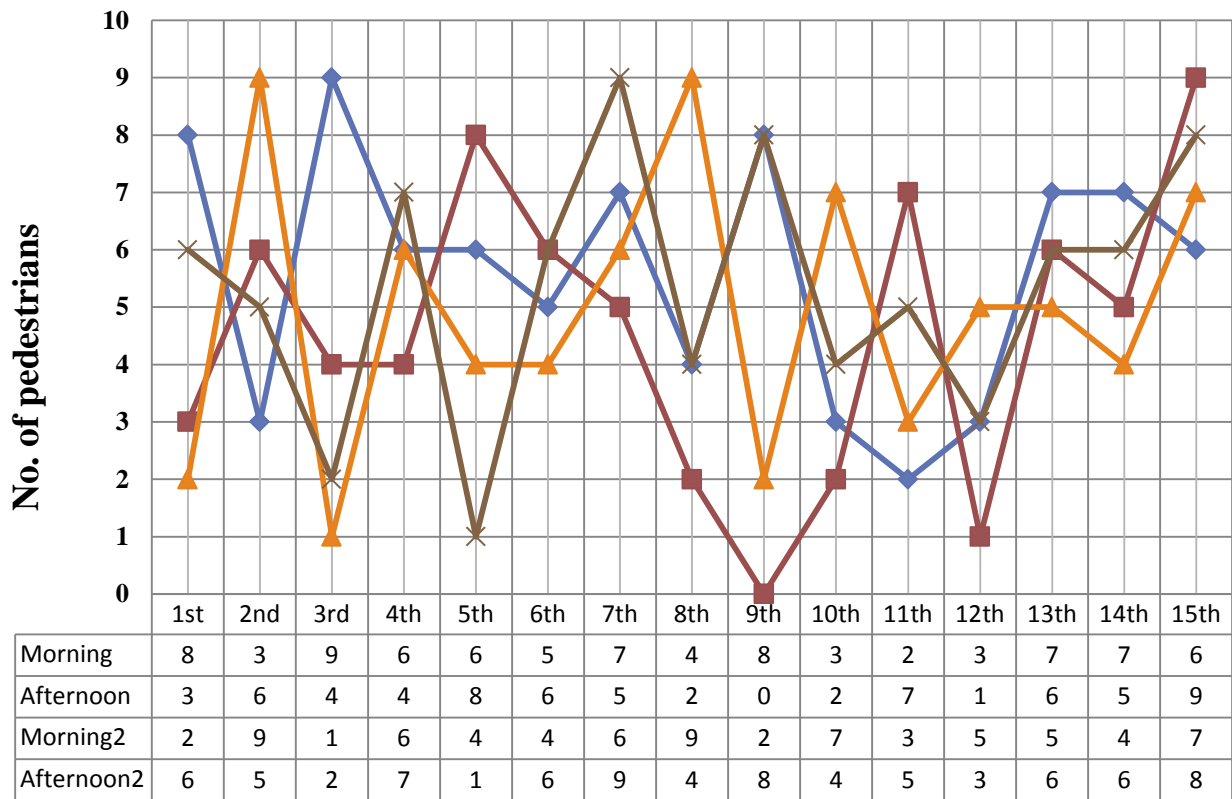


Figure 21: the flow of pedestrians at Salite Mehret station

As shown in the graph, the Total maximum pedestrian flow is registered at the 1st Census (Morning 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 84.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 84 \times 5 = \underline{420}$$

Since the train pedestrian value is <450 [420<450], the pedestrian category for this station is category “B” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At this station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

10. Civil Service College Station (EW 6): it is the 6th station from the east west direction and it's found in front of Ethiopian Civil Service College. The station is on the same level like that of the road adjacent to it.

The data is collected on Tuesday, February 24, 2015 and Wednesday, February 25, 2015. The flow of pedestrians is summarized on the following graph.

