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ADDIS ABABA INSTITUTE OF TECHNOLOGY

AFRICAN RAILWAY CENTER OF EXCELLENCE

HARMONIZING PEDESTRIANS MOBILITY AT LEVEL CROSSING (THE CASE OF SEBATEGNA LEVEL CROSSING IN ADDIS ABABA)

A Thesis in Railway Engineering

(Civil Infrastructure)

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**harmonizing pedestrian mobility at the level crossing (the case of Sebategna level crossing in Addis Ababa)**' presented by **Christine Nyakona**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that the thesis titled "harmonizing mobility for pedestrians at the level crossing (the case of Sebategna level crossing in Addis Ababa)" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

The highway-rail grade crossing is unique in that it constitutes the intersection of two transportation modes, which differ in both the physical characteristics of their traveled ways and their operations. Level crossings involve a considerable number of pedestrians and their harmony with the road and rail traffic, along with railway and road geometry setup is paramount to enhance the economic, social and environmental aspects of public transportation. The level crossing being a shared space, pedestrians experience time and space constrained mobility and their safety at the level crossing is at risk. This research harmonizes the mobility of pedestrians at level crossings. The case of Addis Ababa Light Rail Transit (AALRT) is chosen, with a specific focus on Sebategna level crossing. The current level crossing at Sebategna is a multi-modal shared space that is managed by the train signal, a bell that rings for an approaching train, level crossing signalmen and traffic officers. This setting results in space and time constrained mobility of pedestrians, congestion, and crashes. Constraints to pedestrian mobility and causes of safety-related issues experienced by pedestrians at the level crossing were examined. Using PTV Vissim multi-modal simulation software, this research developed and evaluated two test scenarios that could improve pedestrian mobility and improve their safety at Sebategna level crossing. The results of the study indicate that the constraints to pedestrians' mobility at Sebategna level crossing include; no coordinated signal control at the level crossing, crosswalks opposite the station platforms entrance are not fully observed by vehicular traffic, some sidewalks being blocked by market vendors and congestion on the level crossing during peak hours which causes significant delays. The causes of safety-related incidents experienced by pedestrians' cuts across pedestrians' behavior, driver behavior, pedestrian infrastructure in place and its' utilization. From the results of the simulated test scenarios, improving and adjusting the infrastructure geometry (shared level crossing, lane configuration, conflict areas) in place can improve pedestrian safety and mobility. There are improved queue length and delay times in test scenario 1, compared to test scenario 2, in which signal control was incorporated. However, from a safety perspective, the later would be suitable because of signal control. The queue length and vehicular delay results of the existing scenario is reduced from 66.66 m and 50.52 s to 25.63 m and 14.47 s respectively. The number of conflict areas reduced from 120 in the existing scenario to 110 and 51 in test scenario 1 and 2.

***Key Words**: Pedestrians, Level crossing, Modeling, Simulation, Mobility.*

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List of Acronyms

Term	Explanation / Meaning / Definition
AALRT	Addis Ababa Light Rail Transit
AARP	American Association of Retired Persons
AASHTO	American Association of State Highway and Transportation Officials
EW	East-West line
HAWK	High Intensity Activated Crosswalks
HCM	Highway Capacity Manual
Ibid	In the same source as the former reference
LC	Level Crossing
NS	North-South line
PTV	PTV Planung Transport Verkehr AG
TPMO	Addis Ababa Transport Programs Management Office
LRV	Light Railway Vehicle
CAR	Central African Republic Street

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CHAPTER 1. INTRODUCTION

1.1 Background

Addis Ababa Light Rail Transit (AALRT) has a total length of 34.25 km with two lines: North-South (NS) and East-West line (EW). The NS line stretches 16.9 km with 2.7 being a shared line. Each light rail vehicle has the capacity to carry 286 passengers. The NS line has a total of 22 stations, of which five stations are shared between the NS and EW (Jemere, 2012). Sebategna is one of the 22 stations towards Menelik II square and immediately after this station there is multipurpose level crossing (LC) that is used by the AALRT, Motorists, Cyclists and Pedestrians. The current population of Addis Ababa stands at over 3.5 million people, the majority of which is centralized in the urban area (Wubneh, 2013). Sebategna level crossing, where this study is focused is located in a business center and residential area. This in addition to the adjacent market area attracts many pedestrians that use the current level crossing. Basically, even the passengers that board and alight from the LRT and roadway traffic contribute to the congestion in the area and to the pedestrians that utilize this level crossing. LCs are intersections where road lanes and rail tracks meet at the same level providing a shared area for railway and vehicular traffic, and for other road users including pedestrians. In Australia, the number of collisions at such intersections remains stable and even increased between 2003 and 2011, reflecting a consistent number of crashes with pedestrians compared to a decreasing number of crashes with vehicles (Australian Transport Safety Bureau, 2012). Similar trends are observed internationally which is why improving the safety and mobility of pedestrians at LCs has become an important objective of governments and rail providers in Australia (Transport and Main Roads, 2012; Beanland *et al.*, 2017) and worldwide. Pedestrians form the top priority in transportation and traffic management since all traffic users are pedestrians at one point, through boarding and alighting from the various transportation modes. Thus, planning for the implementation and improvement of their infrastructure and services in harmony with rail and road traffic at the intersection area is paramount. Studies have been conducted to address issues encountered at level crossings. For example, effects of light rail transit on traffic congestion (Chandler and Hoel, 2004), level of service analysis at LRT with a touch on congestion and delay studies (Nigussie, 2014), analysing the performance of level crossings (Teshome, 2016), analysis of traffic congestion and its economic cost (Andargie, Tadele, 2017), integrating light rail transit with other transport modes (Aimero, 2016), analysis of delay related right-of-way problems in Addis Ababa city road projects (Shiferaw, 2016), evaluation of feasibility of at-grade crossings and traffic management strategies for Addis Ababa light rail transit corridor (Tekletsadik, Girma, 2015), evaluation of traffic congestion and level of service at major intersections in Adama city (Ayehu, Mekonnen, 2015), analysing the impact of at-grade crossing on AALRT capacity (Gebru, 2016), analysing the performance of at-grade pedestrian crossings at Gojam Berenda (Ayssa, 2016) and risk assessment for Addis Ababa light rail transit at-grade pedestrian crossing (Mathewos, 2016). From the listed studies, save for the last two cited, none has attempted to address harmonizing pedestrian mobility at level crossings in terms of travel time and space, while considering their interaction with vehicular traffic.

1.2 Statement of the problem

Level crossings (LCs) are points of conflict between rail and road traffic. Therefore, from the aspect of safety, they are potentially high-risk traffic points. Traffic participants at LCs are pedestrians, cyclists, motorcyclists, car drivers, and locomotive drivers. The behavior of traffic participants represents the main cause of traffic crashes at LCs. Since LCs are collision points of two traffic systems, they represent from the safety point of view traffic points of high risk at which there often comes to emergency situations, sometimes with the severest of consequences. Statistical data show that in more than 90% of emergency cases, the main cause lies in the road motor vehicle drivers and pedestrians (Pilko, 2015). A consistent number of crashes between trains and pedestrians compared to a decreasing number of crashes between trains and vehicles calls for a better understanding of the factors underpinning pedestrians' decision-making at such risky intersections (Stefanova et al., 2018). The case of Sebategna level crossing serves as an intersection point for the LRT vehicles, roadway traffic vehicles, pedestrians, cyclists and animals. Adjacent to this level crossing location, there is a market area that serves the community in this area and other communities that come to Sebategna and Merkato market for business. The current level crossing is managed by the train signal, a bell that rings for an approaching train, level crossing signalmen and traffic officers. This setting results in many constraints/challenges including;

- Constrained mobility of the pedestrians - This requires the pedestrians to be very vigilant when crossing this very busy section, and to avoid standing idle at the level crossing, as a safety measure for the current situation. There is no special pedestrian signal that is synchronized with the rest of the traffic and this is a high-end value feature to ensure the safety of the pedestrians and that there is always crossing time allocated to pedestrians at different levels and not only at saturated conditions. Constrained mobility as used here refers to the limitations or restrictions pedestrians encounter at the level crossing in the course of their movement in terms of space, time and safety.

- Crashes (such as collisions and other “near-miss” crashes) relating to insufficient safety measures -the current setting lacks signals for pedestrians, save for the LRT signal and a bell that sounds for an approaching train, traffic is managed by level crossing signalmen and traffic officers.

Harmonizing pedestrians’ mobility at LC (the case of Sebategna level crossing in Addis Ababa) has a core focus on improving the mobility and safety of the pedestrians at the level crossing. This research attempts to improve the mobility and safety constraints to pedestrians by addressing the specific objectives of this study as discussed below.

1.3 Research objectives/aim

The research objective is split into main objective and specific objective as discussed below.

1.3.1 Main objective

The main objective is to improve pedestrian mobility at a level crossing in terms of space, time and safety by modeling and simulation of the existing intersection area and making geometry and traffic control adjustments through modeling and simulation of two test scenarios. In addressing the specific objectives below, this research will examine and summarize the current mobility and safety challenges encountered by pedestrians at a level crossing.

1.3.2 Specific objectives

The specific objectives linked to the main objectives include:

1. To investigate the constraints to pedestrians’ mobility at Sebategna level crossing.
2. To examine the causes of safety-related incidents experienced by pedestrians at Sebategna level crossing.
3. To evaluate alternative scenarios that will improve pedestrian mobility and at the same time the safety at Sebategna level crossing.

1.4 Significance of the study

This research through modeling and simulation will recommend a practical scenario that is best suited for harmonizing mobility for pedestrians at Sebategna LC. This will include a scenario with better safety measures, reduced delay for traffic and reduced queue length. The recommended scenario can be adopted by Addis Ababa transport planning and management agencies together with Ethiopian Railway Corporation to practically improve traffic management at Sebategna LC.

This research will be useful in identifying the causes of safety-related incidents experienced by pedestrians and constraints to pedestrian mobility at level crossings. This can be theoretically documented and used to improve the performance of level crossings in Addis Ababa.

1.5 Scope

This research is focused on pedestrians' mobility and safety and thus provides solutions and recommendations to mitigate the current challenges faced by pedestrians at Sebategna level crossing. This research touches pedestrian signals at level crossings and in turn the roadway and LRT signal system.

1.6 Limitations

The performance measures in this study do not include behavioral aspects of the transport including pedestrian perception score and transit passenger perception score. The intersection capacity assessment and detailed economic assessment are also not considered in this report.

1.7 Thesis structure

A review of relevant literature is presented in Chapter 2. Chapter 3 describes the methodology of attaining study objectives from data collection through to simulation method including scenarios that were considered. Results and discussion of the applied methodology are under Chapter 4, while the conclusions and recommendations are detailed in Chapter 5.

CHAPTER 2. LITERATURE REVIEW

This research study aims at harmonizing pedestrian mobility at Sebategna LC due to the constraints to pedestrian mobility, crashes and near-miss crash from traffic collisions and traffic congestion. This research study is intended to improve the mobility and safety of pedestrians while in harmony with the road and railway geometric setting. The following subsections are discussions of topics relating to this research study together with previous studies conducted in Addis Ababa.

2.1 Level crossings

The highway-rail grade crossing is unique in that it constitutes the intersection of two transportation modes, which differ in both the physical characteristics of their traveled ways and their operations (Ogden, 2007). Railway and road intersection area and level crossings involve a considerable number of humans (pedestrians) and their harmony with the road and rail traffic, along with railway and road geometry setup is paramount to enhance the economic, social and environmental aspects of public transportation. Humans are the weakest link in any embedded system. Failure rates for humans as system components are several orders of magnitude higher than other parts of the system (Kumar, 2012).

A Level crossing (also known as railroad crossing) is a crossing on one level ("at grade intersection") without recourse to an over-bridge or underpass. Railway level crossings (LC) are the interface between roads and railway tracks, and as such is the potential site for vehicle-train collisions and incidents (Kumar, 2012). In general level crossings can be classified as passive level crossings and active level crossings. The passive level crossings are only equipped with signs and roadway marks whereas active level crossings have an alarm, signal light, manned and automatically controlled boom gates (Teshome, 2016).

2.2 Planning for pedestrians

Definition of pedestrians according to global cities design guide is, "Pedestrians include people of all abilities and ages, sitting, walking, pausing, and resting within urban streets" (Designing and Initiative, 2016).

Every trip begins and ends with walking, and therefore everyone is a pedestrian on a city's street at some point. Providing continuous and unobstructed clear paths ensures walkable neighborhoods for everyone. This requires making people the highest priority in street design, with careful consideration for the most vulnerable users: the young, the elderly, and those with diminished perceptual or ambulatory abilities. The types and volumes of people using a given street will depend on the surrounding land use and density, key destinations, and time of day.

Cities can foster the development of safer conditions for all road users through planning that prioritizes mass transport, pedestrians, and bicyclists (World Resources Institute, 2015). Cities can embrace a hierarchy that prioritizes pedestrians, bicyclists, and mass transport. Key elements of urban form that, especially when taken together, can lead to increased safety include; block size, street connectivity, street widths, access to destinations, and population density (World Resources Institute, 2015)

Among the key elements that lead to increased safety is vehicle/travel lane width. Street width often means the roadbed width, which is the distance between curb edges on opposite sides of a street, or where no curbs exist, from pavement edge to pavement edge. The width of space allowed for vehicle travel on streets greatly influences pedestrian crossing distance and the roadway width potentially available for other uses, such as bike lanes, parking lanes, or landscape curb extensions. The recommended design principle would be to minimize vehicle travel lane width to prioritize pedestrians and provide sidewalk on both sides of the street wherever possible (World Resources Institute, 2015).

Designing for pedestrians'; means making streets accessible to the most vulnerable users. It includes designing safe spaces with continuous, unobstructed sidewalks. Including; visual variety, engaging building frontages, designing for human scale, and incorporating protection from extreme weather to ensure an enjoyable street experience. Parameters to be considered while modeling for pedestrians include; speed, pedestrian crossing, pedestrian crossing location, signalization, crossing distance (length), crossing width, traffic calmed crossings, pedestrian ramps and pedestrian countdown signals (Designing and Initiative, 2016).

2.3 Signals

Signs and signals assist with control strategies for intersections and crossings. These intersection control techniques should focus on the goal of safely moving people who are walking, cycling, using transit, and driving, and on reducing overall person delay rather than vehicle delay in order to prioritize pedestrians and enhance private vehicular evaporation especially in congested intersections. Signals directly impact the quality of the transportation system, and the operation of a city’s traffic control system should closely mirror the city's overall transportation policy goals and objectives (Designing and Initiative, 2016).

Signals work in tandem with geometric design to create a highly functional multimodal street with safe crossings and intersections. Signal timing influences delay, compliance, speed, and mode choice. Coordinating the timing of crossing corridors is a challenging but high-value traffic management process. Traffic signal timing with insufficient time for pedestrians to cross a street or long signal cycle that increases waiting times are likely to create an unpleasant or unsafe street and may discourage walking. Significant delays may cause street users to ignore the traffic signal (Designing and Initiative, 2016).

In its’ application, signals should allow ample pedestrian crossing time to ensure reduced street widths will shorten pedestrian crossing distance and exposure to cars. Narrow streets slow traffic by increasing drivers’ perception of impediments to motion and mitigate the potential severity of crashes. On-street parking and street trees visually narrow the street for those traveling along and can help lower vehicle speeds (World Resources Institute, 2015).

2.4 Constraints to pedestrians’ mobility at a level crossing

Walking is one of the main and sustainable traffic modes in urban transportation, because of the flexibility and mobility involved in it. However, pedestrians are encounter numerous challenges and constraints that hinder their mobility. This section explores those challenges, constraints and related factors to pedestrian mobility.

