ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

A COMPREHENSIVE THROUGH LANE SATURATION FLOW RATE MODEL FOR SIGNALIZED INTERSECTION BY CONSIDERING ILLEGAL CROSSING PEDESTRIAN EFFECT AT SELECTED INTERSECTIONS IN ADDIS ABABA

A Thesis in Road and Transport Engineering

By Ephrem Bogale

June, 2025

Addis Ababa Ethiopia

A Thesis Submitted in Partial Fulfillment of the Requirements for Degree of Master of Science in Civil and Environmental Engineering

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

A comprehensive through lane saturation flow rate model for signalized intersection by considering illegal crossing pedestrian effect at selected intersections in Addis Ababa

By Ephrem Bogale

A research thesis submitted to the school of graduate studies of Addis Ababa university institute of technology school of civil and environmental engineering in partial fulfillment of the requirements for the degree of masters in road and transport engineering

Approved by Board of Examiners

Dr. Yonas Minalu Emagnu		
Advisor	signature	Date
Dr. Fitsum Teklu		26/06/2025
Internal examiner	Signature	Date
Emnete Tadesse (Mrs)		26/06/2025
External examiner	Signature	Date
Dr.Ing. Tensay Gebremedhin		27/06/25
Chairman person	Signature	Date

Declaration

I at this moment declare that this research titled "A comprehensive through lane saturation flow rate model for signalized intersection by considering illegal crossing pedestrian effect at selected intersections in Addis Ababa" is my own original work completed under the supervision of Dr. Yonas Minalu Emagnu. The work has not been submitted for a degree at this or any other university, and all sources of materials used in the thesis were fully acknowledged.

Name: Ephrem Bogale Mamo

Signature:

Place: Addis Ababa Institute of Technology

Addis Ababa University,

Addis Ababa

Ethiopia

Date: June, 2025

Acknowledgement

Above all, I would like to thank the Almighty God for keeping me well and helping me finish my thesis. The second is my advisor, Dr. Yonas Minalu Emagnu, who helped me with my thesis work from start to finish without feeling of tiredness. I should give credit to the road and transport engineering department of the Addis Ababa University School of Civil and Environmental Engineering for enabling me to complete my thesis for my master's degree. Third, I want to express my gratitude to my family for their unwavering encouragement and support of my success. Finally, I thank all the organizations that cooperate with me to get data from their workers and offices especially traffic management agency and Addis Ababa city road authority.

Abstract

One significant element influencing urban traffic performance networks is signalized intersections. It can guarantee safe and efficient traffic flow through the crossings and optimize their capacity.

Researchers have been examining signalized junction capacities for a long time. However, the pedestrian effect has not been well studied. Two perspectives are used to analyze the effects of pedestrians: 1) Traffic flow is disrupted by pedestrians; 2) Speed and saturation flow rate are reduced as a result of pedestrian interference.

One of the crucial aspects of analyzing the capacity of signalized junctions that is influenced by several circumstances is saturation flow rate.

Geometric conditions, traffic conditions, driver conduct, traffic light timing, gradient direction, number of lanes, lane width, volume and kind of turning actions, and pedestrian movement are some of the effective aspects that HCM identifies as determining saturation flow.

Walking is a popular form of transportation in Addis Ababa, and people who cross the street when green traffic light is on have an impact on traffic flow.

We chose five Addis Ababa signalized crossings to examine how pedestrians affect signal capacity. St. Estifanos, Banko de Roma, Ayer Tena, Jemo Michael, and Saris Abo. Their current functional status, being four-legged, high pedestrian flow, High traffic volume, least interference to entry and exit traffic due to parking activities were the criteria for their selection.

Video graphic method was used to gather pedestrian and traffic data from the field. The hours of 8:00 AM to 9:00 AM and 3:00 PM to 4:00 PM were used to gather traffic data.

To develop a suitable saturation flow equation for estimating capacity and designing traffic infrastructure for heterogeneous traffic, the heterogeneous traffic must be transformed into homogeneous using a common unit, called the PCU.