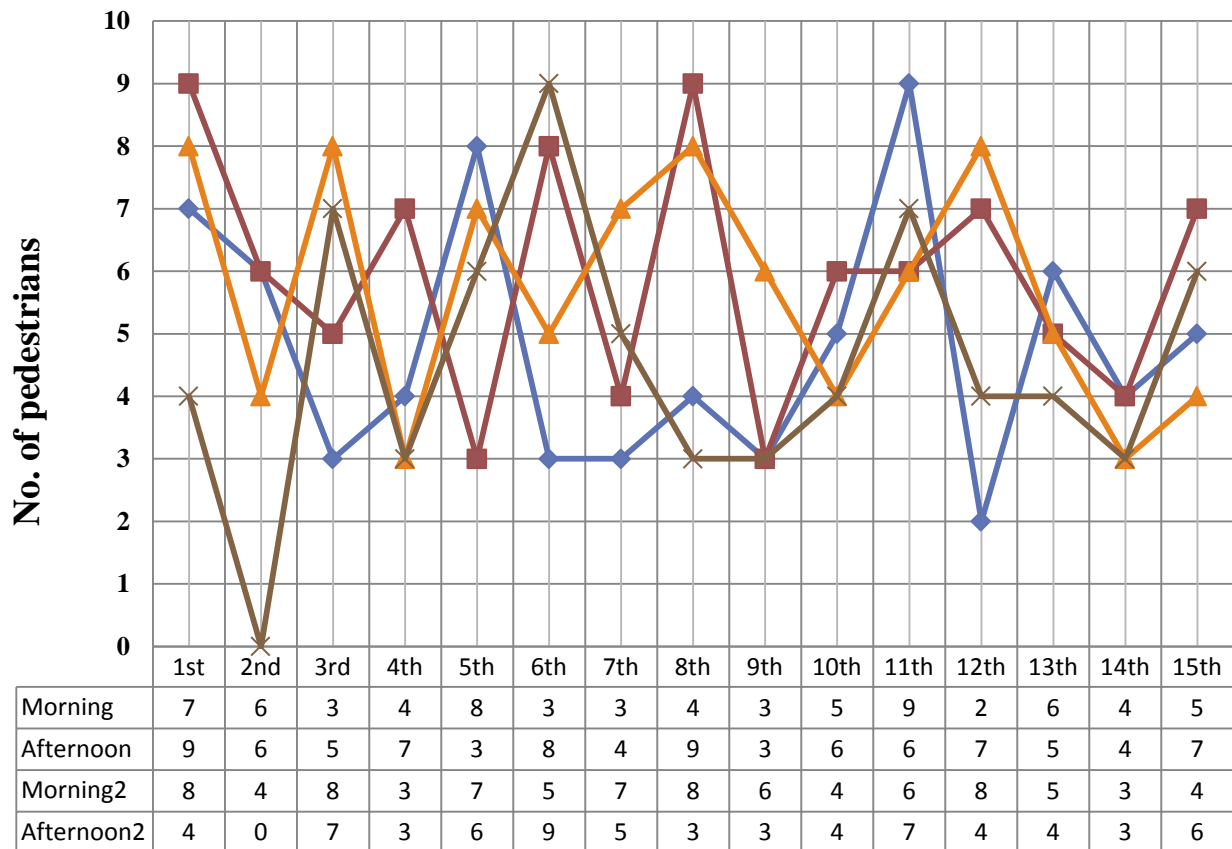


Figure 22: the flow of pedestrians at Ethiopian Civil Service College station

As shown in the graph, the Total maximum pedestrian flow is registered at the 2nd Census (Afternoon 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 88.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 88 \times 5 = \underline{440}$$

Since the train pedestrian value is <450 [440<450], the pedestrian category for this station is category “B” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Civil Service station, the crossings and adjacent footways are not at the same level. Therefore, the tactile thresholds should not be placed.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

11. Saint Michael Church Station (EW 5): it is another big station in the east west line of Addis Ababa Light Rail Transit. It is found in front of St. Michael Church.

The data is collected on Thursday, February 26, 2015 and Friday, February 27, 2015. The flow of pedestrians is summarized on the following graph.