Pedestrians face problems while crossing at signalized intersection crosswalks under mixed traffic condition. Of all the problems faced by pedestrians in signalized intersection crosswalks, the pedestrians delay is the most important parameter and it is difficult to estimate. Pedestrian delay at the signalized intersection is more complex to estimate accurately because of pedestrian crossing behavior and mixed traffic conditions. Thus, the pedestrian delay is the key performance indicator to evaluate a signalized intersection Level of Service for pedestrians. Pedestrian crossing behavioral factors such as pedestrians adjusting their crossing speed based on the traffic condition, the pedestrian non-uniform arrival pattern, and some pedestrians crossing the crosswalk during flashing red signal phase and red phase (pedestrian violation), are linked to pedestrian delay and contribute to constraints to pedestrian mobility at level crossing (Marisamynathan and Vedagiri, 2013).

Some of the factors that constrain pedestrian mobility and safety are linked to the road user him/herself (i.e., declines in sensory, cognitive, and physical abilities, and incorrect estimation of one's own capabilities). Risk factors linked to the road environment also play an important role (e.g., the complexity of road infrastructures, vehicle speed) (Tournier, Dommes and Cavallo, 2016).

Public space features also influence the pedestrian traffic and in turn, may come out as constraints to pedestrian mobility. The figure below summarizes public space features that influence pedestrian traffic (Amoroso, Castelluccio, and Maritano, 2012). A level crossing is an active urban feature and the indicators summarized below may also constrain pedestrian mobility at level crossings.

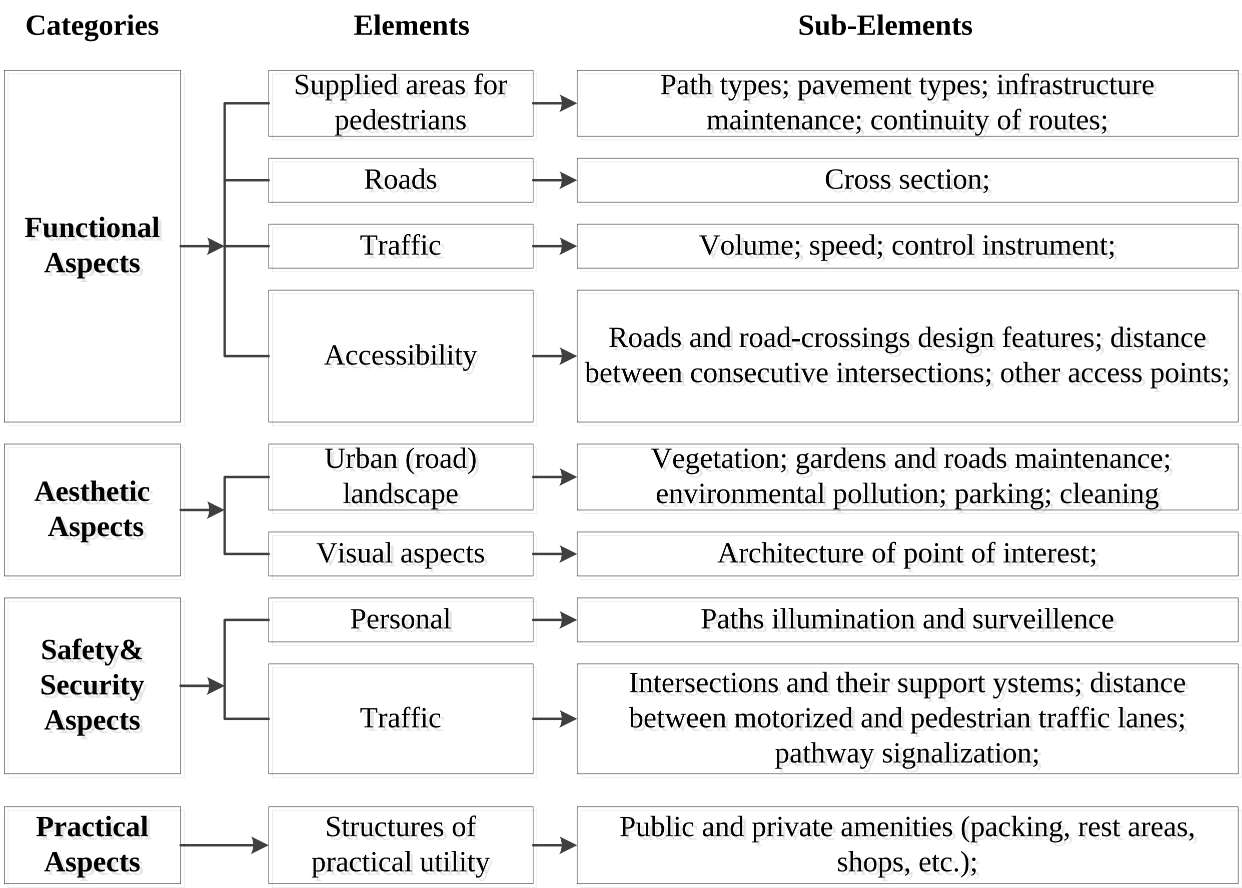

Figure 1: Public space features that influence pedestrian traffic adopted from Indicators for sustainable pedestrian mobility (Amoroso, Castelluccio, and Maritano, 2012).

The following is a summary to the above literature review on constraints to pedestrians' mobility at a level crossing.

- Pedestrian delay; results in pedestrians adjusting their crossing speed based on traffic condition and pedestrians' violation of traffic signals.
- Pedestrian crossing behavior.
- Configuration of the intersection and road environment.
- Public space features including; aesthetic aspects, safety and security aspects, functional aspects, practical aspects (structures of practical utility).

2.5 Causes of safety-related incidents experienced by pedestrians at a level crossing

Safety is the state of being away from hazards caused by natural forces or human errors randomly (Definitions, 2015). Human factors rather than technical failures or other external events are found to be the main contributor to crashes, injuries, and near-misses at railways and specifically at LCs (Stefanova et al., 2018). A better understanding of the core factors contributing to pedestrians' unsafe crossing decisions is necessary to improve safety at intersections.

In regard to pedestrians' unsafe behavior at active LCs, a distinction must be made between the intentional transgression of the law – violations, and the non-volitional transgression of the law – errors. Errors may be associated with failures of the attentional resources (e.g., failure to see the pedestrian light), with poor judgments based on wrong assessment of the situation (e.g., others are crossing so the lights must be off) or resulting from poor knowledge about the properties of the LC system and its performance (e.g., crossing is allowed and safe until the pedestrian gate starts closing). Violations, on the other hand, imply that the decision to cross is based on the conscious weighing of the costs and benefits of risk-taking. For a pedestrian, the costs of risk-taking could be associated with the perceived risk of being involved in a crash or with the perceived risk of being penalized for the transgression of the road rules. Positive outcomes could be associated with perceived benefits such as saving time (e.g., by reducing waiting time or by taking a shortcut), avoid missing the train, or being socially accepted by a group of important others (Stefanova et al., 2018). Thus, it can be inferred that pedestrian unsafe behavior is one of the causes of safety-related issues experienced by pedestrians at a level crossing.

Pedestrian behavior that can increase the risk of collisions and crashes between pedestrians and vehicular traffic at the LCs/intersection area can be classified as (Martin, 2006):

- Choice of crossing place;
- Non-compliance at designated crossings;
- Crossing speed;
- Failure to attend to traffic;
- Pedestrian alcohol consumption.

These behaviors are described in turn in the following section.

Choice of the crossing place

Types of behaviors that influence the choice of crossing place include; effects of traffic volume, effects of pedestrian delay, effects of demographic variables, effects of pedestrian physical impairment, and effects of peer pressure. Where pedestrians choose to cross can have a big impact on the risk associated with that crossing maneuver. The acts of risky behavior involving choosing where to cross that have been found in the literature relate predominantly to pedestrians choosing to cross at or away from pedestrian crossings but also include choosing to cross when obstructed by vehicles (e.g. between cars) (Martin, 2006).

In the case of level crossings, pedestrians will have a choice of crossing place prior to the crossing, for example crossing the roads that intersect with the level crossings. However, after that, the only option for crossing may be the level crossing, to connect to their destinations. Their safety will thus be influenced by the interaction of effects, traffic volume, pedestrian delay, demographic variables, pedestrian physical impairment, and peer pressure.

Non-compliance at designated crossings

Pedestrians tend to cross the road when it suits them, in terms of convenience and saving time rather than thinking of potential safety implications. Factors that influence pedestrian non-compliance at designated crossings include; effects of traffic volume and speed, the effect of waiting times, effects of demographic variables, effects of pedestrian impairment, effects of peer pressure/group dynamics, and effects of social psychological variables (Martin, 2006).

Crossing speed

The time taken to cross the road depends on the road width and on walking speed. The crossing speed is also influenced by the effects of demographic variables (Martin, 2006). Pedestrians with lower walking speed, whether because of age, infirmity or simply carrying a heavy object, may not have sufficient time to cross if they start at the end of the green period. Extra time might, therefore, be worth considering if the local population is elderly, as these users may have a speed less than 1m/s (Martin, 2006). According to research conducted by (Alver, 2017), the average crossing speed is found to be 1.31 m/s and the average 15th percentile crossing speed is found to be 1.07 m/s.

Failure to attend to traffic

Contributory factors that lead to pedestrian failure to attend to traffic can be subjective. However, one factor that influences failure to attend to traffic is the effects of demographic variables. Failure to attend to traffic is one of the main causes of both adult and child pedestrian collisions (Martin, 2006).

Pedestrian Alcohol Consumption

Pedestrian alcohol consumption reduces their concentration at level crossings. Thus, the risk of their safety while crossing is high. Effects of demographic variables also play a major role, where male pedestrian alcohol consumption is most times higher than the female alcohol consumption and the same comparison relates to their risk of safety (Martin, 2006).

Following pedestrians' unsafe behavior, the complexity of intersections also imposes particular constraints to the understanding of pedestrians' crossing behavior (Stefanova et al., 2015).

Awareness of one's vulnerability with advancing age may explain why older pedestrians, as compared to younger ones, prefer to use pedestrian crosswalks and intersections with signals. It should be noted that the risk of collision on crosswalks without signals is linked to incautious behavior on the part of pedestrians but also to the failure of drivers to stop at pedestrian crossings. Choosing a safe place to cross is particularly challenging for older pedestrians because they often suffer from physical impairments that reduce their ability to get to a pedestrian crossing that is too far away. Consequently, they sometimes even decide to "jaywalk", i.e., cross where there is no crosswalk (Tournier, Dommes and Cavallo, 2016). Thus, pedestrians' age difference is one of the causes of safety-related incidents at level crossings.

High-risk motorist behavior is also a contributing factor to causes of safety-related issues experienced by pedestrians at level crossings. High-risk motorist behavior identified by train drivers include (from highest to lowest risk):

- Trying to cross the LC fast ahead of an approaching train;
- Crossing with undue haste;
- Crossing in poor visibility situations;

- Ignoring warning devices; and
- Crossing without due attention to the conditions in front of them.

The following factors are the most common factors in driver error and deliberate violations at level crossings:

- Drivers' difficulty in gauging the time and space required to cross safely;
- Risk-taking behaviors such as trying to cross the LC fast ahead of an approaching train to avoid frustrating delays and meet unrealistic delivery schedules;
- Driver complacency due to familiarity with the travel route;
- Not driving according to the conditions; and
- Distraction.

The high-risk motorist behavior and the most common factors in drivers' errors, together contribute to safety-related issues experienced by pedestrians at level crossings (Center for Accident Research and Road Safety - Queensland (CARRS-Q), 2015).

In informing the results of the hazard by cause categories, there are five cause categories of safety at level crossings, including; human factors, technical problems, non-compliance with standards, visibility, and others (Berrado, 2011).

2.5.1 Pedestrian Unsafe Level Crossing framework (PULC)

The PULC as summarized in the figure below identifies factors on four system levels and is tailored to the particular context of pedestrian crossing behavior. Each level lists system components responsible for various safety constraints associated with corresponding risk-factors potentially contributing to unsafe crossing (Stefanova et al., 2015).

From the PULC, it can be inferred that the causes of safety-related incidents experienced by pedestrians at level crossings stem from four levels including;

- Organizational level
- Equipment and surroundings level
- Social environment level
- Pedestrian level

The components of each of the four levels and risk contributing factors associated with the components are summarized in the Figure below (Stefanova et al., 2015). The outcome of the pedestrian crossing behavior could be safe crossing, errors or crossing out of violations.

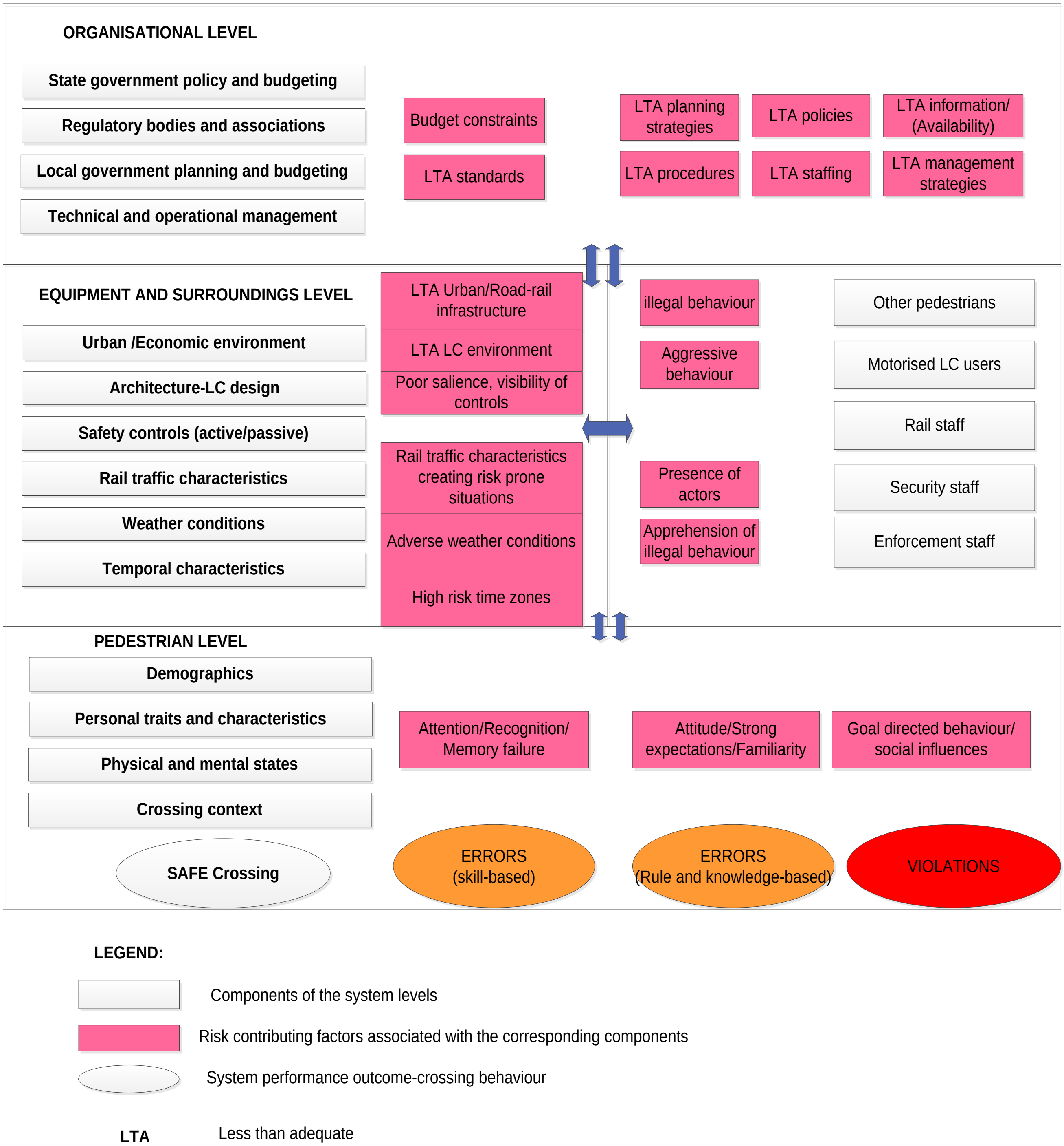

Figure 2: Pedestrian Unsafe Level Crossing Framework (Stefanova et al., 2015)

2.6 Performance measures

The performance criteria that were used to evaluate the test scenarios in this study including; delay, queue length, and pedestrian safety measures are discussed below.