The dynamic PCUs have been computed in this study, which takes vehicle size and speed into account as key variables for PCU component estimation. The Method adopted in this thesis work

to generate a model equation to calculate PCU is Speed-Area method which is developed by Dr. Satish Chandra, according to Chandra's method (1)

This study presents a saturation flow rate analysis of selected Addis Ababa's signalized crossings under mixed traffic situations. In order to collect information on traffic volume and speed on city roads, a video graphic technique was used to determine the saturation flow.

The headway which is the amount of time that passes between successive cars crossing the stop line had calculated and then 3600 divided by this headway to get the saturation flow rate.

Measurements of saturation flow rates generally show 2.47% - 29.53% lower values than those currently used in the Highway Capacity Manual. The saturation flow rates at the local crossings will be overstated if HCM's suggested value is implemented in study intersections; the presence of pedestrians didn't show significance in through lane saturation flow rate. A general model for the saturation flow rate analysis should have been created in the spot while we design and maintain an intersection in Addis Ababa.

.

TABLE OF Contents

List of figures

List of tables

List of abbreviation

HCM – Highway Capacity Manual

PVI --- Pedestrian-vehicle interactions

PCU – Passenger Car Unit

PCE – Passenger Car Equivalent

SPSS – Statistical Package for Social Science software

ANOVA – Analysis of Variance

USA – United States of America

UAE – United Arab Emirates

PHV – Pick Hour Volume

SFR – Saturation Flow Rate

CBD – Central Business District

HGV – Heavy Good Vehicles

HT – Heavy Truck

MT – Medium Truck

LOS – Level of Service

MAPE – Mean Absolute Percentage Error

ERA --- Ethiopian Road Authority

AACRA --- Addis Ababa City Road Authority

1. Introduction

1.1 Background

Signalized intersections are important factors that affect how well urban traffic networks function, it is important to make the most of them by timing traffic signals so that they can maximize their capacity and guarantee safe and efficient traffic flow (2).

The HCM defines capacity as the maximum quantity of vehicles that can traverse the crossing in green period while traffic, road conditions, and signalization are in effect.

For many years, researchers have been studying the capacities of signalized junctions. Few studies have been conducted on the pedestrian effect, though. The consequences of pedestrians are examined from two angles: 1) Pedestrians disrupt traffic flow; 2) Pedestrian interference causes the speed and saturation flow rate to drop. Findings demonstrated that vehicle delay was significantly impacted by pedestrian-vehicle interaction (3).

The saturation flow is the maximum number of vehicles that can pass through a particular lane group under the existing traffic, road, and control conditions (4). It is one of the crucial aspects of analyzing the capacity of signalized junctions that is influenced by several circumstances. (5,6).

Because of the existing traffic volumes and inadequate traffic management techniques, signalized intersections are the most significant and frequently experienced bottleneck places in Addis Ababa. The quick increase in vehicle traffic has led to a rise in the number of collisions between cars and pedestrians. Variations in pedestrian, vehicle, and roadway geometry factors affect how severe these encounters are.

When analyzing the capacity of signalized junctions, saturation flow rate is a crucial factor that depends on a number of factors. Pedestrian crossings are one of the factors that influence how vehicles move through a signalized intersection. Given their size and influence, pedestrians may have a more significant role in determining the saturation flow rate and intersection capacity, particularly at crossroads situated in city centers or other traffic regions (5) and the effect of pedestrians on the performance measures of signalized intersections is a considerable element (7).

Saturation flow rate is a crucial part of the performance analysis of signalized crossings since it is used to determine junction capacity, delays, level of service, and signal timing. A saturated approach lane's expected average discharge flow during its green time, the maximum discharge flow from an approach lane that can be observed during its effective green time, the number of vehicles that can discharge from an approach lane during an uninterrupted one-hour green phase, etc. are some definitions given by various studies (8).