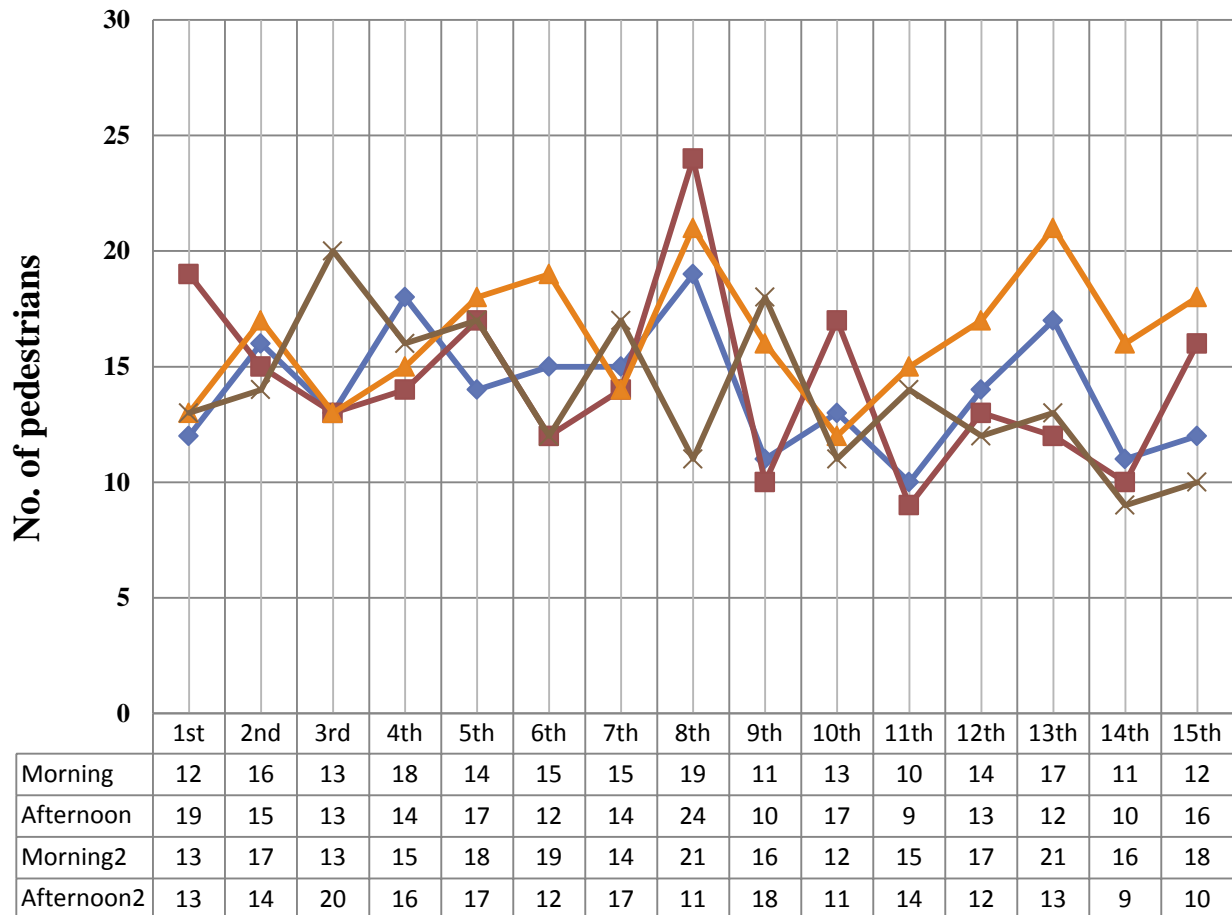


Figure 23: the flow of pedestrians at Megenagna Saint Micheal Church station

As shown in the graph, the Total maximum pedestrian flow is registered at the 3rd Census (Morning 2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 245.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 245 \times 5 = \underline{1225}$$

Since the train pedestrian value is >450 [$1225 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Saint Michael station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

12. CMC 1 Station (EW 4): the 4th station in the east west line of Addis Ababa Light Rail Transit. It is found near to the Semit Square. The flow of pedestrian along this station is too low.