Control delay-for automobile mode

Delay is an important performance measure for interrupted-flow system elements. There are several types of delay, but control delay; brought about by the presence of a traffic control device; is the principal service measure for evaluating the level of service at signalized intersections and those that are not. Control delay includes delay associated with vehicles slowing in advance of an intersection, the time spent stopped on an intersection approach, the time spent as vehicles move up in the queue, and the time needed for vehicles to accelerate to their desired speed. Delay can be measured at existing intersections as an alternative to the estimation of delay (Transportation Research Board, 2010a). A summary of the estimation technique and field measurement technique is discussed below.

Estimation of control delay

Methodology for evaluating signalized intersection performance from motorist perspective is computationally intense and requires software to implement. The intensity stems partly from the need to model traffic-actuated signal operation. The sequence of calculations needed to estimate selected performance measures is provided by the highway capacity manual (Transportation Research Board, 2010b). Average control delay experienced by all vehicles that arrive during the analysis period includes any delay incurred by vehicles that are still in the queue after the analysis period ends. The control delay for a given lane group is computed using the equation below;

Control delay, $d = d_1 + d_2 + d_3.$ Equation (1)

Where, d represents control delay (s/veh), d_1 represents uniform delay (s/veh), d_2 represents incremental delay (s/veh), and d_3 initial queue delay (s/veh) (Transportation Research Board, 2010b).

Field measurement technique

Among the existing measurement methods; test-car survey, vehicle path tracing and input-output analysis, the queue-count technique is recommended for control delay measurement as it is amenable to delay measurement on a lane group basis and it requires less time to implement (Transportation Research Board, 2010c).

Queue counting technique.

This technique is based on direct observation of vehicle-in-queue counts for a subject lane group. It requires two field personnel for each lane group surveyed a multifunction digital watch that includes a countdown-repeat timer and a volume-count board with at least two tally counters. Appropriate adjustment factors are used to estimate control delay. One accounts for sampling errors that may occur, the second accounts for unmeasured acceleration-deceleration delay. The HCM, 2010 chapter 31 provides a sample of the intersection control delay worksheet that can be used for recording observations. Before the start of the survey, the approach speed, survey period, count interval should be determined. The survey should begin at the start of the red indication associated with the subject lane group and, ideally when no initial queue is present (Transportation Research Board, 2010c).

The control delay is the summation of the time in queue per vehicle (d_{vq}) and acceleration-deceleration correction delay (d_{ad}). The equation is illustrated below (Transportation Research Board, 2010c).

Control delay, $d = d_{vq} + d_{ad}$. Equation (2)

Time in queue per vehicle (s/veh), $d_{vq} = I_s \left(\frac{\sum V_{Iq}}{V_{tot}}\right) * 0.9$. Equation (3)

I_s represents the survey count interval, V_{Iq} represents the vehicles in queue counts, V_{tot} represents the total vehicles arriving during the survey period, 0.9 accounts for the errors that may occur when the queue-count technique is used to estimate delay (sampling errors).

Acceleration-deceleration correction delay, $d_{ad} = FVS * CF$. Equation (4)

Where FVS represents the fraction of vehicles stopping and CF represents the acceleration-deceleration correction factor. For the present study, queue length was evaluated using the queue counting feature in Vissim (as discussed under the methodology section).

Pedestrian delay

The pedestrian delay represents the average time a pedestrian waits for a legal opportunity to cross an intersection leg. In general, pedestrians become impatient when they experience delays in excess of 30s/p, and there is a high likelihood of their not complying with the signal indication. In contrast, pedestrians are very likely to comply with the signal indication if their expected delay is less than 10 s/p (Transportation Research Board, 2010b).

The pedestrian delay while waiting to cross the major street is computed with the equation below;

Pedestrian delay, $D_p = \frac{(C - g_{walk,mi})^2}{2*C}$. Equation (5)

Where D_p is a pedestrian delay (s/p), C is the cycle length (s), and $g_{walk, mi}$ is the effective walk time for the phase serving the minor-street through movement (s) (Transportation Research Board, 2010b). If the phase providing service to the pedestrians is either actuated with a pedestrian signal head and rest-in-walk not enabled or pretimed with a pedestrian signal head, then;

Effective walk time, $g_{walk,mi} = Walk_{mi} + 4.0$ Equation (6)

Otherwise if no signal pedestrian signal head, then;

Effective walk time, $g_{walk,mi} = D_{p,mi} - Y_{mi} - R_{c,mi}$ Equation (7)

Where $Walk_{mi,}$ is pedestrian walk setting for the phase serving the minor-street through movement(s), $D_{p, mi}$ is the duration of the phase serving the minor-street through movement(s), Y_{mi} is yellow change interval of the phase serving the minor-street through movement(s), $R_{c, mi}$ is red clearance interval of the phase serving the minor-street through movement (s) (Transportation Research Board, 2010b).

2.7 Previous studies

Analyzing the performance of at-grade pedestrian crossing: a case study of Gojam Berenda at-grade pedestrian crossing (GBAPC) in the North-South section of AALRT (Ayssa, 2016). In this study, the author's objective was to determine the capacity of GBAPC by analysis method. The main objective of the study was to analyze the performance of at-grade pedestrian crossings and to recommend desirable mitigations based on attained results.

The treatment method adopted for the analysis of GBAPC was the Transit Cooperative Research Program (TCRP) Pedestrian-controls decision tree method. This was first compared and contrasted with another method, the Minnesota Department of transportation decision tree-based treatment selection hierarchy. The finding of the project work showed that GBAPC needed the provision of pedestrian access, passive warning devices, active warning devices, barrier channelization, swing gates and stripped channelization for the safe, fast and profitable operation of AALRT. Provision of pedestrian access existed but not suitable for pedestrians with wheelchairs thus, reducing the performance of the crossing. There was no other treatment installed other than pedestrian access (Ayssa, 2016). While this study focused on performance analysis of at-grade pedestrian crossing along AALRT, the present study focuses on pedestrians' mobility and safety at shared level crossings. Both studies, however, focused on pedestrians.

Level crossings pose major safety challenges since it is a shared area for multimodal traffic. (Mathewos, 2016) studied risk assessment for AALRT at-grade pedestrians' crossings by direct observation to examine the status, flow of pedestrians and trains along with the pedestrians' at-grade crossings. From the results, the necessity of installing warning signs was analyzed. The result of this study recommended the installation of all warning signs (active and passive) at all at-grade pedestrians' crossings and the need to intensify educational and enforcement campaigns to convince all pedestrians that it is illegal crossing tracks at locations other than a pedestrian crossing. The data was analyzed using TriMet standard to assess and identify the risks and propose mitigation methods for the identified risks (Mathewos, 2016). While this study focused on risk assessment of at-grade pedestrian crossing, the present study focuses on pedestrians' mobility and safety at shared level crossings. Both studies, however, focused on pedestrians.

(Nigussie, 2014) carried out research on the level of service analysis at light rail transit grade crossing under different operational conditions. The study used PTV VISSIM multi-modal traffic simulation software to evaluate the level of service at LRT grade crossings and the effects of light rail crossings on average delays experienced by vehicles. The study noted that the interaction of LRT at a grade crossing with various other road users present multiple objective problems among which is traffic congestion and their countermeasures at light rail grade crossings. Using Vissim 6.00-17 simulation software, the Addis Ababa East-West light rail transit corridor where LRT grade crossings exist, between Megenagna and Ayat, was modeled. According to current and future demands, different scenarios with LRT in the median for the two-roundabout intersection, Salitemhiret, and CMC roundabout were evaluated for 5,10,15 and 20 minutes LRT arrival frequencies as well as permitted and prohibited street parking traffic consideration. The study aimed to evaluate traffic congestion and recommend countermeasures based on the level of service at level crossings (Nigussie, 2014).

The result of test scenarios showed that due to the full priority given to light rail vehicle, the level of service of the intersection and average additional delays from light rail transit crossings increase with increasing light rail crossing frequencies. The study also showed that allowing street parking along the roadside corridor will also increase the same. The study concluded that Since LRT is moving in median and passengers have a tendency to cross both the left and right side of the road when they are alighting and boarding at ground stations, the impact of pedestrians or passengers crossing the street near ground station results in interruption of traffic movement and increases the delays of vehicular traffic (Nigussie, 2014). While this study focused level of service analysis at light rail transit grade crossing under different operational conditions, the present study focuses on pedestrians’ mobility and safety at shared level crossings. Both studies are on level crossings and carry out modeling and simulation using Vissim software.

2.8 Summary of literature

Studies have been conducted worldwide on matters relating to pedestrians on LCs; pedestrian behavior, safety, and risk while using the LCs and interacting with other traffic modes. There are a few studies in Addis Ababa that have attempted to address issues relating to pedestrians at level crossings, and issues relating to level crossings. Those that have done, for example, tackled risk assessment of LRT at grade pedestrian crossings, analyzing the performance of level crossings and level of service analysis of level crossings. With reference to related literature, the present study examines the constraints to pedestrians' mobility and safety issues on LCs, and to improve pedestrian mobility and safety at Sebategna LC.

CHAPTER 3. MATERIALS, METHODS, AND PROCEDURES

This section contains a description of how the study was conducted; the data collection materials and methods, the strategy used in achieving objectives 1 and 2, followed by model building and simulation in line with the set-out study objectives.

3.1 Description of the study area

The study area selected for this research is along the NS line of AALRT lines. The present study is focused on prioritizing pedestrian mobility in harmony with mass transit at Sebategna level crossing. Sebategna LC is located in proximity to Sebategna station, which is one of the stations along the NS light rail transit line 2. The geo-location of Sebategna LC is shown in the Figure below.

Figure 3: Geo-location of Sebategna intersection area

3.2 Method of data collection

For this study, both primary and secondary data were collected as described below.

Primary data:

The primary data is mainly visual condition assessment of Sebategna intersection area as described below.

Characteristics of Sebategna intersection area

To examine the constraints to pedestrians' mobility and causes of safety-related incidents experienced by pedestrians at Sebategna level crossing, a visual condition survey was conducted through direct observation while taking note of the following features;

- The general layout of Sebategna intersection area
- Sidewalks
- Safety features and issues
- Comfort and appeal
- Driver behavior
- Usage of the level crossing by all traffic

The visual condition survey through direct observation was carried out for one day, by one person and the observations made were summarized on a note paper. The observations made in line with the above-bulleted features included mobility and safety problems experienced by pedestrians at Sebategna intersection area and geometric characteristics of the intersection area. The materials used include; notepaper and pens, the smartphone camera and comfortable walking shoes. The results of the data collected through direct observation are included under Chapter 4 of this report.

Secondary data:

The secondary data for this study was collected from TPMO office and LRT maintenance and ticketing department. Following is a description of the collected data.

Video footage

This was collected from Addis Ababa Transport Programs Management Office (TPMO), Traffic Safety and Management Division, using an external drive. The video footage of the intersection area collected was captured on weekdays; November 4th, 2017, November 7th, 2017 and November 8th, 2017. Each day having video footage of morning, mid-day and evening hours. The video footage was used to get an estimated number of passengers that alight from Sebategna station and use the pedestrian crosswalks at the intersection area. The video data was used to count the number of pedestrians that are alighting from AALRT station and using the crosswalks adjacent to the station area. The counting was made for the same duration as the video data and the pedestrian counts were noted on paper in the form of tallies. The counting was done for all the three-day video data.

Vehicular count data

The count data were collected for three consecutive days; on December 14th, 2017, December 15th, 2017 and December 16th, 2017. The three days were peak traffic days, considering two working days in a week and one weekend day to capture any alterations in vehicular traffic volume. From the count data, peak periods were identified, considering morning, mid-day and evening hours. The vehicular count data was used to determine the hour of maximum demand for each of the approaches; Autobus-Tera, Abnet, Merkato, and Amanuel approach. For each approach, vehicular data for a U-turn, left turn, through movement and right turn movements are required.

Pedestrian count

This included pedestrians using the intersection area and pedestrians boarding the LRT from Sebategna station. The pedestrian count for pedestrians using the intersection area was conducted in the morning, mid-day and evening for three consecutive days; on December 14th, 2017, December 15th, 2017, and December 16th, 2017. The three days were peak traffic days, considering two working days in a week and one weekend day to capture any alterations in pedestrian volume. Peak periods of the pedestrian count were identified, considering morning (7:35 a.m. to 8:35 a.m.), mid-day (12:30 p.m. to 1:30 p.m.) and evening (5:00 p.m. to 6:00 p.m.) hours and the period of maximum demand was used in simulation using Vissim. 2018 monthly data of pedestrians boarding from Sebategna was used to determine the month of peak demand, from which the peak average daily volume and average hourly volume were determined and used for simulation.

Books and reports

Global Street Design Guide book and cities safer by design report were received in soft copy format from TPMO. The book and report were reviewed to get relevant information regarding pedestrian mobility in urban areas and relevant information to this study which is captured in the literature review.

Description of variables

Lane width

Lane width is the arithmetic mean of the lane widths of a roadway in one direction expressed in meters. The typical lane width is 3.6m. Urban street lane widths can be as narrow as 3.0 m. The lane width that will be used for analysis excludes parking lanes. Lane width less than 3.6m reduce travel speeds; however, widths of more than 3.6m are not considered to increase the travel speed above base level (Transportation Research Board, 2000).

Crosswalks and walkways

A crosswalk is a marked area for pedestrians crossing the street at an intersection or designated midblock location. Crosswalk length is the sum of widths of approach lanes, the median, and the adjacent outbound lanes (Transportation Research Board, 2000).

Walkways and sidewalks are facilities such as paths designated exclusively for pedestrians. The American Association of State Highway and Transportation Officials (AASHTO) recommend that clear sidewalk width should be 1.5m minimum. Widths of 2.4m or greater may be necessary for commercial areas (Transportation Research Board, 2000).

Pedestrian volume

Pedestrian volume is the sum of individual pedestrians crossing individually and groups of pedestrians crossing together during the analysis time period (Transportation Research Board, 2000).

Vehicular volume

Total vehicle volume will represent the sum of vehicles entering the intersection from all approaches and through vehicles as well (Transportation Research Board, 2000).

3.3 The strategy used in achieving the first and second specific objectives

The Figure below is a summary of the strategy used in realizing specific objectives 1 and 2 for the present study. The presentation of the specific objectives 1 and 2, will synthesize literature findings and direct observation of pedestrian interaction with other traffic at Sebategna intersection area. Thus, it is worth noting that other important relevant issues not found in the literature review but identified through direct observation of the case study area are presented in achieving specific objectives 1 and 2.

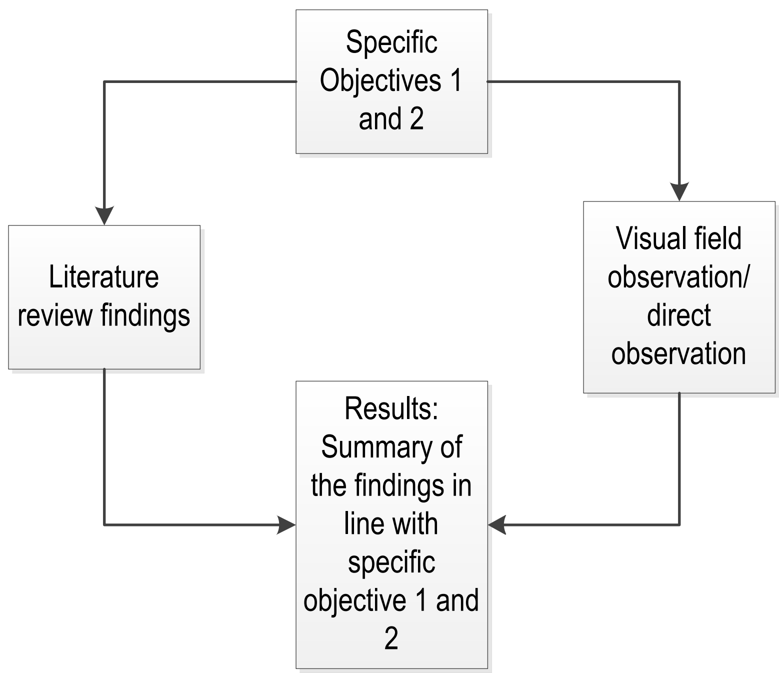

Figure 4: Strategy for achieving specific objective 1 and 2

3.4 Modeling and simulation using VISSIM

Modeling and simulation of Sebategna intersection area were executed using PTV VISSIM. VISSIM is a microscopic, time step and a behavior-based simulation model developed to model urban traffic and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness (Tel, 2003).