Generally, it is defined as the comparable hourly rate at which cars in a prior line can cross an intersection approach, provided that the green signal is always accessible and there are no lost hours (9). It is the maximum discharge rate during green time, which is the maximum volume in passenger car units per hour (PCU/h) that can cross the approach lane stop line at a green light when there is a line of cars at the vehicle lane. It is expressed as an expected average hourly rate in units of vehicles per hour per lane (10).

When a pedestrian crosses a road in a manner that is against the law, it is referred to as illegal pedestrian crossing. It is mandatory for pedestrians to utilize authorized crosswalks and walk signals that specify when they are permitted to cross. A pedestrian may receive a citation for illegal if they cross the roadway without utilizing the crosswalk or if they fail to precisely obey the signals. Pedestrian-vehicle interactions (PVIs) can occur in many situations, including at intersections, mid-block crossings, and when pedestrians walk in or cross a roadway with an act contravenes traffic regulations. A study done on Analysis on Illegal Crossing Behavior of Pedestrians at Signalized Intersections Based on Bayesian Network states that about 17 pedestrians on average cross at a red light every signal cycle, with a proportion of 11.5%, and pedestrian standing on crosswalks during red lights accounts for 3.5%.

Numerous earlier studies have demonstrated that pedestrian traffic has a major impact on vehicle flow, particularly operating speed. The volume of pedestrians and the separation between pedestrians and cars are the primary determinants of the impact level. In China, pedestrians frequently cross at signalized junctions, affecting vehicle movement during a protected phase. This is a particular issue in many growing or developing nations (3).

Although only a portion of the influence factors are examined in the paper, a study conducted in China revealed that the results obtained may differ from the HCM due to cultural and driving differences, and it suggests that a more thorough investigation be carried out using the data gathered there (13)

Because developed and developing nations have various traffic cultures, the parameters influencing saturation flow value varies as well. Heterogeneous traffic is less well-suited for methodologies designed for homogenous traffic situations. Estimating saturation flow for mixed traffic is difficult because of the wide range of vehicles with varying attributes and their poor lane discipline (11).

1.2 Statement of the problem

In different nations, intersections which are crucial components and the main locations of congestion in metropolitan roadway networks may perform differently. This is mostly because different countries may have different driving habits, car attributes, control systems, and environmental elements that affect their performance (12).

According to the examined literature, the identified impacts on saturation flow are divided into four categories: environmental, operational, traffic intrinsic, and infrastructure (8).

Various researchers use highway capacity manual (HCM) without making any adjustments. It identifies the effective factors that determine saturation flow, such as geometric conditions, traffic conditions, drivers' behavior, traffic light timing, gradient direction, number of lanes, lane width, volume and type of turning movements, and pedestrian movement. Highway Capacity Manual (HCM) mostly suggest saturation flow rate for homogenous situations and has little capacity to handle heterogeneity (13).

However it recommends that saturation flows are assessed in each country and city according to their own local conditions (9). Additionally, a Chinese study demonstrates that the Highway Capacity Manual (HCM) process and related research were based on ideal conditions and were not appropriate in situations with mixed traffic (14).

In our country also there is a use of other countries model or HCM default value without adjusting for those factors since there is no research done for the standard saturation flow rate in Ethiopia (15). We must therefore ascertain the percentage influence of illegal pedestrians on saturation flow in order to account for the impact of illegal pedestrian crossings based on our circumstances, since research indicates that 60% of our city's modal share and 70% of all journeys are made on foot. Furthermore, more individuals are spending time on roadways and crossing them to access their properties that contribute to illegal pedestrian crossings (16).

In this study we develop a model for saturation flow rate that fulfill the local condition and it results in replacing the HCM ideal value that slightly deviation from the reality.

1.3 Research question

What should be the model for saturation flow rate in pedestrian movement, and how much is the percentage discrepancy of saturation flow rate between the real ground level and the HCM default value considering illegal pedestrians.

1.4 Significance of the study

Many studies have been done to determine how various variable types affect signalized intersection capacity. The primary focus of this review will be on how pedestrian movement interactions affect signalized intersection capacity and to develop a model that has been used to measure saturation traffic.