The data is collected on Tuesday, February 24, 2015 and Friday, February 27, 2015. The flow of pedestrians is summarized on the following graph.

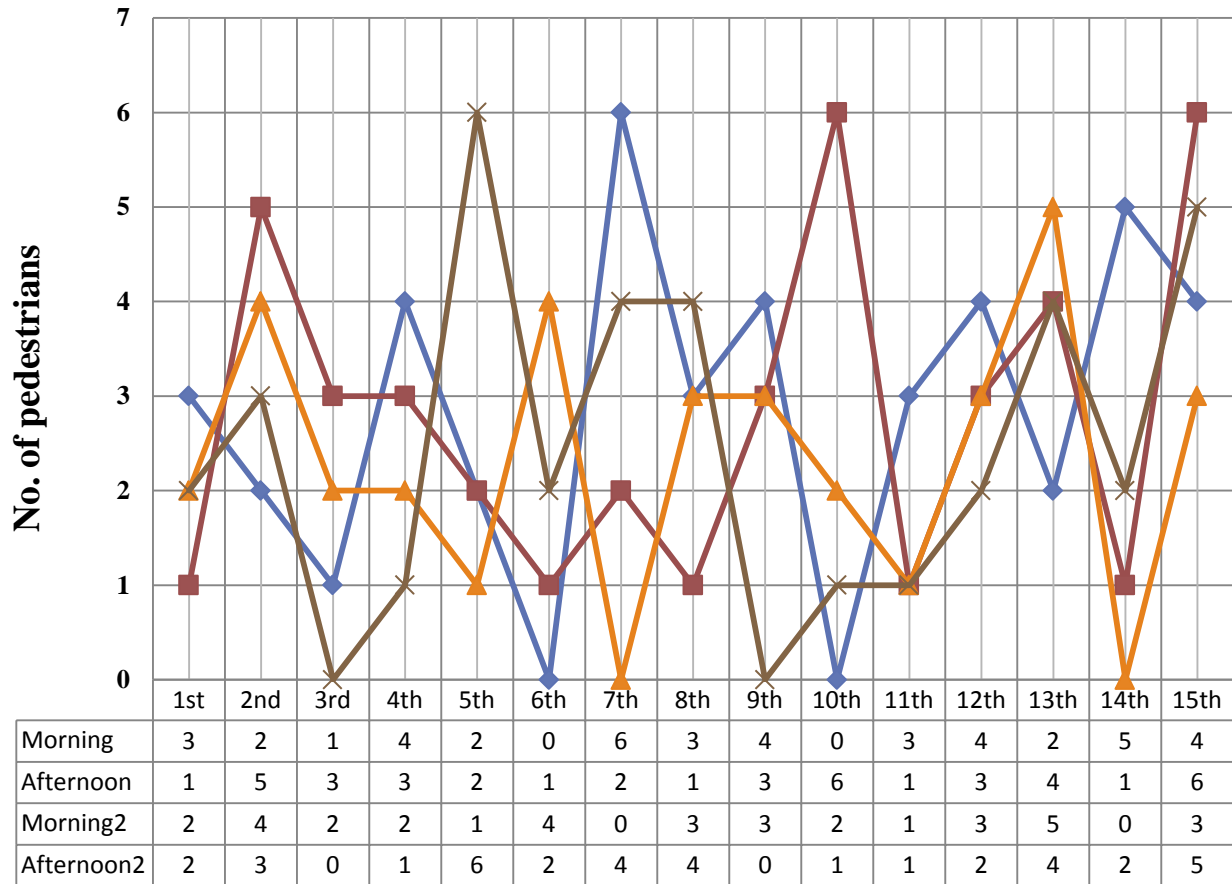


Figure 24: the flow of pedestrians at CMC 1 station

As shown in the graph, the Total maximum pedestrian flow is registered at the 1st Census (Morning 1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 43.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

Train pedestrian value = No. Of pedestrians X No. Of trains

$$TPV = 43 \times 5 = \underline{215}$$

Since the train pedestrian value is >450 [$215 < 450$], the pedestrian category for this station is category “B” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing (See Table 3). The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station (See Table 3). so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the CMC 1 station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing. And also, According to the Train Pedestrian Value Calculation, No need to construct guard rails.