The data collected were used as inputs into the VISSIM interface to aid modeling and simulation and it is through the inputs, that output such queue length, vehicular delay, and the pedestrian delay was generated after a simulation run. The steps followed in modeling and simulations were as per the guidelines of Vissim manual. Modeling and simulation involved importing a background image into the network editor. The background image and all the network objects used in modeling and simulation are found under the network objects section of Vissim. After importing the background image, sizing and scaling of the background image were done as per the guidelines in Vissim manual used. The network objects used for modelling and simulation of the existing scenario include: links, that acted as roads; connectors, that are embedded with the links and join two links together within the network or within the intersection area that was simulated; vehicle inputs, from which vehicular volume is input; vehicle routes, which helps in creating the different vehicle routes and turns within the network area; public transport stops, which was used to simulate LRT station area; public transport lines, from which the LRT 15 minute headway was input; Conflict areas, which was used to assign control in shared areas between vehicles and pedestrians and priority rules, was used to assign priority to the LRT at the LC. The network objects used to model and simulate pedestrians in the network include areas, this was used to add various pedestrian areas within the network like crosswalks; pedestrian inputs, from which pedestrian volume was added and pedestrian routes, was used to add the pedestrian direction of movement within the network. Nodes from the network objects were created last around the intersection area of the network, and this was to help in generating delay and queue length results required after running the simulation. Node evaluation is used especially to determine specific data from intersections without first having to define all sections manually in order to determine the data (Tel, 2003).

3.5 Description of test scenarios and existing situation

Two simulation test scenarios were used in harmonizing pedestrian mobility at Sebategna intersection area, and are described in this section. The existing situation was modeled and simulated and this together with the two test scenarios were evaluated based on performance criteria described under this section. The present study focused on two test Scenarios, which involve reducing the shared space between pedestrians and all other modes of traffic. The present study considered ground space separation and not grade separation because of its' limitations to reduce risk at the present study area. Based on the widely accepted hierarchy of controls approach to safety management, the ideal solution to reduce collision potential at level crossings is to engineer out the hazard of rail-road interaction (i.e. grade separate). However, this involves redesigning the road network, installing bridges and tunnels, and can cost millions per crossing, a cost often viewed as highly disproportionate to the risk (Larue, Naweed and Rodwell, 2018).

Geometric layout of Sebategna junction:

AutoCAD drawing of the geometric layout of Sebategna junction, representing the current condition was collected from TPMO using an external disk and this was used to describe the current setting in comparison to two test scenarios that were used in modeling and simulation. The AutoCAD drawing was used as the background image in Vissim.

Existing situation:

The existing scenario was simulated using the current geometry setup of the case study area. The background image (AutoCAD drawing) of the case study area was added in PTV Vissim. The current geometry includes LRT in the median of railway-roadway intersection area. The intersection area serves four approaches; Autobus Tera, Abnet, Merkato, and Amanuel. Autobus Tera Approach has four driveway lanes, two lanes each on the sides of the LRT line with varying lane width of 3.0 m to 3.3 m and two parking lanes, one on either side. Abnet has four driveway lanes, two lanes each on the sides of the LRT line with two parking lanes, one on either side. The lane width ranges from 3m to 3.3 m. Merkato has four driveway lanes and two parking lanes with lane width ranging from 3.0 m to 3.3 m. Amanuel has two lanes with 3.5m width each. The existing situation was modeled and simulated using vehicular volume and pedestrian volume, with LRT 15-minute headway. The 15-minute headway is the average and current operating headway of the LRT in the field. Figures 4 and 5 below illustrate the geometric layout of the current intersection Sebategna intersection area.

The current layout of Sebategna intersection area has a multi-modal shared level crossing that imposes safety risks to pedestrians and mobility constraints to pedestrians since they cannot move with ease. The traffic management plan in place is not organized; pedestrian areas like sidewalks are misused by both vehicular traffic and market vendors. Pedestrian crosswalks are not wide enough and are not fully observed by vehicular traffic, forcing pedestrians to utilize the gaps and shortest crossing distance they find along the vehicular lanes.

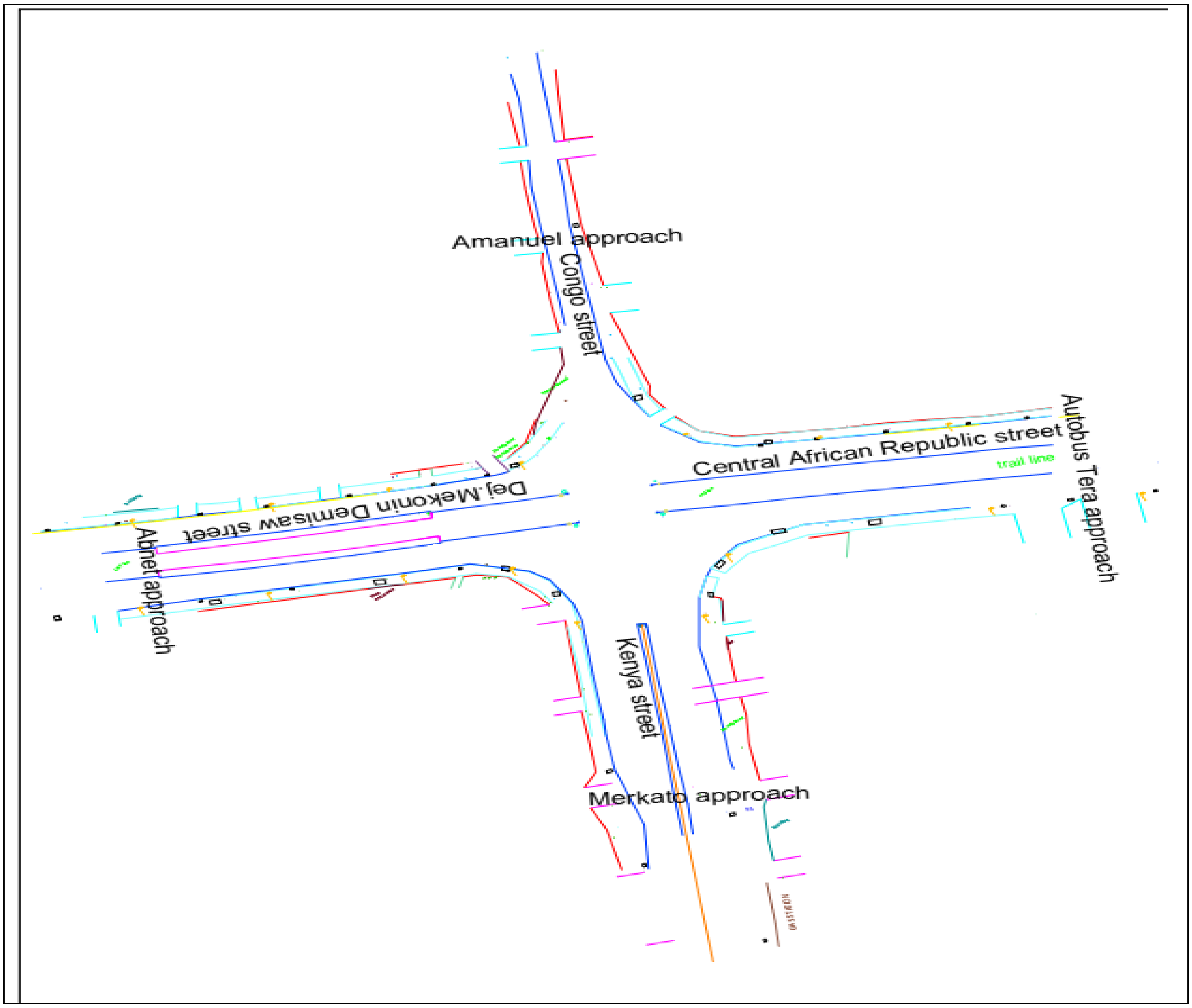

Figure 5: Layout of the current geometry of Sebategna intersection area (AutoCAD drawing from TPMO)

Figure 6: Sebategna intersection area

Scenario one:

The first test scenario involves providing separate pedestrian crosswalk away but close to the existing shared level crossing and adjusting the vehicular lanes as described in here. The lane width of approaches having 3.5 m width was adjusted to a lower value and the right turn lanes were reduced to single lanes of 3.0 m wide. Pedestrian crosswalks of 2.4 m and 10 m wide were used in the simulated Sebategna network using PTV Vissim. This scenario was tested using vehicular volume and pedestrian volume with LRT 15-minute headway. This scenario aims to improve pedestrian mobility and safety by providing wider crosswalks at appropriate locations within the intersection area, reducing pedestrian and vehicular conflict areas to improve pedestrian safety and improve general traffic management plan of Sebategna intersection area.

Scenario two:

Scenario two is a supplement to test scenario 1 by incorporating coordinated signal control. For signal control, the LRT was given full priority and pedestrian green time was balanced and coordinated with tram and vehicular traffic to ensure ample time for pedestrian safe mobility at the intersection area and to cater for varying walking speeds of pedestrians. The signal control was programmed using Visual Vehicle Actuated Programme (VisVAP), that is inbuilt within PTV Vissim. This scenario aims to improve general traffic management of the intersection area by introducing a coordinated traffic control that caters for pedestrians as well to improve pedestrian safety.

3.5.1 Performance Criteria

The performance criteria that were used to evaluate the test scenarios in this study including delay, queue length, and pedestrian safety measures are discussed below.

Control delay

PTV Vissim evaluations are in accordance with HCM model of determining delay. It is worth noting that in Vissim the total delay in seconds is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account). The delay time does not include passenger stop times at transit stops. However, the lost time caused by acceleration or deceleration, because of such a stop remains part of the delay time. Thus, for each scenario, the total delay generated from Vissim node results was noted for comparison of the scenarios. To take into account pedestrian delay from Vissim evaluations, pedestrian network performance was extracted from result attributes from which the average stop time for the pedestrians in the network was recorded. The average stop time for all pedestrians was noted for each scenario for comparison and recommendation of the best scenario.

Queue length

When demand exceeds capacity for a period of time or when arrival headway is less than the service time at a specific location, a queue form. Queuing is both an important operational measure and a design consideration for an intersection and its vicinity (Transportation Research Board, 2010a). The queue counter feature in VISSIM provides as output the average queue length, maximum queue length and number of vehicles stops within the queue. Queues are counted from the location of the queue counter on the link or connector upstream to the final vehicle that is in queue condition (Tel, 2003).

Pedestrian safety measures

Safety is provided by separating pedestrians from vehicular traffic both horizontally, by using pedestrian zones and other vehicle-free areas, and vertically, by using overpasses and underpasses. Traffic control devices such as pedestrian signals can provide time separation of pedestrian and vehicular traffic, which improves pedestrian safety (Transportation Research Board, 2010a). Safety performance measures look at the impact of a project on the well-being and safety of network users. Safety can be measured by objective metrics like a number of collisions, crime rate and a number of on-duty police officers. They can also be estimated using proxy variables such as driver yield rates at pedestrian crossings or evaluated through surveys that capture user perceptions of safety and personal security (Fehr & Peers, 2015).

Factors that are thought to significantly affect pedestrians' sense of safety include the following;

- Presence of a sidewalk,
- Lateral separation from motor vehicle traffic,
- Barriers and buffers between pedestrians and motor vehicle traffic,
- Motor vehicle volume and composition,
- Effects of motor vehicle traffic speed, and
- Driveway frequency and access volume.

The perception of safety is a qualitative measure of effectiveness recognized by the highway capacity manual (Bruce W *et al.*, no date). The safety performance measures that were used to qualitatively assess pedestrian safety include; pedestrian traffic control, crosswalk width, a number of conflict areas, presence of sidewalks and its use, lateral separation from motor vehicle traffic and barriers and buffers between pedestrians and motor vehicle traffic.

A condition survey of the study area was conducted to assess the safety measures in place and to collect geometric, operational and traffic characteristics of crosswalks, sidewalks, pedestrian-vehicle conflict areas and any other pedestrian safety measures that could be identified in the field. From the safety performance measures identified in the field, the test scenarios were modeled and simulated in Vissim to enhance the safety features and controls for pedestrians. The test scenario with more plus on safety and mobility while considering the delay and queue length results was recommended. For each scenario; the number of conflict areas generated from evaluation of the simulations was noted, width and location of the crosswalks and presence traffic control within each scenario were also noted. The scenario with fewer conflict areas, sufficient crosswalks width and having traffic control measure was considered safe for pedestrians.

CHAPTER 4. RESULTS AND DISCUSSION

This section contains results and discussion from data collection and modeling, and simulation using PTV Vissim.

4.1 Results from condition survey of the study area by direct observation

From the direct observations made at the present case study area, and what literature review revealed regarding constraints to pedestrians' mobility and causes of safety-related incidents at level crossings, the following can be inferred:

- Safety of pedestrians at level crossings cuts across pedestrian safety features on the ground and/or conflict areas, comfort, convenience, human behavior, driver behavior, et cetera.
- Pedestrians at Sebategna level crossing have the responsibility of being cautious while using the level crossing since the section is busy and traffic signal coordination relies on human beings that are also prone to error.
- Constraints to pedestrians' mobility at the level crossing are closely linked to safety because pedestrians' comfort influences their behavior.

4.1.1 Constraints to pedestrians' mobility at Sebategna level crossing

The identified constraints to pedestrians' mobility at Sebategna level crossing are summarized below.

- There is no coordinated traffic signal control at the level crossing.
- Some conflict areas like the crosswalks opposite the station platform entrance are not fully observed by vehicular traffic.
- Some sidewalks are blocked by market vendors, and forcing pedestrians on the carriageway.
- Congestion on the level crossing during peak hours which causes significant delays.

4.1.2 Causes of safety-related incidents experienced by pedestrians at LC

The identified causes of safety-related incidents experienced by pedestrians at Sebategna level crossing are summarized below.

- There is no pedestrian timed signal at the level crossing.
- There is poor coordination of traffic movement at the level crossing.

- Some conflict areas like the crosswalks opposite the station platform entrance are not fully observed by vehicular traffic.
- Some walkways are blocked by market vendors, and forcing pedestrians on the driveway.
- Drivers trying to cross the LC fast ahead of an approaching train.
- Crossing with undue haste.
- Driver complacency due to familiarity with the level crossing.
- Drivers hesitant to stop before crosswalks to allow waiting pedestrians to cross (they mostly stop when there is vehicular queue ahead).
- Traffic jam at the LC while a train is approaching the LC. This can easily lead to collisions and other safety-related incidents.

With the information acquired thus far, it is possible to model and simulate test scenarios that will improve the mobility and safety situation at Sebategna level crossings and recommend additional possible measures to be undertaken to reduce the risks and improve mobility for pedestrians at Sebategna level crossing.

4.2 Results from secondary data collection

The results from secondary data, including vehicular count data and pedestrian count data, are discussed below.

4.2.1 Pedestrian volume alighting from Sebategna junction

A summary of the data extracted from the video footage is summarized in the Table below and it was used in the modeling and simulation of alternative scenarios in the present study. The total number of pedestrians alighting from line 1 and 2 for the corresponding days, were summed up and the day giving the highest number of pedestrians, were adopted for simulation using Vissim9. The adopted number of pedestrians for line 1 and 2 were 252 and 501 pedestrians respectively. The pedestrian volume boarding and using the level crossing is summarized under secondary data received in sub-section 4.2.