In addition to improving the planning and design of signalized intersections and pedestrian crossings, the current research will be useful in estimating realistic saturation flow values in the selected Addis Ababa's intersections where high pedestrian flows and crossing behavior compliance with pedestrian regulation are observed (16) The model will be essential for determining how pedestrians affect signals and for helping to plan new crossings or alter existing ones.

1.5 Objective

1.5.1 General objective

To measure the impact of illegal pedestrian crossing on through lane saturation flow rate during traffic green time on selected intersections in Addis Ababa.

1.5.2 Specific objective

- Model through lane saturation flow rate considering the impact of illegal pedestrians.
- Comparing saturation flow values obtained in field with HCM

1.6 Conceptual frame work

Figure 1 shows the research frame work of this study. Firstly, data collection was done with two approaches. A primary data like number of vehicles and pedestrian, width of lane, signal timing, road gradient, and number of lanes are collected with the investigator directly from the field using video camera measuring tape and observation. Secondary data like number of signalized intersections with their functional status are gained from Traffic Management Authority. Secondly data analysis and modeling were done by IBM SPSS Software and then comparison between the developed model and Highway capacity manual was done. At the last discussion and conclusion had done.

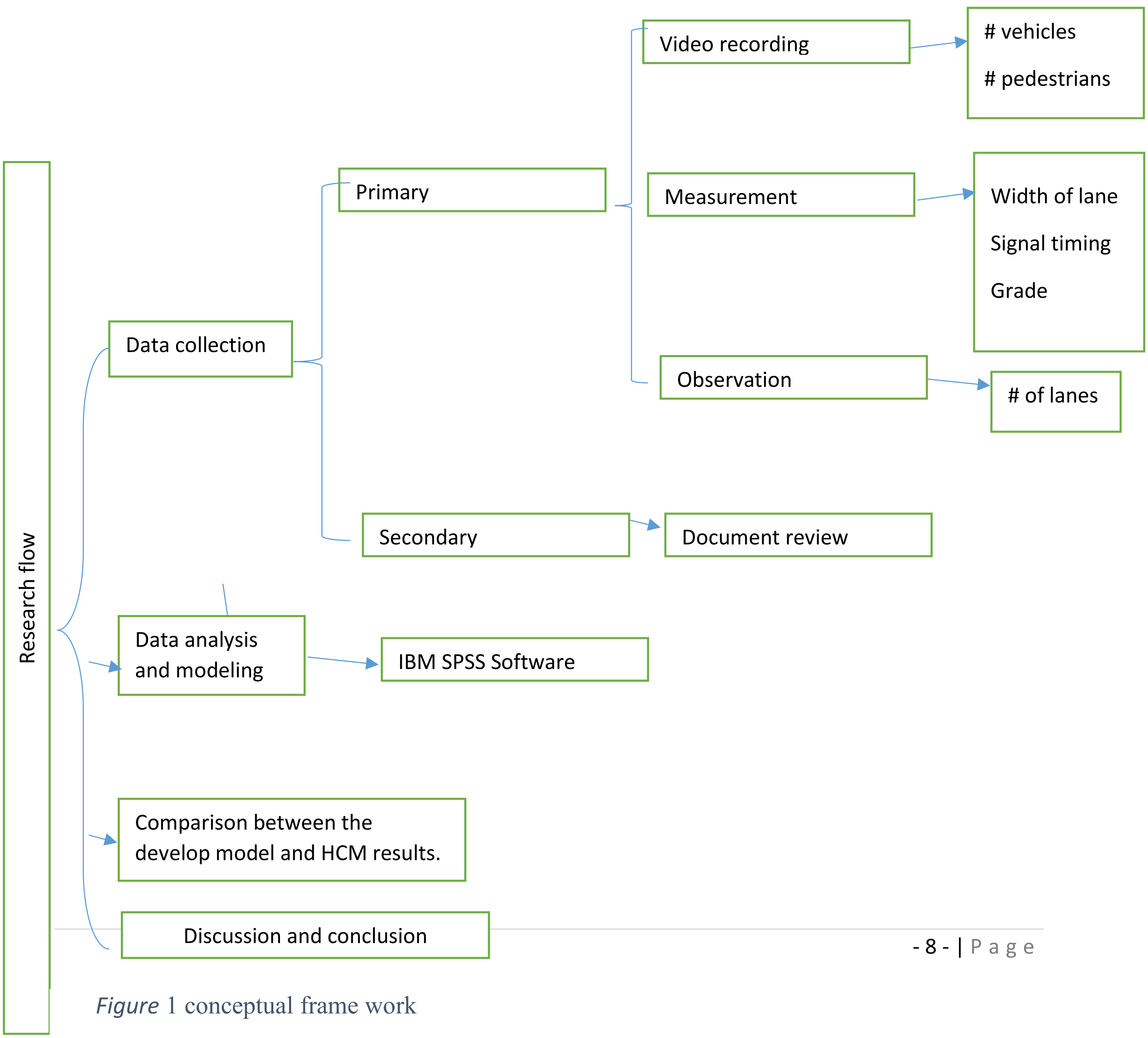

Figure 1 conceptual frame work

1.7 research hypothesis

Ho = There is no difference in saturation flow rate at signalized intersection with influence of pedestrians

HA= There is a difference in saturation flow rate at signalized intersection with influence of pedestrians

1.8 organization of the Thesis

There are six chapters in this thesis. Background, problem statement, research question, study importance, general and particular objectives, idea framework, and research hypothesis comprise the introduction, which is included in Chapter 1 of the thesis.

The literature review and other studies on the topic are discussed in Chapter 2. The methodology section, which is covered in Chapter 3 of the thesis work, includes the study area, variables, sample size and sampling techniques, and procedures for data collection and analysis.

Results are presented in Chapter 4, in this chapter PCU was computed, saturation headway was established, and a saturation flow rate model was created.