As shown on the above graph, the flow of pedestrians along this station is low and fluctuated. Therefore, no need to build any grade separation around this area.

13. Meri CMC 2 Station (EW 3): the flow of pedestrians along this station is very high and the biggest in the east west line of Addis Ababa Light Rail Transit. The elevation of the station is different from the vehicle road.

The data is collected on Wednesday, February 25, 2015 and Thursday, February 26, 2015. The flow of pedestrians is summarized on the following graph.

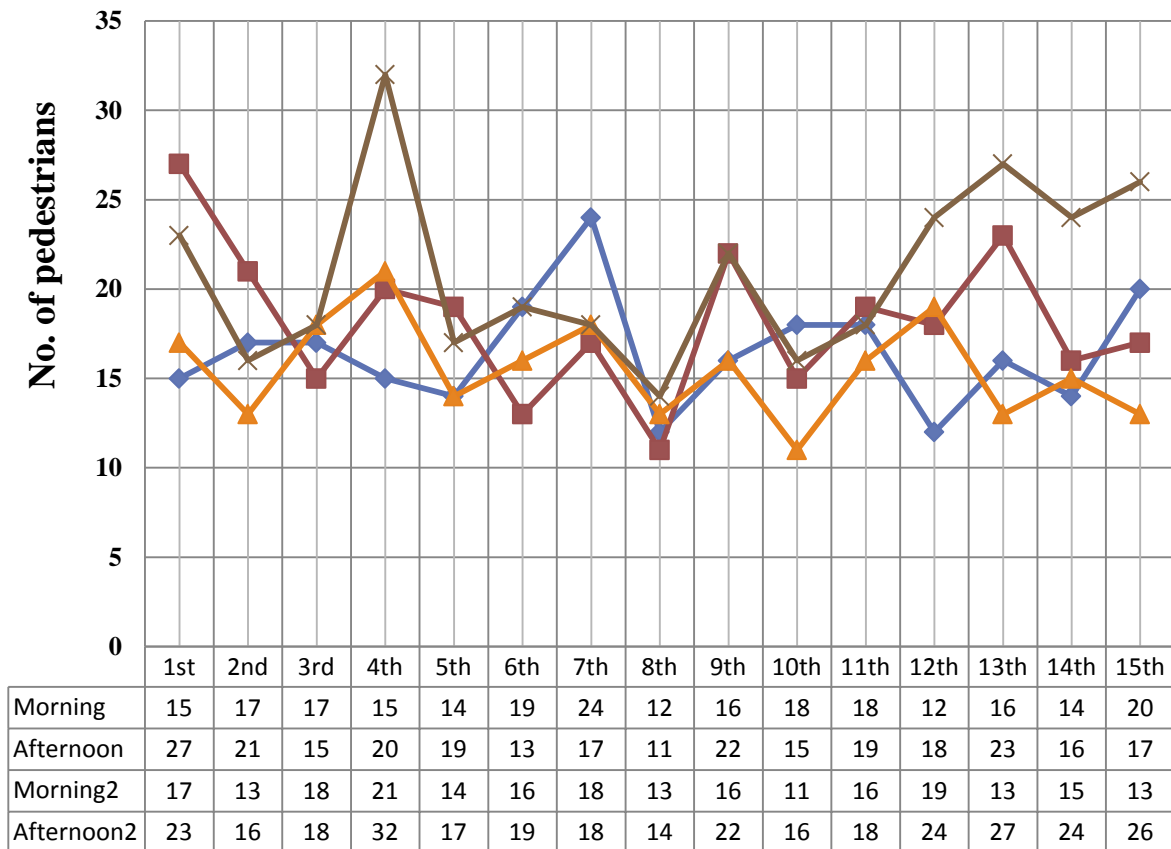


Figure 25: the flow of pedestrians at Meri CMC 2 station

As shown in the graph, the Total maximum pedestrian flow is registered at the 4th Census (Afternoon2) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 314.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 314 \times 5 = \underline{1570}$$

Since the train pedestrian value is >450 [$1570 > 450$], the pedestrian category for this station is category “A” according to Table 2.