Table 1: Estimate Pedestrians alighting from Sebategna junction

November 8th (morning)				November 8th (afternoon)				November 8th (evening)			
00019 (00:37:12)		00020(00:24:25)		00021 (00:36:58)		00022(00:23:34)		00023 (00:37:08)			
Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)		
35	**121**	**34**	**93**	**37**	**65**	**18**	**85**	**43**	**140**		
November 7th (morning)				**November 7th (afternoon)**				**November 7th (evening)**			
00013 (00:37:12)		00014(00:27:31)		00015 (00:36:58)		00016(00:23:34)		00017 (00:37:08)		00018 (00:22:41)	
Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)
49	**119**	**26**	**110**	**44**	**45**	**31**	**80**	**62**	**70**	**40**	**77**
November 4th (morning)				**November 4th (afternoon)**				**November 4th (mid-day)**			
00007 (00:37:08)		00008(00:26:01)		00011 (00:37:01)		00012(00:35:03)		00003(00:37:16)		00004(00:26:30)	
Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)	Left (line 1)	Right (line 2)
0	**0**	**0**	**0**	**54**	**80**	**64**	**85**	**34**	**40**	**30**	**142**

4.2.2 Vehicular count data

A summary of the vehicular count-data for three consecutive days is summarized in Table 2 below. From the count-data, the vehicular traffic was categorized into the car, truck, bus, minibus, LRT, and two-wheelers and the relative flow of each vehicle composition was calculated relative to the total volume per hour per direction of travel. This was done for all the three day-count and the morning count volume was adopted for simulation use since it had a higher average compared to mid-day and evening count. The count for each day (morning, mid-day, evening) was for one hour and they were all peak hours as indicated in the methodology – data collection section. Details of the relative flow and vehicle composition used are in Appendix A.

Table 2: Summary of the vehicular volume for the three-day count

December 14th, 2017 - Morning count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
0	148	412	263	0	167	45	72	0	148	567	21	0	53	83	96	**2075**

December 14th, 2017 - Mid-day count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
90	42	172	189	0	174	43	81	0	96	432	29	0	34	53	59	**1494**

December 14th, 2017 - Evening count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
89	34	173	203	0	233	65	107	0	71	470	35	0	44	49	99	**1672**

December 15th, 2017 - Morning count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
98	22	164	177	0	148	59	60	81	136	498	18	0	66	111	95	**1733**

December 15th, 2017 - Mid-day count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
73	37	157	168	0	167	39	99	44	83	469	26	0	35	69	73	**1539**

December 15th, 2017 - Evening count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
84	38	225	245	0	242	62	84	50	87	557	36	0	34	58	88	**1890**

December 16th, 2017 - Morning count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
60	17	262	199	0	169	41	41	88	156	393	26	0	48	114	67	**1681**

December 16th, 2017 - Mid-day count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
58	13	198	206	0	205	43	71	53	106	522	29	0	44	61	74	**1683**

December 16th, 2017 - Evening count

Abnet				Merkato				Autobus Tera				Amanuel				Total
U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	U-Turn	Left	Through	Right	
56	20	231	175	0	257	57	81	40	79	465	32	0	30	54	103	**1680**

For Abnet; the right turn is from Abnet to Merkato approach, the through movement is from Abnet to Autobus Tera approach, the left turn is from Abnet to Amanuel approach and the u-turn is from Abnet to Abnet approach. For Merkato; the right turn is from Merkato to Autobus Tera approach, the through movement is from Merkato to Amanuel approach, the left turn movement is from Merkato to Abnet approach and the U-turn movement is from Merkato to Merkato approach. For Amanuel; the right turn is from Amanuel to Abnet approach, the through movement is from Amanuel to Merkato approach, the left turn is from Amanuel to Autobus Tera and the u-turn is from Amanuel to Amanuel approach. For Autobus Tera; the right turn is from Autobus Tera to Amanuel approach, the through movement is from Autobus Tera to Abnet approach, the left turn is from Autobus Tera to Merkato approach and the u-turn is from Autobus Tera to Autobus Tera approach. The total vehicular volume per hour for each approach used for simulation in Vissim is summarized in the Table below.

Table 3: Vehicular volume per hour per approach

Abnet	Merkato	Autobus Tera	Amanuel
823	284	736	232

4.2.3 Pedestrian count data

The period of maximum demand from the pedestrians' counts for three consecutive days was found to be morning as summarized in Table 4 below. The pedestrians' categories captured inside and outside the crosswalks include; walking adult, walking old (persons using a walking stick for support), walking child and person on a wheelchair as summarized in Table 5 below. Pedestrian count inside and outside the crosswalks adjacent to Sebategna level crossing was adopted for simulation using Vissim.

Table 4: Summary of pedestrian count for three consecutive days

14th December 2017		15th December 2017		16th December 2017	
Time of the day	**Total pedestrians**	**Time of the day**	**Total pedestrians**	**Time of the day**	**Total pedestrians**
Morning	9,483	Morning	11,260	Morning	**12,040**
Mid-day	8,181	Mid-day	7,889	Mid-day	9,656
Evening	10,538	Evening	12,040	Evening	10,197

Table 5: Pedestrian morning count

Direction of movement	Inside Crosswalk				Outside Crosswalk				Total Inside Crosswalk	Total outside crosswalk	Total Pedestrians
	Walking Adult	Walking Old	Walking Child	Person on wheelchair	Walking Adult	Walking Old	Walking Child	Person on wheelchair			
R to S	335	24	19	0	89	8	6	0	378	103	481
S to R	673	7	0	3	45	3	0	1	683	49	732
S to T	2635	2	8	0	80	0	0	0	2645	80	2725
T to S	835	1	4	0	200	0	0	0	840	200	1040
T to Q	22	7	1	0	645	9	9	0	30	663	693
Q to T	78	5	1	0	433	8	9	0	84	450	534
R to Q	1925	7	31	0	865	0	0	0	1963	865	2828
Q to R	1833	56	46	0	1070	2	0	0	1935	1072	3007
									8,558	**3,482**	**12,040**

The illustration of the direction of movement (for the pedestrian count) in the first column of Table 5 above is shown in Figure 7 below.

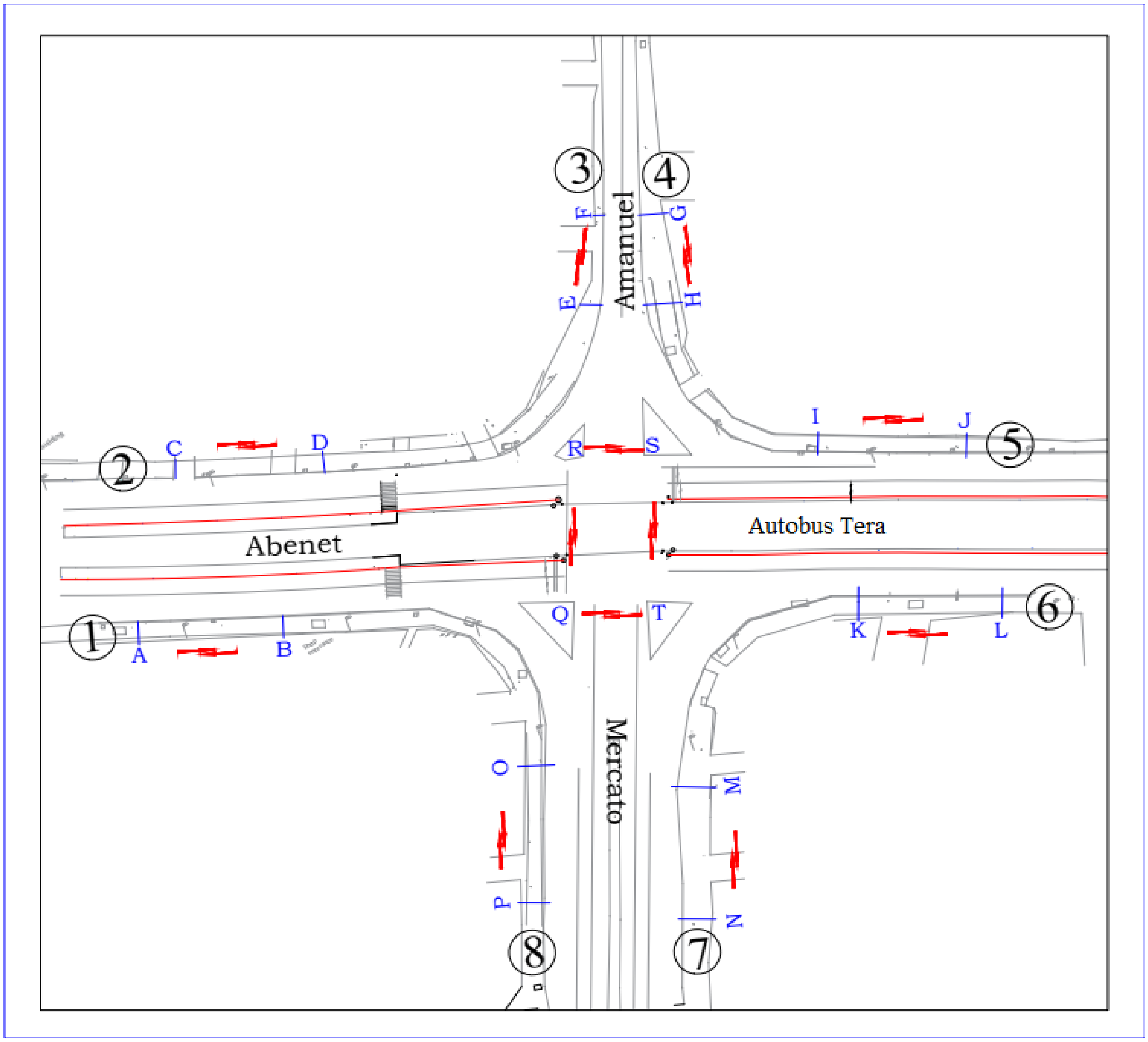

Figure 7: Guide to the pedestrian direction of movement as used in Table 5 above

Pedestrians boarding the train from Sebategna station

2018 monthly data of pedestrians boarding the train from Sebategna station were collected from AALRT, ticketing office. This is helpful in capturing the pedestrians that are expected to use the crosswalk on opposite sides of the station entrance as they proceed to board the train. Since the train operation is for 16 hours, the monthly pedestrian volume was converted to average daily volume and then to average hourly volume considering 16 operation hours in a day. The peak hour and day are in the month of December as shown in the Table below.

Table 6: Pedestrians boarding from Sebategna station

Operation Months	Average/day	Average/hr.
Jan-18	2601.129032	162.5705645
Feb-18	2848.178571	178.0111607
Mar-18	2804.83871	175.3024194
Apr-18	2651.354839	165.7096774
May-18	2706.677419	169.1673387
Jun-18	2845.967742	177.8729839
Jul-18	2695.967742	168.4979839
Aug-18	3006.806452	187.9254032
Sep-18	2627.612903	164.2258065
Oct-18	3120.483871	195.0302419
Nov-18	3197.322581	199.8326613
Dec-18	**3243.064516**	**202.6915323**
Total Average/hr./year		**2146.837774**

4.3 Simulation results

Results from the simulation of the existing scenario of Sebategna intersection area and two test scenarios adopted in this study are summarized under this sub-section. The inputs used for generating the results using PTV Vissim are also summarized below.

4.3.1 Inputs used for simulation

The vehicle and pedestrian volume used as inputs are summarized in Table 7 below. Please note that the volume data used is for each approach to the intersection.

Table 7: Vehicle and Pedestrian volume used in Vissim

Vehicle inputs	
Approach	**Volume**
Abnet	823
Merkato	284
Autobus Tera	736
Amanuel	232
Pedestrian inputs	
Direction of movement	**Volume**
R1	2341.2
R	2341.2
S	3328
T	870
Q1	2019.2
Q	2019.2
alighting line 1	252
alighting line 2	500
boarding line 1	1144
boarding line 2	1144

The vehicle compositions and pedestrian compositions used in the simulation are summarized in Tables 8 and 9 below respectively. Drawing from the literature findings, the average walking speed for this study is taken to be 1m/s. The vehicular speed limit at the present case stud area is 40 km/hr. for private cars and the lower speed limit for heavy goods vehicles and buses (these values were arrived at after consultation with TPMO team).

Table 8: Vehicle compositions

Vehicle compositions		
Vehicle type	**Desired speed distribution**	**Relative flow**
Abnet		
100: Car	40: 40 km/h	322
200: HGV	30: 30 km/h	84
300: Bus	30: 30 km/h	83
650: Mini bus	40: 40 km/h	324
Autobus Tera		
100: Car	40: 40 km/h	295
200: HGV	30: 30 km/h	348

Vehicle compositions		
300: Bus	30: 30 km/h	44
650: Mini bus	40: 40 km/h	304
Merkato		
Merkato		
100: Car	40: 40 km/h	82
200: HGV	30: 30 km/h	170
300: Bus	30: 30 km/h	42
650: Mini bus	40: 40 km/h	128
Amanuel		
100: Car	40: 40 km/h	79
200: HGV	30: 30 km/h	128
300: Bus	30: 30 km/h	1
650: Mini bus	40: 40 km/h	127
Tram lines		
400: Tram	25: 25 km/h	7
400: Tram	25: 25 km/h	5

Table 9: Pedestrian compositions

Pedestrian compositions		
Pedestrian compositions	**Desired speed distribution**	**Relative flow**
Pedestrian area R		
300: Wheelchair User	1004: 3.60 km/h (1.00 m/s) ±	0
310: walking adult	1004: 3.60 km/h (1.00 m/s) ±	565
320: walking old	1004: 3.60 km/h (1.00 m/s) ±	7.75
330: walking child	1004: 3.60 km/h (1.00 m/s) ±	12.5
Pedestrian area S		
300: Wheelchair User	1004: 3.60 km/h (1.00 m/s) ±	0.75
310: walking adult	1004: 3.60 km/h (1.00 m/s) ±	827
320: walking old	1004: 3.60 km/h (1.00 m/s) ±	2.25
330: walking child	1004: 3.60 km/h (1.00 m/s) ±	2
Pedestrian area T		
300: Wheelchair User	1004: 3.60 km/h (1.00 m/s) ±	0
310: walking adult	1004: 3.60 km/h (1.00 m/s) ±	214.25
320: walking old	1004: 3.60 km/h (1.00 m/s) ±	2
330: walking child	1004: 3.60 km/h (1.00 m/s) ±	1.25
Pedestrian area Q		
300: Wheelchair User	1004: 3.60 km/h (1.00 m/s) ±	0

Pedestrian compositions		
310: walking adult	1004: 3.60 km/h (1.00 m/s) ±	477.75
320: walking old	1004: 3.60 km/h (1.00 m/s) ±	15.25
330: walking child	1004: 3.60 km/h (1.00 m/s) ±	11.75
Pedestrian boarding line 1		
100: Man	1004: 3.60 km/h (1.00 m/s) ±	134
200: Woman	1004: 3.60 km/h (1.00 m/s) ±	134
Pedestrian boarding line 2		
100: Man	1004: 3.60 km/h (1.00 m/s) ±	134
200: Woman	1004: 3.60 km/h (1.00 m/s) ±	134
Pedestrian boarding line 1		
100: Man	1004: 3.60 km/h (1.00 m/s) ±	31.5
200: Woman	1004: 3.60 km/h (1.00 m/s) ±	31.5
Pedestrian boarding line 2		
100: Man	1004: 3.60 km/h (1.00 m/s) ±	62.625
200: Woman	1004: 3.60 km/h (1.00 m/s) ±	62.625

In addition to the above inputs, test scenario two involved signal control and the inputs were signal groups, intergreen matrix and stage assignments from which stage sequence and signal program were generated. The signal program developed was used to generate an interstages (ASCII) file, which was used as an input file for vehicle actuated program (VAP) control logic. Another file, called VAP logic file with signal control program logic of a VAP controller, was also used as an input file for the VAP control logic. The VAP logic file was generated using Visual VAP (VisVAP), an add-on module within Vissim. The VisVAP flowchart that was used to generate the VAP logic file is in Appendix B of this report.