Chapter five of the study include the discussion part and on the last chapter, Chapter six, the researcher tried to conclude the study and recommend the respective bodies.

2. Literature review

The maximum number of cars that would cross the stop line of an approach lane if the signal stayed green at all times is known as saturation flow, and it is estimated in terms of vehicles per hour of green time. The vehicular composition of the traffic stream determines the saturation flow rate at signalized intersections in developing countries, where traffic flow is highly heterogeneous (17).

The conventional western formulas for estimating saturation flow and PCU factor values are inappropriate for emerging nations like Ethiopia because of these basic distinctions, drivers and pedestrian behavior, and hetrogenousity of traffic movement.

Data collection techniques used to determine saturation flow rate may not be able to handle the wide range of vehicle types or "uncontrolled" activity that characterizes traffic behavior in developing countries because traffic conditions there are frequently somewhat different from those in industrialized ones. Furthermore, a lot of the conventional methods depend on advanced traffic counters or data loggers, which could be too expensive to employ in underdeveloped nations (18).

For analysis, the Highway Capacity Manual and other publications make the assumption that traffic is uniform and lane-based, which is the case in developed nations. Even during the saturated portion of the green phase, there is noticeable lateral movement at junctions, and cars frequently use lateral gaps to get to the front of the line and pass.

One of the most important factors affecting the design and signal plan of the signalized intersection is the saturation flow, which plays a major role in determining the level of service (LOS) and capacity of a signalized intersection. If the saturation flow rate can be computed with enough accuracy, the capacity of the signalized intersection can be evaluated (19).

The standard western relationships for predicting saturation flow and PCU factor values are inappropriate for developing countries. In these countries, road traffic is extremely heterogeneous, with vehicles sharing the same road space without any segregation and varying greatly in their static and dynamic characteristics. (19).

There are two methods for determining the saturation flow needed to determine a signalized intersection's capacity. To quantify saturation flows at an intersection the first method is field research. The observed saturation flows in this method depict the intersection capacity under the current circumstances, and capacity-influencing elements are empirically added.