Longitudinal road markings should be marked along each edge of the footway, to delineate the required width and define the safe route for pedestrians walking over the crossing. The width of the footway should be 2 or 4 meter. The Overall road section width of this path is 40 meter and the railway occupy 11 meter width of it. Therefore, a longitudinal road marking with 3 meter width should be designed.

Audible warning devices and pedestrian signals should be installed at this station. so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At the Meri CMC 2 station, the crossings and adjacent footways are not at the same level. Therefore, the tactile thresholds are not necessary at this station. And also According to the Train Pedestrian Value Calculation, No need to construct guard rails.

14. Ayat 2 Station (EW 1): it is the starting point of the east west line of Addis Ababa Light Rail Transit. The station is found 50 meters away from the Ayat square. There is train marshal depot near to this station.

The data is collected on Tuesday, February 24, 2015 and Friday, February 27, 2015. The flow of pedestrians is summarized on the following graph.

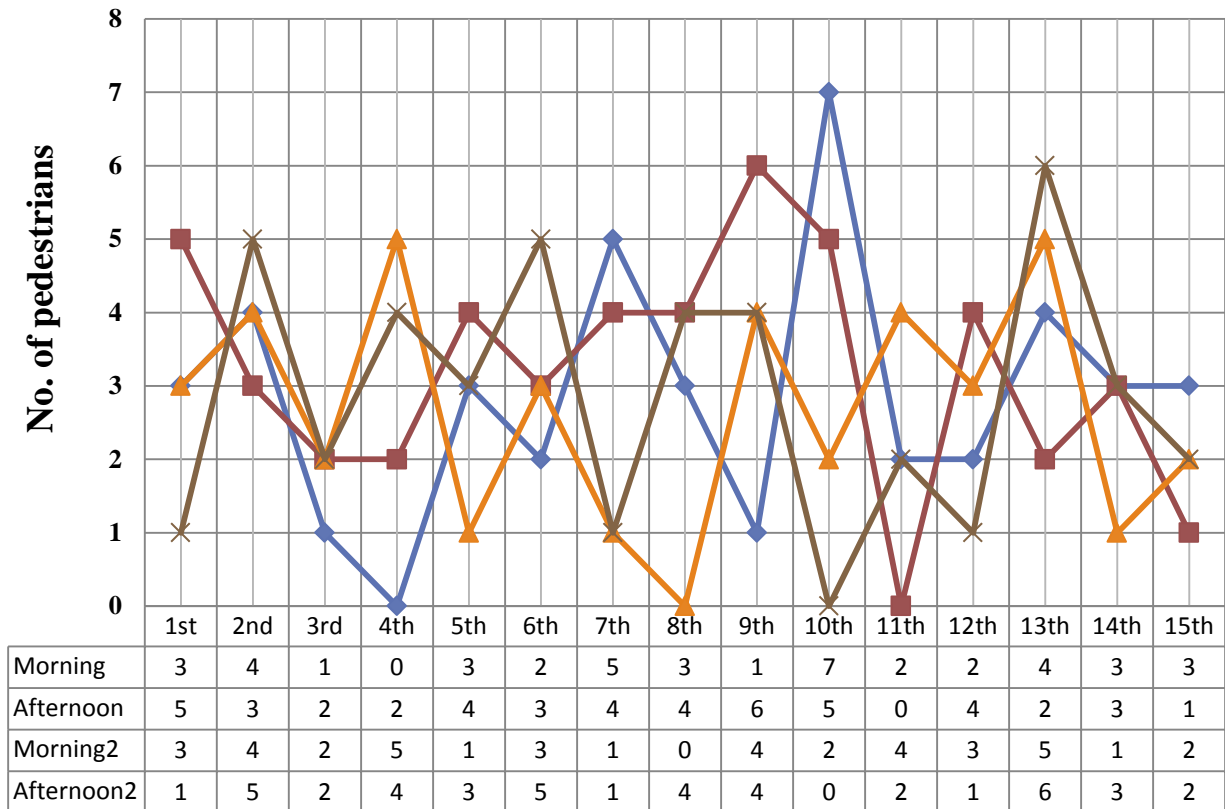


Figure 26: the flow of pedestrians at Ayat 2 station

As shown in the graph, the Total maximum pedestrian flow is registered at the 2nd Census (Afternoon1) which is the sum of each minutes flow. Therefore the maximum pedestrian flow is 50.

At least 1 train crosses this level crossing (station) in each 6 minutes. It means in 15 minutes atleast 5 trains will cross the level crossing in the two lines.

The volume of pedestrian and train flow may be determined by the train pedestrian value (TPV) which in turn defines the pedestrian categories. Therefore, using the equation:

$$\text{Train pedestrian value} = \text{No. Of pedestrians} \times \text{No. Of trains}$$

$$\text{TPV} = 50 \times 5 = \underline{250}$$

Since the train pedestrian value is <450 [250<450], the pedestrian category for this station is category “B” according to Table 2.

This station has a pedestrian category of “B” (See Table 3). Therefore, longitudinal road markings should be marked along each edge of the footway.