Figure 8 below, is an illustration of the names of the signal groups used. VAuTR stands for Autobus Tera through and right turns; VAuLU stands for Autobus Tera left and U-turns; VATR stands for Abnet through and right turns, VALU stands for Abnet left and U-turns; VMTRLU stands for Merkato through, right, left and U-turns; VAmTRLU stands for Amanuel through, right, left and U-turns; p9 through p14 are pedestrians signal groups.

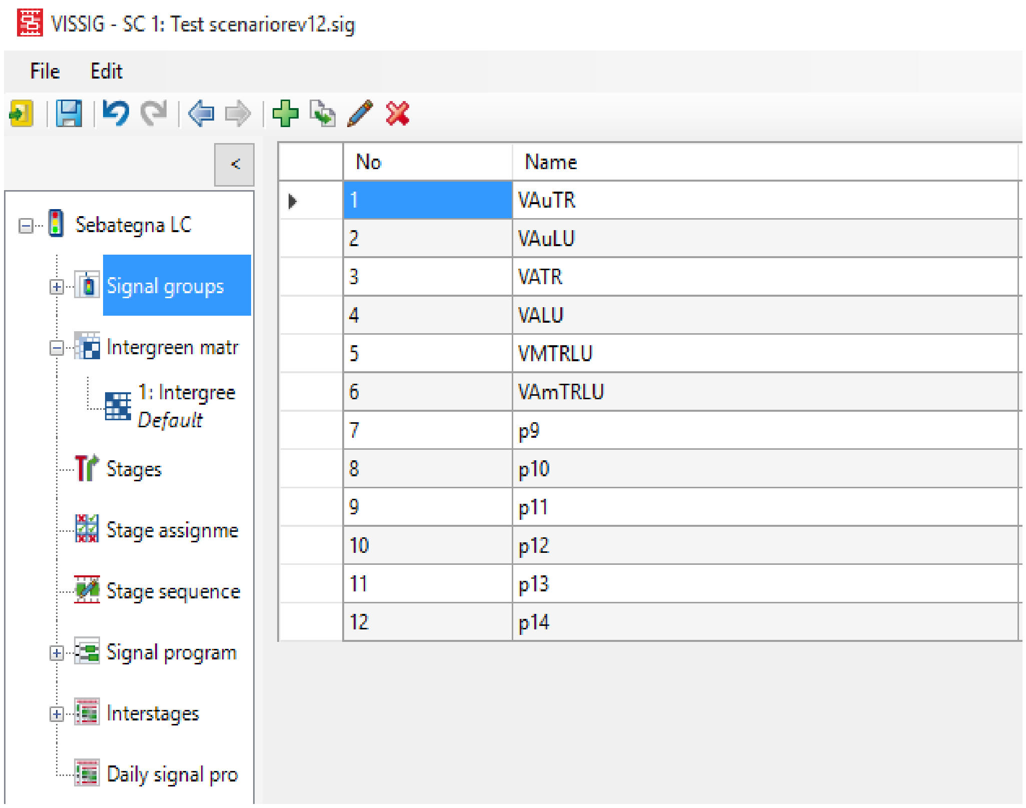

Figure 8: Signal groups

The intergreen matrix used for signal control is shown in the Figure below.

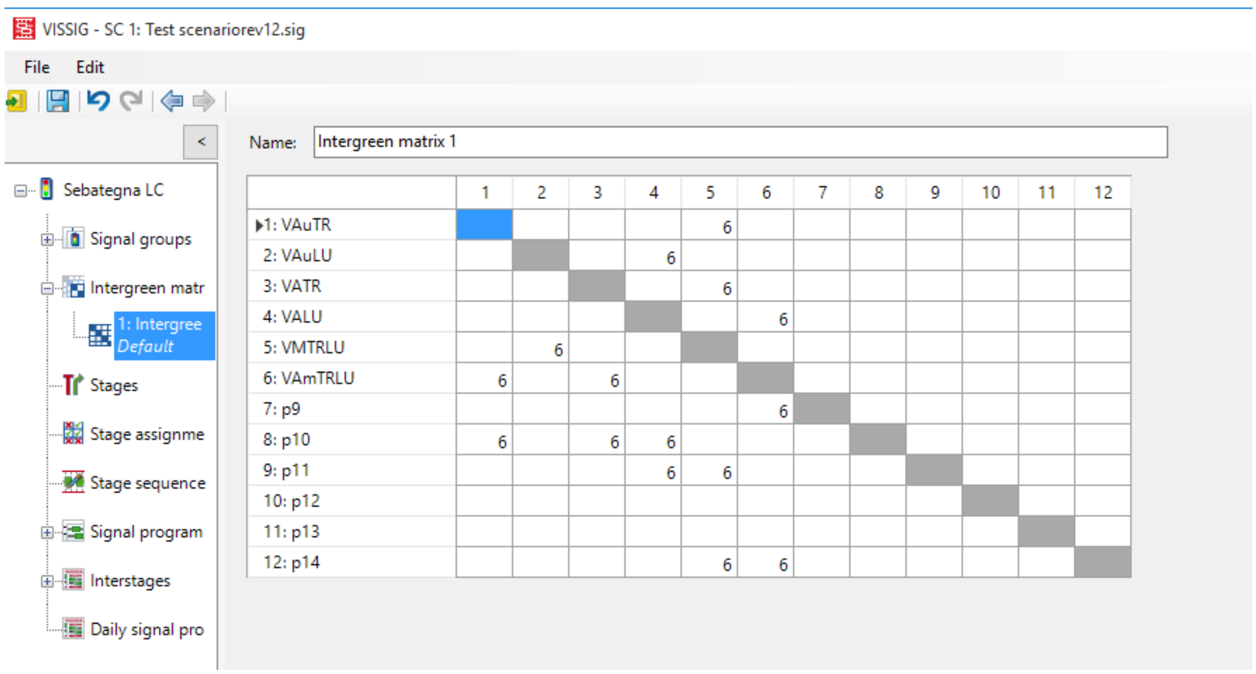

Figure 9: Intergreen matrix

The stage assignment used for the signal program is illustrated in the Figure below.

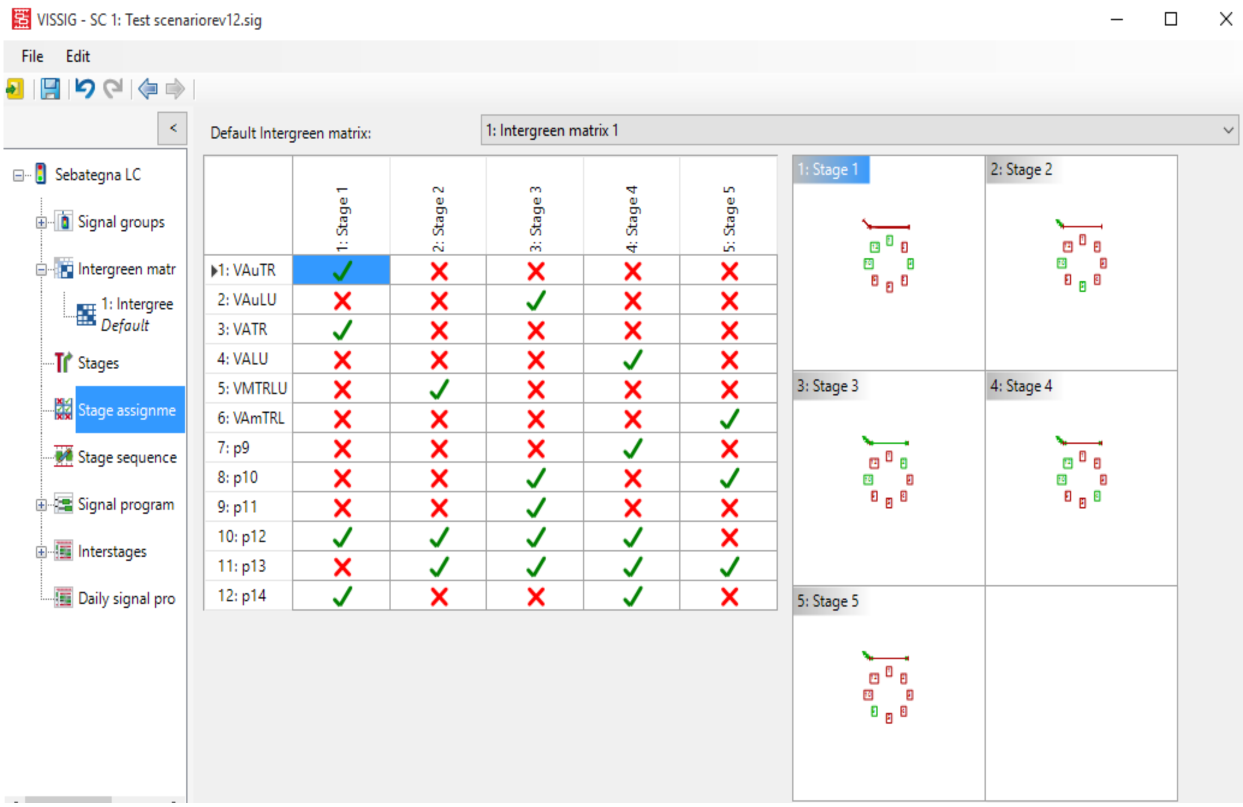

Figure 10: Stage assignment

4.3.2 Simulation results for the existing scenario, test scenario 1 and test scenario 2

Illustration of the simulation models of the existing scenario, test scenario 1 and test scenario 2 are shown in Figures 11, 12, 13 below respectively. The green areas are non-shared pedestrian areas and the crosswalks area shared pedestrian areas between vehicular and human traffic. The gray links that interconnect at the intersection area/level crossing represent lanes of the different approaches. The simulation results including queue length, vehicle delay and pedestrian average stop time for the existing scenario, test scenario 1 and test scenario 2 are summarized in Table 10 below.