Using ideal base saturation flow values is the second method of approaching the problem. These baseline values can be modified to take into consideration the crossings' operational and physical characteristics, as well as the methods being examined and applied in intersection capacity assessments (20).

Under ideal traffic, geometry, and highway conditions all of which may not always be present the HCM suggests an ideal saturation flow rate. It has been a worldwide resource for traffic and transportation engineering practitioners and students, and it has been the basis for specialized capacity manuals in numerous nations. Notwithstanding the importance of saturation flow rate, most government agencies use the HCM's recommended ideal value during constructing and evaluating signalized crossings. If the ideal value is applied, the capacity of signalized crossings could be overstated or underestimated (2).

In developing nations, traffic conditions are frequently different. The following things have an impact on the difference: Roadside activity: activities that restrict the effective road width, such as parking and non-transport land-use; vehicle mix: an extensive range of motorized and non-powered vehicles with varying operational capabilities; driver conduct: disregard for road laws and inadequate lane discipline; public transportation: a diverse range of bus models, locations for stops, and driving techniques; (21).

Generally, procedures for estimating signalized intersection capacity are based on the use of ideal maximum traffic flow rate (saturation flow) that is adjusted to reflect site-specific conditions that may not be ideal. But regardless of the precise method used in signalized intersection capacity analyses, saturation flow is used as the base flow rate, and various capacity influencing factors are then used to modify this base flow value to reflect prevailing conditions (22).

The predicted average flow rate for a through-traffic lane with geometry and traffic circumstances that correspond to a value of 1.0 is the base saturation flow rate for each adjustment factor. To cover all signalized junctions in the jurisdiction where the intersection in issue is located, a single base rate is typically chosen. The default values that HCM provides for metro areas with 25,000 or more inhabitants are 1900 pc/h/ln (9).

Lane width, heavy vehicles in the traffic stream, approach grade, presence of a parking lane and parking activity adjacent to lane group, blocking effect of local buses that stop within intersection area, area type, lane utilization, left-turn vehicle presence in a lane group, right-turn vehicle presence in a lane group, pedestrian for left-turn groups, and pedestrian for right-turn groups are the 11 factors that the HCM considers to exist that affect saturation flow estimates (23).

1. Lane width (ft.)

One of the most important factors in estimating saturation flow is lane width. According to the majority of research, saturation flow rises as lane width increases (4). It is evident that other factors also influence the saturation flow rate because the variation of SFR values for different approach widths does not follow the general pattern that an increase in approach width results in an increase in SFR values (24).

The lane width adjustment factor (fw) permits a higher flow rate on broad lanes while taking into consideration the detrimental effect of tight lanes on saturation flow rate. Normal lanes have a width of 12 feet. For lane widths larger than 16 feet, the lane width factor should be utilized cautiously. Alternatively, an analysis with two narrow lanes could be carried out. A single broad lane will always have a lower saturation flow rate than two narrow lanes combined, but in both situations, the analysis should take into account how the width is presently or is anticipated to be used. This factor should never be used to calculate the saturation flow rate of a group of lanes whose average lane width is less than 8.0 ft.(9)

Saturation flow increases with the size of the approach road. However, the relationship between approach width and saturation flow is not quite linear. It displays the overall effect of the lane-disciplined behavior. When there is no lane discipline, every car tries to use all available area. It results in more effective vehicle movement, so more discharge happens per unit width of the approach as the approach width grows and individual vehicle freedom improves (25).

with an increase in the width of each lane from 2.5 to 4 meters, the saturation flow rate of that lane would be increased nonlinearly (12). When comparing the survey results with the baseline condition surveys, Zegeer et al. examined the saturation flow rate under various conditions with a lane width of 2.6 to 4.7 m (8.5 to 15.5 ft). The narrower lane widths showed saturation flow rates that were 2% to 5% lower than those in the baseline surveys, while the wider lane widths showed saturation flow rates that were 5% higher. (23).