For pedestrian category “B” (See Table 3): audible warning devices and pedestrian signals should be installed at this station. so that pedestrians on or approaching the crossings are given adequate warning of the closure of the crossing. Devices should be capable of volume adjustment to suit local requirements. It is another means of precaution for blind pedestrians. Pedestrian signals should face outwards from the crossing towards approaching pedestrians.

At this station, the crossings and adjacent footways are at the same level. Therefore, the tactile thresholds should be placed before pedestrian before pedestrian stop markings across the footway on approach to the crossing.

According to the Train Pedestrian Value Calculation, No need to construct guard rails. And also the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

Data analysis is done for each level crossing (stations), to identify which types of precautions are necessary to ensure the safety of pedestrians. And also, by reading the graph which shows the flow of pedestrians along the level crossings; grade separations necessity is analyzed.

The *Findings* for appropriate precaution for pedestrians in each level crossing (Stations) is summarized in the following Table.

Table 4: An appropriate precaution for pedestrians in each level crossing (Stations)

No.	Stations	Pedestrians categories	Width of footway	Road markings	Audible warnings	Pedestrians signals	Tactile threshold	Guard rails
1	Torhailoch	A	$\geq 3.6\text{m}$	✓	✓	✓	✓	X
2	Coca cola	B	$\geq 3.6\text{m}$	✓	✓	✓	X	X
3	Yodranos Hotel	A	$\geq 3.6\text{m}$	✓	✓	✓	X	X
4	Chemical corporation	A	$\geq 4\text{m}$	✓	✓	✓	✓	X
5	Mazoria (traffic head quarter)	A	$\geq 4\text{m}$	✓	✓	✓	✓	X
6	Lem hotel	A	$\geq 4\text{m}$	✓	✓	✓	✓	X
7	Megenagna square	A	$\geq 4\text{m}$	✓	✓	✓	X	X
8	Gurd shola	A	$\geq 4\text{m}$	✓	✓	✓	X	X
9	Salite mehret church	B	$\geq 4\text{m}$	✓	✓	✓	✓	X
10	Civil service	B	$\geq 3.6\text{m}$	✓	✓	✓	X	X
11	Saint michael church	A	$\geq 4\text{m}$	✓	✓	✓	✓	X
12	CMC 1	B	$\geq 4\text{m}$	✓	✓	✓	✓	X
13	Meri CMC 2	A	$\geq 4\text{m}$	✓	✓	✓	X	X
14	Ayat 2	B	$\geq 3.6\text{m}$	✓	✓	✓	✓	X

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Appropriate provision should be made for pedestrians, taking account of the number and frequency of pedestrians and trains, at all public level crossings. There should be sufficient space, taking into account the volume and nature of the users. As shown in the table 4, in all stations (level crossings); road markings, audible warnings and pedestrian signals should be installed.