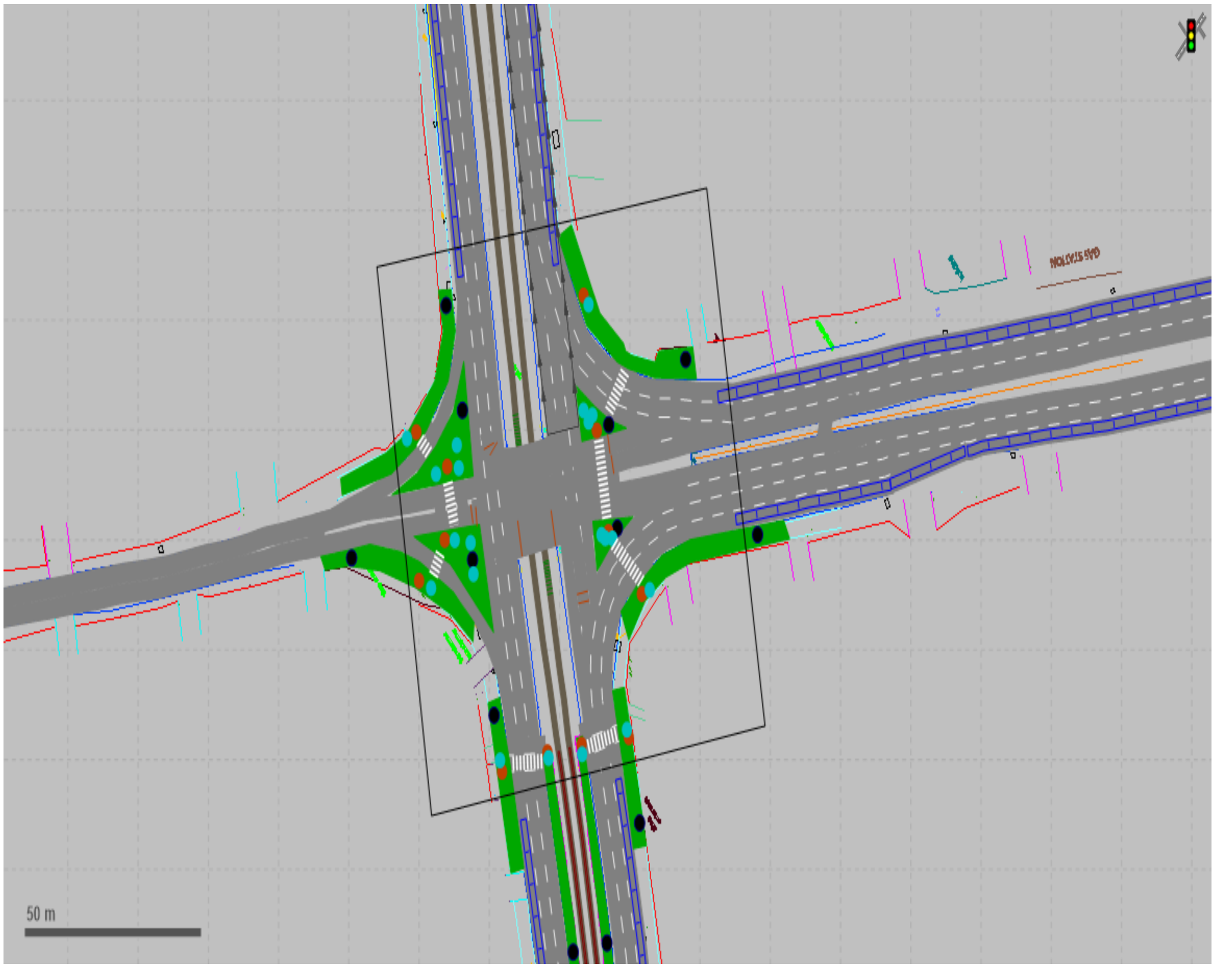

Figure 11: Model of the existing scenario

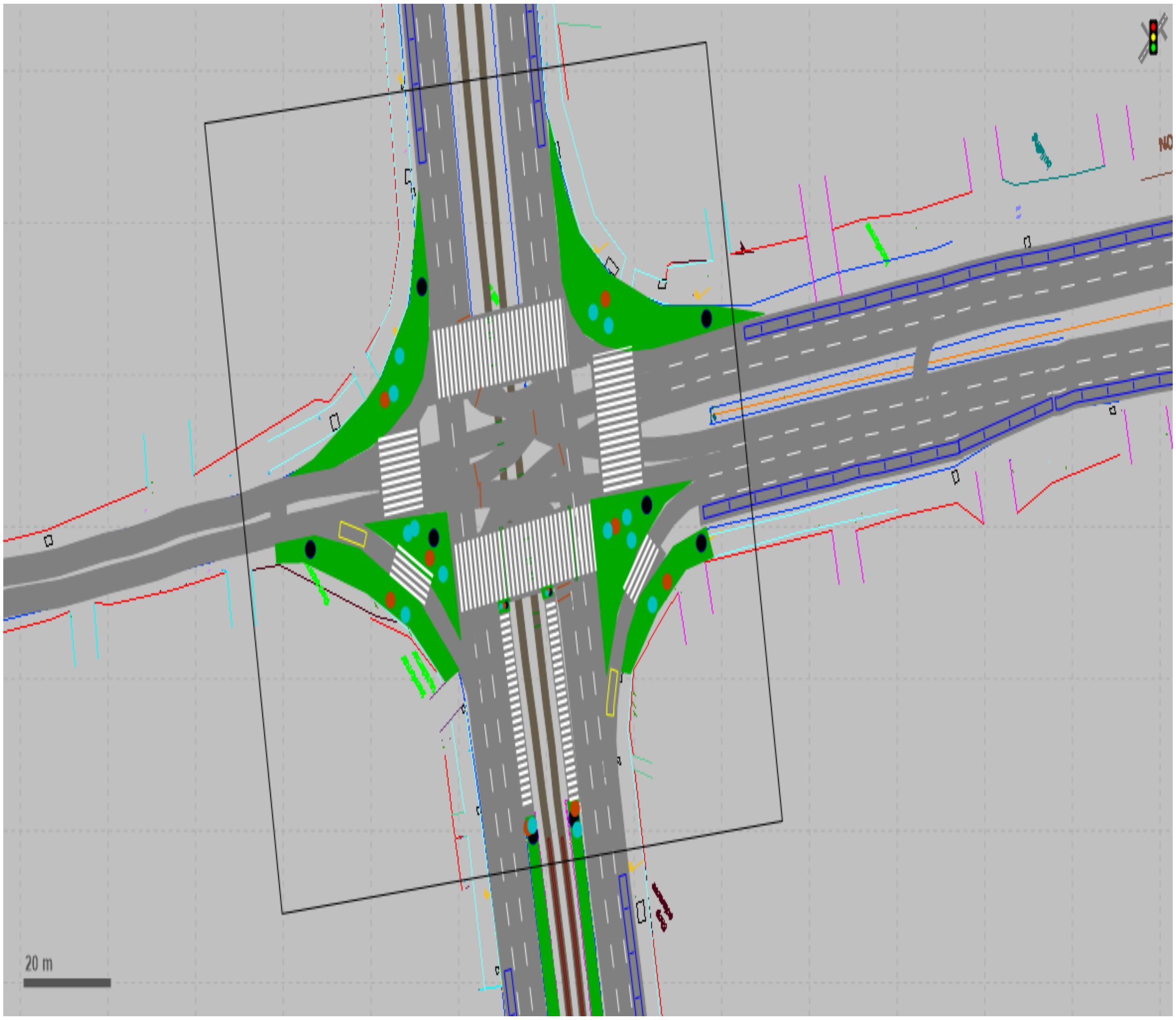

Figure 12: Model of test scenario 1

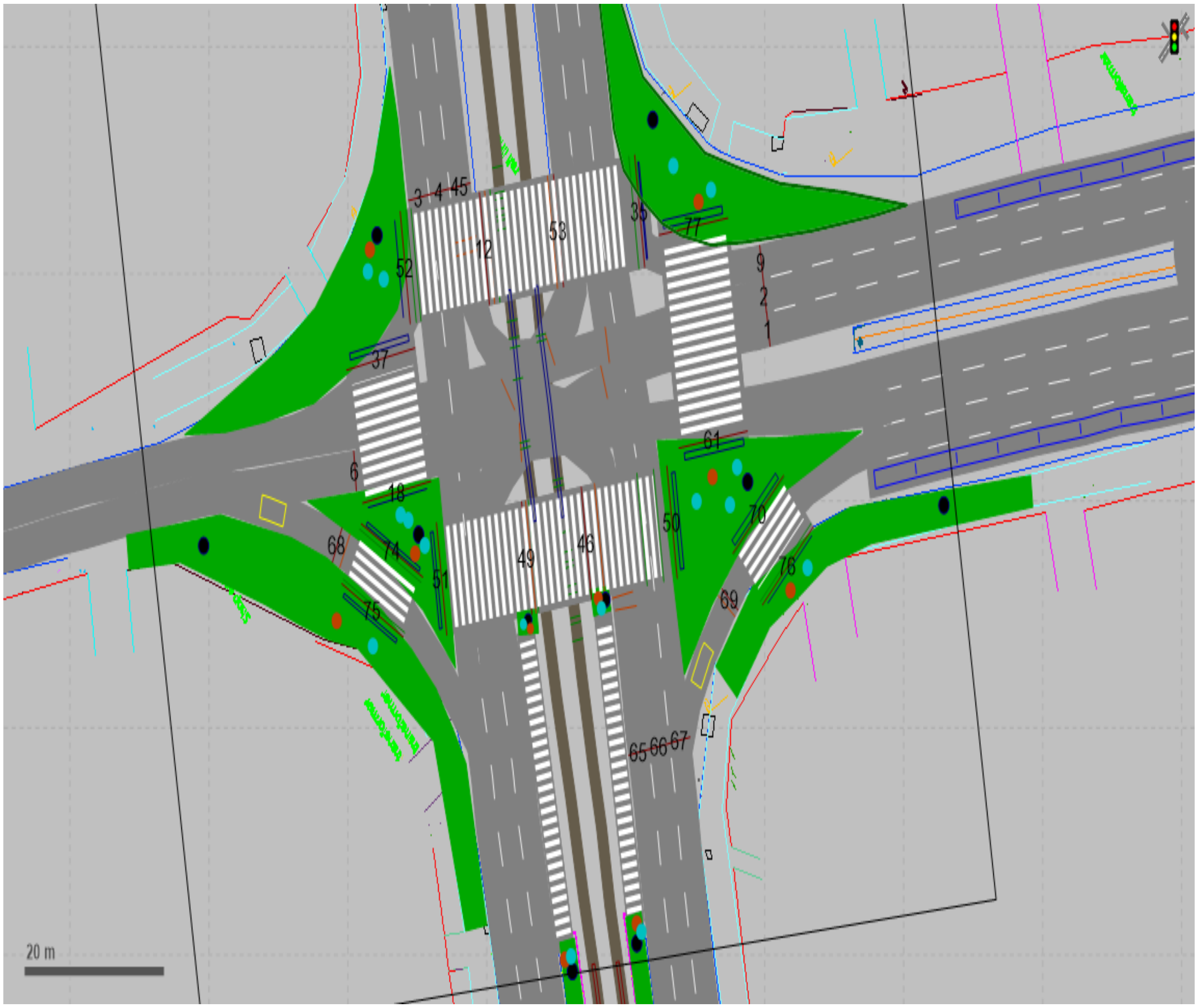

Figure 13: Model of test scenario 2

The model of test scenario 2 is a supplement to test scenario 1, by addition of coordinated signal control.

Table 10: Simulation results for existing, test scenario 1 and test scenario 2

Simulation Run	Existing Scenario				Test Scenario 1				Test Scenario 2			
	Queue Length, m	Queue Length Max, m	Vehicle Delay (All), s	Pedestrian Average Stop Time (All), s	Queue Length, m	Queue Length Max, m	Vehicle Delay (All), s	Pedestrian Average Stop Time (All), s	Queue Length, m	Queue Length Max, m	Vehicle Delay (All), s	Pedestrian Average Stop Time (All), s
1		261.68	53.89	0.01	25.4	174.85	22.66	0.03	85.21	345.13	172.64	0.04
2	50.78	198.08	41.04	0.02	11.27	124.32	17.64	0.02	82.12	297.11	144.08	0.04
3	68.21	190.15	62.63	0.01	30.94	246.67	11.25	0.04	102.42	343.03	178.04	0.04
4	67.62	269.62	57.62	0.01	12.15	122.92	20.7	0.02	98.85	304.8	176.16	0.04
5	61.11	238.05	40.14	0.01	18.88	147.78	21.34	0.02	76.26	303.75	171.84	0.04
6	75.36	302.47	63.46	0.01	24.26	188.44	11.53	0.02	93.02	345.16	182.25	0.04
7	57.62	192.42	35.07	0.01	49.66	311.82	9.08	0.06	92.3	286.3	161.7	0.04
8	64.06	196.28	54.12	0.01	26.82	192.46	13.38	0.03	97.7	302.58	191.08	0.04
9	67.43	211.28	64.13	0.01	48.24	318.96	6.59	0.05	77.4	343.04	155.26	0.04
10	62.1	213.97	33.07	0.01	8.68	112.2	10.57	0.02	99.31	307.66	168.3	0.04
Average	**64.66**	**227.4**	**50.52**	**0.01**	**25.63**	**194.04**	**14.47**	**0.03**	**90.46**	**317.85**	**170.13**	**0.04**
Minimum	50.78	190.15	33.07	0.00	8.68	112.2	6.59	0.01	76.26	286.3	144.08	0
Maximum	75.36	302.47	64.13	0.01	49.66	318.96	22.66	0.02	102.42	345.16	191.08	0.04

4.3.2.1Discussion of results from existing, test scenario 1 and test scenario 2

From Table 10 above, the first column represents a total of ten simulation runs that were considered for the simulation, each run within a time interval of 15 minutes. From the ten simulation runs, an average, minimum and maximum of queue length and delay values were generated for each scenario. The second and third column represents the average queue length and maximum queue length respectively. The fourth and fifth column represents the vehicle delay and pedestrian average stop time respectively. In order to obtain the evaluation results in Table 10 above, a node was drawn around the intersection area of the existing and test scenarios simulated using PTV Vissim. The vehicular delay results and queue length results were generated by the software for each movement within the node. The movements included turning movements from each of the approaches of the intersection area, including track lines movement. The pedestrian average stop time was generated by evaluation of the pedestrian network performance using Vissim and it represents the average number of stops per pedestrian.

The average delay of all vehicles in leaving a travel time measurement is obtained by subtracting the theoretical delay (ideal) travel time from actual travel time. The theoretical travel time is the travel time which could be achieved if there were no signal control or other reasons stopping. The actual travel time does not include any passenger service times of public transport vehicles at line stops and no parking in real parking lots.

Test scenario 1

The average results for queue length, vehicular delay and pedestrian average stop time shown in bold letters in Table 17 above were considered as the final evaluation results for this study and for purpose of comparison between the scenarios. Average values for queue length (m), maximum queue length (m), vehicle delay(s) and pedestrian average stop time (s), were 25.63, 194.04, 14 and 0.03 respectively for test scenario 1. The above values are lower than the queue length and delay values obtained under the existing scenario however, the pedestrian average stop time increased from 0.01 to 0.03s. The difference in the values was a result of the geometric adjustment of the intersection area as follows:

- The pedestrian crosswalk width was widened to 10 meters, from 3 meters to accommodate the high pedestrian volume, to improve their mobility in space and safety.

- The right turn lanes were reduced to one lane of 3 meters wide, thus reducing the crossing distance for pedestrians and increasing their safety.
- The number of conflict areas reduced from 120 in the existing scenario to 110 in test scenario 1
- The pedestrian crossing right opposite the station area was removed and a pedestrian passage of width 2.4 meters that links the pedestrians from the station area to the crosswalk adjacent to the level crossing was provided. This reduces vehicle stopping times and improves pedestrian safety because of reduced conflict areas.

Test scenario 2 (is a supplement to test scenario 1 by incorporation of coordinated signal control)

The average values for queue length (m), maximum queue length (m), vehicle delay(s) and pedestrian average stop time (s), for test scenario 2 are 90.46, 317.85, 170 and 0.04 respectively. The above values are higher than the queue length, delay values, and pedestrian average stop time obtained under the existing scenario and test scenario 1. The difference in the values is as a result of incorporating coordinated signal control to the intersection area for traffic management. There is also a reduction in the number of conflict areas from 120 in the existing scenario to 51 in test scenario 2. Providing signal control improves safety since pedestrians and vehicles have to wait for the green time before crossing, however, the delay and queue length results do not render this scenario a better option than test scenario 1. Moreover, the pedestrian average stop time increased from 0.01 in the existing scenario to 0.04 in test scenario 2. Thus, in terms of mobility and safety for pedestrians, test scenario 1 improves the current situation, while considering vehicular traffic in the area.

Comparison of the results with actual field observations

From the existing scenario, the queue length and delay values obtained correlates to the field condition since tram has priority at the level crossing. Thus, the maneuvers are balanced among the volume from the different approaches and pedestrian volume that uses the existing level crossing, which creates queue and congestion within the available time. The pedestrian average stop time in the existing scenario was lower than the test scenario 1 and 2 values. This is identical to the field observations since pedestrians try to find suitable gaps within vehicular traffic, from which they can cross at the expense of their safety. Providing sufficient exclusive pedestrian crosswalk at the upstream and the downstream of the existing level crossing; improves pedestrian safety and mobility, and traffic management thus, reduced queue length and delays.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This report examined the constraints to pedestrian mobility at a level crossing and the causes of safety-related incidents experienced by pedestrians at the level crossing. It aimed at improving pedestrian mobility at the level crossing by using Vissim multi-modal computer simulation software, to model and simulate the existing scenario along with two test scenarios; using delay, queue length, and pedestrian safety performance measures.

5.1 Conclusions

Based on the results from the condition survey by direct observation and literature review; constraints to pedestrians at Sebategna level crossing include; no coordinated signal control at the level crossing, crosswalks opposite the station platform entrance are not fully observed by vehicular traffic, some sidewalks are blocked by market vendors and congestion on the level crossing during peak hours which causes significant delays.

The causes of safety-related incidents experienced by pedestrians' cuts across pedestrians' behavior, driver behavior, pedestrians' infrastructure in place and its' utilization. Thus, harmonizing mobility for pedestrians at level crossing requires proper optimization and usage of the pedestrian and vehicular infrastructure in place. The pedestrians' need to be persistently aware of their responsibility while using the level crossing, to enhance their safety and there is a need for persistent enforcement of the traffic rules in place, for the system to be adaptable in the long run.

From the simulation results, test scenario 1 had reduction in the number of conflict areas from 120 to 110 and reduced queue length and delays time values for vehicular traffic from 64.66 m and 50.52 s to 25.63 m and 14.47 s respectively. Test scenario 2 had a reduction in 1 had reduction in the number of conflict areas from 120 to 51 and reduced queue length and delays time values for vehicular traffic from 64.66 m and 50.52 s to 90.46 m and 170.13 s respectively. The difference is with respect to hourly traffic. The difference in the values is expected to be higher considering daily traffic volume. Considering the benefits from each scenario and the aim of this study (improving pedestrian mobility and safety at LC), Scenario 2, that supplements

Scenario 1 with coordinated signal control would be a better option. However, from the time value perspective, test Scenario 1 would be a cheaper option to implement.

5.2 Recommendations

Improving the infrastructure geometry at a level crossing for pedestrians requires the coordination of the transportation department and railway authorities. The infrastructure adjustment and improvement plan need to be incorporated in the planning budget of the two authorities. There should be consistent enforcement laws and clear safety measures at the intersection area, to ensure the pedestrians use the designated pedestrian crosswalk areas. Pedestrian volume should be considered during the initial planning and upgrading of multi-modal shared level crossings.

5.2.1 Suggestions for future research

The following areas should be considered for future research.

- Further investigation into the impact of coordinated signal control on pedestrian mobility at level crossings should be done through modeling and simulation and using any suitable programming language that is compatible with the simulation software of choice. The outcome should consider the impact on pedestrian delay, vehicle delay, and queue length.
- A detailed economic analysis using BCA tool could be conducted on the alternatives and base scenario of this study.
- Effectiveness of the safety and mobility measures recommended for mitigating crash incidents at LCs.

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APPENDICES

Appendix A. Relative flow and vehicle compositions of the morning count

This Appendix shows the relative flow, vehicle composition and respective volumes of the morning count.