According to various studies, the value of the passenger car unit rises as the carriageway's width increases because, under wider carriageways, all vehicles travel at their normal or maximum speed because the road is wider. This causes the speed difference to widen, which raises the passenger car unit's value (1).

A study by Shao et al. (2011) found that the saturation flow rate increased with lane width, while a study by Potts et al. (2007) found that the saturation flow has insignificant change up to 9 m of road width and that there was a noticeable discrepancy between the calculated and observed saturation flow values as the road width increased beyond 9 m (4).

2. *Number of lanes*

Through movement approaches, the saturation flow rate (SFR) rises by around 4.3% in three-lane traffic compared to two-lane traffic, and it rises by 25% for every extra through lane (4).

Saturation flow data for 2901 signal cycles is measured by McMahon et al. On three-lane approaches, they discovered that the saturation flow rate of through movements was 1910 pc/h/ln. It was 1790 pc/h/ln for two-lane approaches and 1670 pc/h/ln for one-through-lane approaches. They came to the conclusion that the more through lanes there are on the approach, the higher the saturation flow rate (26).

For a lane group with multiple exclusive lanes, the saturation flow rate is estimated using the input lane utilization adjustment factor. This factor is 1.0 if there is just one shared or exclusive lane in the lane group (9)

3. *Green time and cycle time (sec)*

The percentage of cars that arrive at a signalized intersection during the green and red signal indications has a significant impact on the control delay and queue size. When a greater percentage of vehicles arrive during the green indication, there is less delay and a smaller line (9).

Both cycle time and green time have an impact on saturation flow rate, but green time has a stronger effect. Due to driver weariness and other causes, longer green times may eventually result in a modest drop-in saturation flow rate. On the other hand, cycle time influences the percentage of time spent in the green phase and the formation of platoons, which indirectly affects saturation flow(27).

It is advised that, whenever feasible, the green time stage's duration be kept to a maximum of 45 seconds. Since the amount of cycle time used by the lost time may significantly impair capacity for short green time stages, a lower limit of below 20 seconds is not recommended(27).

4. *Number of pedestrian crossings and bicycles*

The concept of conflict zone occupancy serves as the foundation for the computation of the pedestrian-bike adjustment factor (fRpb) for right turns and the pedestrian-bike adjustment factor (fLpb) for left turns. This accounts for the conflicts that occur between bicycles, walkers, and turning autos. When determining the relevant conflict zone occupancy, it is taken into account if the left-turn movement and the opposing vehicle flow are at odds (9).

5. *Heavy Vehicles and Grade*

Studies shows that big vehicles require more space and have different operational capabilities than passenger cars and impact of approach grade on vehicle performance is taken into account by the grade component. An upward gradient has a positive value, while a descending gradient has a negative value (9).

The approach grade is regarded as one of the key determinants of capacity in the HCM. According to the analysis of a study by Changqiao Shao et al. (2011), the saturation flow rate will rise as the grade increases when the approach grade is greater than 2% (28).

During the green phase, motorized 2Ws and 3Ws can drive in a zigzag pattern and through tiny places with rapid acceleration due to their better mobility and small size. This interrupts the movements of other vehicle types and reduces saturation flow. Nevertheless, because HV has worse dynamic characteristics than other vehicles, saturation flow at the intersection rises at a flatter rate as HVs grow. This is because the percentage of cars, BC, and HV increases over time. (25).

The impact of approach lane gradient on saturation flow rate in South Africa was examined by Bruwer et al. in 2019. The observed saturation flow rates, which varied greatly from the ideal value, ranged from 1766 pc/h/ln to 2386 pc/h/ln. Furthermore, the results demonstrated that gradient significantly affects saturation flow rates; in this study, the influence of gradient is six times larger than that suggested by the HCM2010 (2).

The fraction of heavy vehicles had a greater effect on saturation flow rate in narrow lanes than in wide ones, and the saturation flow rate in South Africa deviates significantly from the HCM 2010 anticipated value. Additionally, HCM downplayed the impact of gradient on saturation flow rate. (23).