Audible warnings and pedestrian signals gives adequate warning for pedestrians on or approaching the closure of the crossing. Pedestrian signals should face outwards from the crossing towards approaching pedestrians. Road markings define the safe route for pedestrians walking over the crossing.

Tactile thresholds are provided in 8 out of 14 stations in which, the crossings and adjacent footways are at the same level. Since, the location of the all railway stations is at the middle of vehicle road. So, it is unable to construct a guard rail on it.

Around *Torhailoch Mazoria, Lem Hotel and Meri CMC 2 Stations* there is high pedestrian demand (crowded) to cross the level crossing and the flow is uniform as shown in figure 13, 17, 18 and 25 respectively. And also these areas are pedestrian origin and destination for other means of transportations.

The distance between there consecutive stations is also too far. Therefore the grade separation system should be applied. It is summarized below:

Table 5: Grade Separation Options

Location	No. of Flow of pedestrians	Distance from the consecutive station	Grade separation option
Torhailoch	136	1.2km	Tunnel
Lem Hotel	236	1.2km	Bridge
Meri CMC 2	314	963m	Bridge

From the findings of the paper it is *recommend* that:

At the moment, pedestrians are preferred to cross at the vehicle turning routes since the level crossings are too far from their location. Therefore Pedestrian precautions should be installed as soon as possible to avoid the collision between pedestrians and road vehicles due to the congestion. And also in some areas: Pedestrians are allowed to cross over the gates due to the shortage of level crossings on the design. For the safety of pedestrians, the Ethiopian railway corporation should close the gates.

In 6 out of 14 stations, the alignment of the level crossing and the footway is not the same. So, it is hard to build tactile thresholds around this area. Therefore, the corporation should built ramps along these areas for the safe of blind pedestrians.

Around *Coca cola station*, there is a tunnel which is built for the use of vehicle crossings. But the tunnel does not include pedestrian's footway at the edge. Pedestrians seem to cross along this tunnel since they don't have choice and it may cause a disaster on pedestrians. Therefore pedestrian's footway should be include simultaneously with the vehicle crossing tunnels.

Since the light rail transit project is new for the country, Awareness creation should be done on pedestrians. From some countries experience, the following strategies should be made [15].

1. Media and education campaign.
2. Implement an awareness advertising campaign supported by targeted media relations and police enforcement.
3. Install level crossing education signage at selected rest stop areas.
4. Consider the inclusion of level crossing safety into road safety programs delivered to schools.
5. Improve the awareness, consultation and education about the use of level crossings on private roads.
6. Incorporate level crossing safety into road safety strategies and training programs, e.g. in driver licensing.
7. Monitor and evaluate national and international research into level crossings.

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APPENDIX

Train pedestrian value (TPV) calculation

1. TPVs are calculated by multiplying the number of pedestrians who pass over the railway by any route at the crossing within any period of 15 minutes by the number of trains passing over the crossing in the same period.
2. Normally a census should be taken over a 3 day period, between the hours 06.00 and 12.00, particularly where high volumes or vulnerable groups of pedestrians are involved. Where the number of pedestrians is low, the actual number may be determined by an estimate. Where there are regular events which boost pedestrian usage, these should be included in the census.
3. Where the data are obtained from a census, only the maximum number of pedestrians in any period of 15 minutes in the day needs to be established. Where an estimate is accepted, the number of pedestrians used in calculating TPV should be deemed to be 75% of the largest hourly value to obtain an equivalent maximum figure for a period of 15 minutes to cater for the non-uniform distribution of pedestrian flow.
4. The number of trains should be deemed to be 25% of those passing over the crossing in a period of one hour. This hour should be either:
 - a. the same hour used to give the estimated hourly value of numbers of pedestrians; or
 - b. The hour which includes the 15 minutes when the pedestrian number is established by census.
5. The number of trains should be rounded up to the next integer and should not normally be less than one.