Table 11: Abnet approach relative flow and vehicle composition

Abnet Approach							
Right Turn							
	Car	Truck	Bus	Minibus	LRT	Two wheelers	
	16	8	10	17	0	0	
	26	6	12	17	0	0	
	23	5	17	27	0	0	
	24	2	18	35	0	0	
	89	**21**	**57**	**96**	**0**	**0**	**263**
Relative flow	**0.3384**	**0.07985**	**0.21673**	**0.36502**	**0**	**0**	
Through movement							
	Car	Truck	Bus	Mini-bus	LRT	Two wheelers	
	39	13	2	36	1	1	
	42	7	3	41	1	0	
	40	13	4	50	1	2	
	53	10	4	45	1	3	
	174	**43**	**13**	**172**	**4**	**6**	**412**
Relative flow	**0.42233**	**0.10437**	**0.03155**	**0.41748**	**0**	**0**	
Left Turn							
	Car	Truck	Bus	Mini-bus	LRT	Two wheelers	
	17	5	1	15	0	0	
	10	3	4	13	0	0	
	16	6	4	14	0	0	
	16	6	4	14	0	0	
	59	**20**	**13**	**56**	**0**	**0**	**148**
Relative flow	**0.39865**	**0.13514**	**0.08784**	**0.37838**	**0**	**0**	
U-Turn							
	Car	Truck	Bus	Mini-bus	LRT	Two wheelers	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	**0**	**0**	**0**	**0**	**0**	**0**

Abnet Approach							
Relative flow	0	0	0	0	0	0	
Total flow per composition per approach	322	84	83	324	4	6	823

Table 12: Merkato approach relative flow and vehicle composition

Merkato Approach							
Right Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	7	2	0	6	0	2	
	3	1	3	6	0	0	
	5	3	3	7	0	2	
	7	3	6	5	0	1	
	22	**9**	**12**	**24**	**0**	**5**	**72**
Relative flow	**0.305556**	**0.125**	**0.166667**	**0.333333**	**0**	**0**	
Through Movement							
	Car	Truck	Bus		LRT	Two wheelers	
	5	0	0	7	0	0	
	1	1	0	5	0	0	
	5	4	1	5	0	1	
	1	1	1	7	0	0	
	12	**6**	**2**	**24**	**0**	**1**	**45**
Relative flow	**0.266667**	**0.133333**	**0.044444**	**0.533333**	**0**	**0**	
Left Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	11	2	8	16	0	0	
	7	3	6	17	0	0	
	18	2	11	22	0	0	
	12	4	3	25	0	0	
	48	**11**	**28**	**80**	**0**	**0**	**167**
Relative flow	**0.287425**	**0.065868**	**0.167665**	**0.479042**	**0**	**0**	
U-Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	**0**	**0**	**0**	**0**	**0**	**0**

Merkato Approach							
Relative flow	**0**	**0**	**0**	**0**	**0**	**0**	
Total per composition per approach	**82**	**26**	**42**	**128**	**0**	**6**	**284**

Table 13: Amanuel approach relative flow and vehicle composition

Amanuel Approach							
Right Turn							
	Car	**Truck**	**Bus**		**LRT**	**Two wheelers**	
	10	2	0	19	0	0	
	5	2	0	15	0	1	
	6	1	0	7	0	3	
	10	1	1	12	0	1	
	31	**6**	**1**	**53**	**0**	**5**	**96**
Relative flow	**0.322917**	**0.0625**	**0.010**	**0.552**	**0**	**0**	
Through Movement							
	Car	Truck	Bus		LRT		
	8	5	0	14	0		
	6	1	0	13	0		
	4	1	0	7	0		
	7	3	0	14	0		
	25	**10**	**0**	**48**	**0**		**83**
Relative flow	**0.301205**	**0.120482**	**0.000**	**0.578**	**0**		
Left Turn							
	Car	**Truck**	**Bus**		**LRT**		
	6	1	0	5	0		
	4	0	0	8	0		
	7	2	0	7	0		
	6	1	0	6	0		
	23	**4**	**0**	**26**	**0**		**53**
Relative flow	**0.433962**	**0.075472**	**0.000**	**0.491**	**0**		
U-Turn							
	Car	**Truck**	**Bus**		**LRT**		
	0	0	0	0	0		
	0	0	0	0	0		
	0	0	0	0	0		
	0	0	0	0	0		
	0	**0**	**0**	**0**	**0**		**0**
Relative flow	**0**	**0**	**0.000**	**0.000**	**0**		

Amanuel Approach							
Total per composition per approach	79	20	1	127	0	5	232

Table 14: Autobus-Tera approach relative flow and vehicle composition

Autobus-Tera Approach							
Right Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	3	0	3	2	0	0	
	3	0	0	2	0	2	
	1	2	0	2	0	1	
	0	0	0	0	0	0	
	7	**2**	**3**	**6**	**0**	**3**	**21**
Relative flow	**0.333333**	**0.095238**	**0.143**	**0.286**	**0**	**0**	
Through Movement							
	Car	Truck	Bus		LRT	Two wheelers	
	57	20	13	65	1	1	
	44	9	9	53	1	2	
	50	7	7	48	0	0	
	80	22	8	64	2	4	
	231	**58**	**37**	**230**	**4**	**7**	**567**
Relative flow	**0.407407**	**0.102293**	**0.065256**	**0.405644**	**0**	**0**	
Left Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	13	5	1	18	0	0	
	19	6	0	22	0	0	
	12	2	2	15	0	0	
	13	6	1	13	0	0	
	57	**19**	**4**	**68**	**0**	**0**	**148**
Relative flow	**0.385135**	**0.128378**	**0.027027**	**0.459459**	**0**	**0**	
U-Turn							
	Car	Truck	Bus		LRT	Two wheelers	
	0	0	0	0	0	0	
	0	0	0	0	0	0	
	0	0	0	0	0	0	

Autobus-Tera Approach							
	0	0	0	0	0	0	
	0	**0**	**0**	**0**	**0**	**0**	**0**
Relative flow	0	0	0	0	0	0	
Total per composition per approach	**295**	**79**	**44**	**304**	**4**	**10**	**736**

Appendix B. VisVAP flowchart used to generate VAP logic file

This Appendix shows the VisVAP flowchart that was used to generate the VAP logic file.

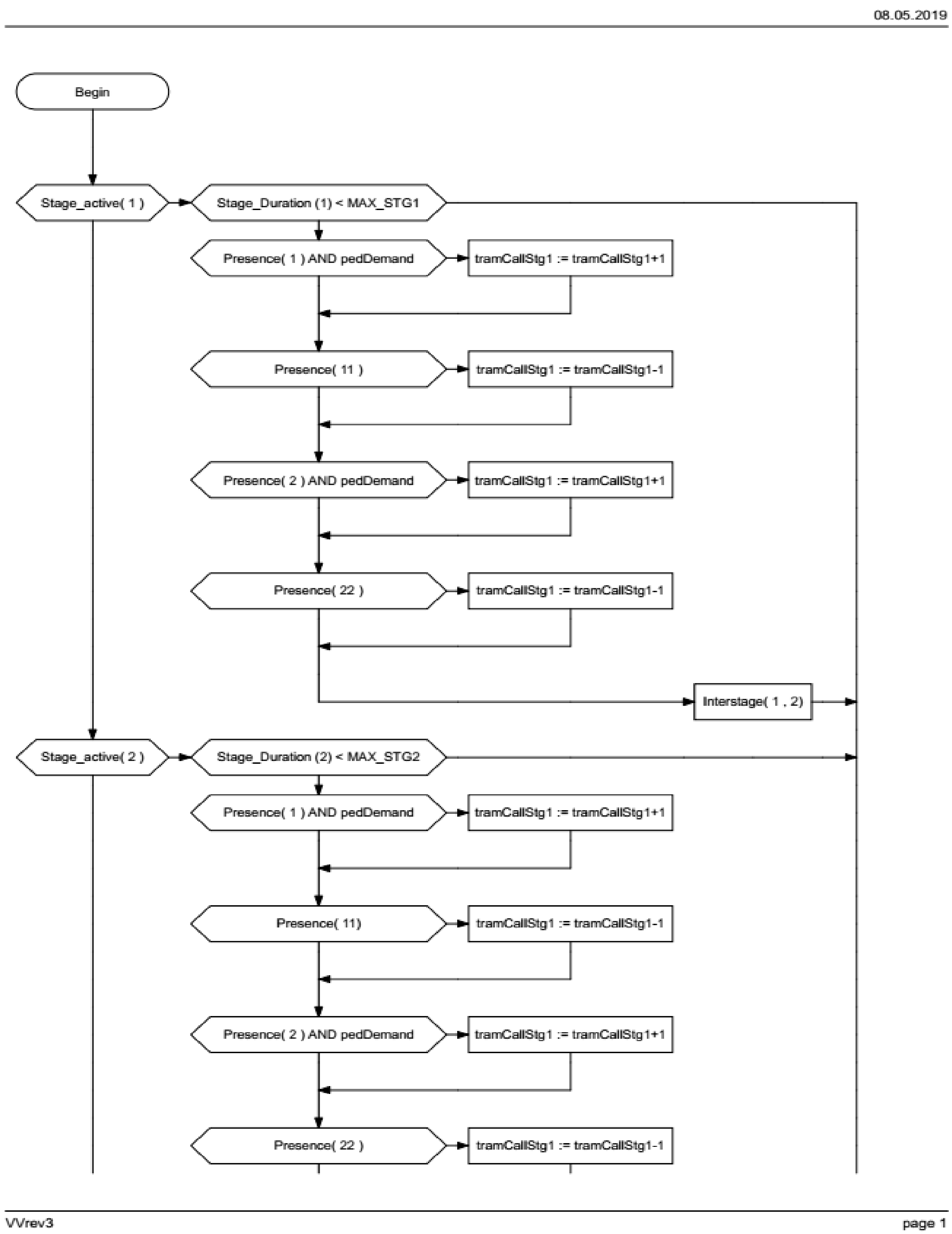

Figure 14: VisVAP flowchart

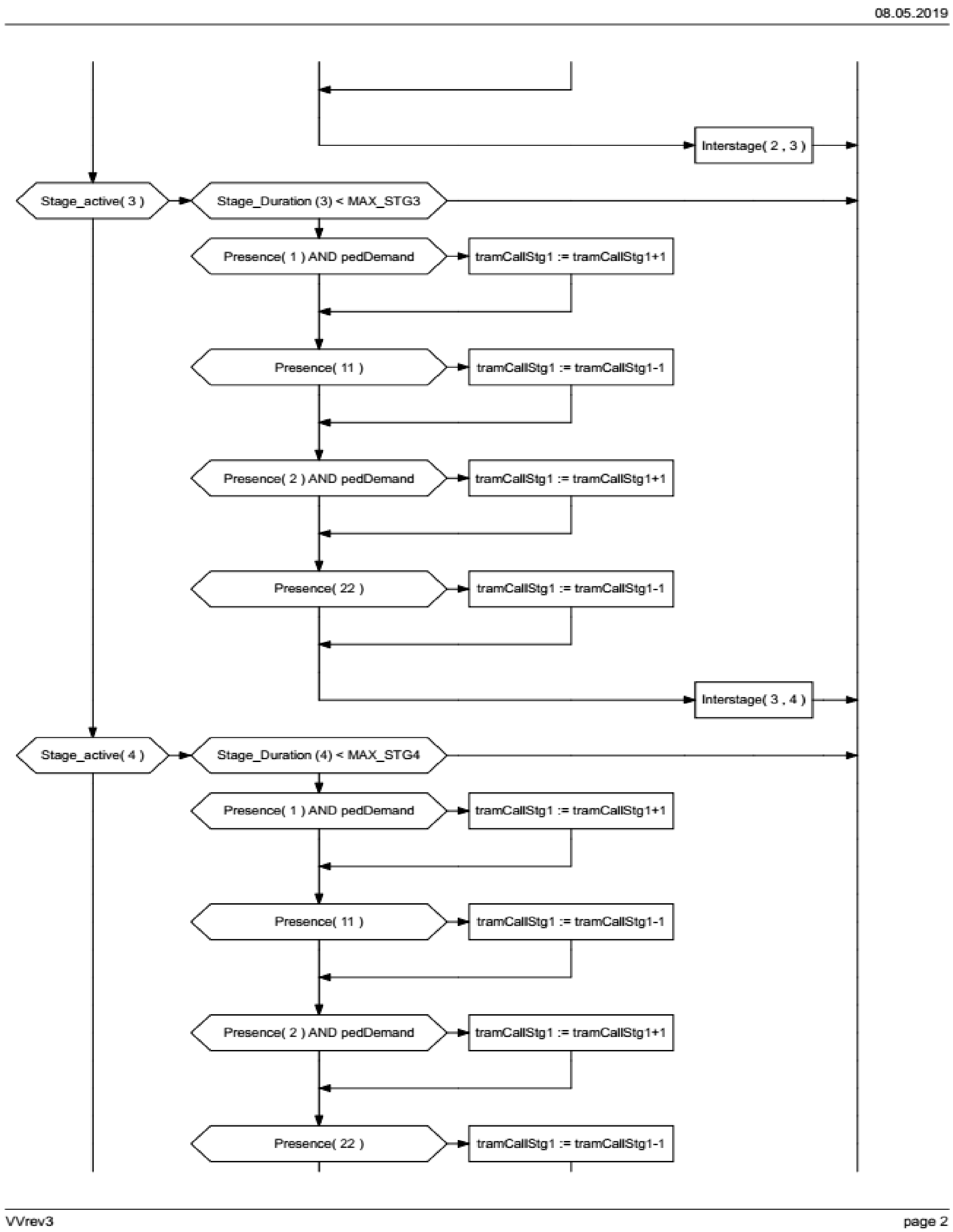

Figure 15: VisVAP flowchart

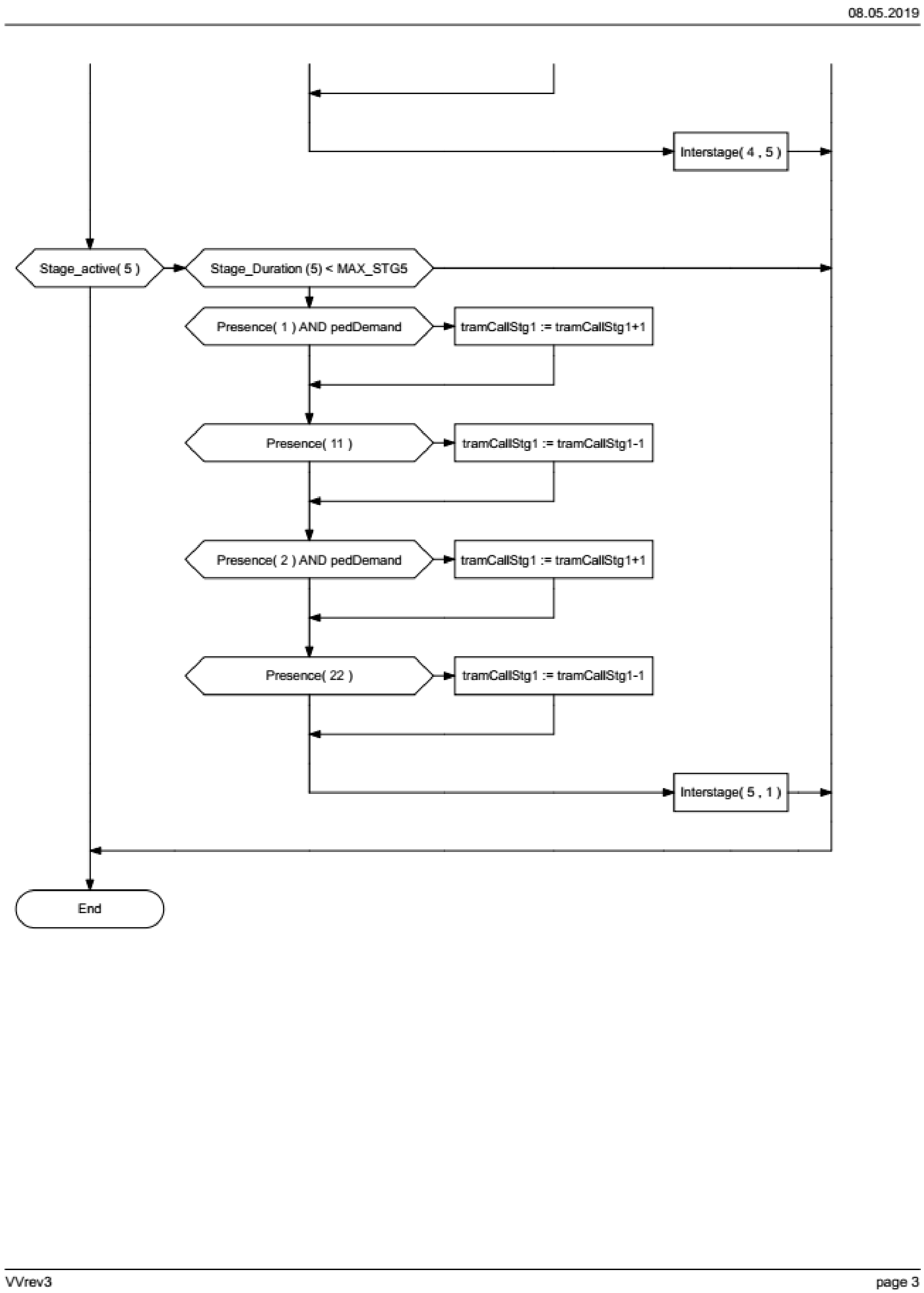

Figure 16: VisVAP flowchart