As traffic volume rises, passenger car unit values rise as well. This resulted from an increase in traffic volume. Smaller cars do not experience a drop in speed, but larger vehicles do. As a result, there is a greater speed differential between passenger cars and other vehicles, which raises the value of passenger car units as traffic volume rises. According to this perspective, the number of passenger cars rises in tandem with the volume of traffic. It implies that traffic volume levels at a certain time of day may have an impact on the value of a passenger automobile unit (1).

A study done in Kampala shows that the low value of saturation flow rate at Kampala Entebbe road junction is explained by the fact that traffic goes through a 3.67% upgrade which impacts significantly on the discharge characteristics. The percentage grade on industrial area bound traffic is -0.37% (downgrade) which explains higher saturation flow rate value computed. (29)

According to research by Lewis and Benekohal (2007) and Kockelman and Shabih (2000), the capacity is reduced by up to 30% when 40% of the traffic stream is made up of heavy vehicles, a percentage that is inversely proportionate to the saturation flow rate (4)

6. *Bus Blockage*

The bus-blockage adjustment factor accounts for the effect of local transit buses that stop to retrieve or drop off passengers at a far-side or near-side bus stop within 250 feet of the stop line (9).

The near-side or far-side of a nearby crossroads can be where a bus stop is situated. In either scenario, a bus may reside at the stop to load and unload people, using either a bus bay or a regular traffic lane. Buses exercising right-of-way and pulling out of bus bays might disrupt regular traffic flow in the next lane. Additionally, regular traffic movement in the adjacent lane may be disrupted by geometric delay caused by buses accelerating and decelerating into and out of the bus stop (30).

7. Parking activities

When examining the traffic in the lane group next to a parking lane, the parking adjustment factor takes this frictional effect into consideration. It also takes into consideration the sporadic obstruction of a nearby road caused by cars entering and exiting parking spots. The value of this factor is 1.00 if parking is inaccessible (9).

8. Area Type

The area type input indicates whether a junction is situated in an area that resembles a central business district (CBD). An intersection is considered to be in a central business district (CBD) or an area comparable to one when it contains characteristics such as narrow radius turns, restricted usage of exclusive turn lanes, midblock curb cuts, frequent parking maneuvers, vehicle blockages, significant pedestrian activity, taxi and bus traffic, and dense population. Compared to crossings in less restricted and less visually intense regions, the average saturation headway at intersections in areas with CBD-like characteristics is noticeably longer (9)(26).

9. Right Turns

The right-turn adjustment factor is primarily used to assess the effect of right-turn path shape on saturation flow rate. If the right-turn movement shares a lane with another movement or is permitted to operate, a procedure should be followed to calculate the modified saturation flow rate for the shared-lane lane group. (9).

The saturation flow for an approach is affected by right-turning motions. The suggested adjustment factor, in contrast to existing ones, is developed by taking into account the number of categorized vehicles for both right-turning and through motions independently as the important elements (25).

10.Left Turns

The left-turn adjustment factor is primarily intended to illustrate how the saturation flow rate is impacted by the geometry of the left-turn path. If the left-turn movement shares a lane with another movement or is authorized to operate, the procedure for determining the adjusted saturation flow rate for the shared-lane lane group should be followed (9)

11.Unauthorized pedestrians

Pedestrian crossings can reduce the saturation flow rate by 15.7%. The findings demonstrate the need of enforcing pedestrian traffic control at heavily populated urban crossings (3). A multiple linear regression model developed by Sushmitha Ramireddy on effect of pedestrian crossing on saturation flow at signalized intersections in mixed traffic conditions also shows that saturation flow is decreasing with the increase in unauthorized pedestrian volume count (31).

12.pavement condition

Aleksandr Novikov et al. conducted a study in Russia that examined and calculated the saturation flow's dependence on the type and condition of the road surface, which are characterized by the friction coefficient. They found a direct correlation, meaning that a section of the street and road network's capacity decreases as the road surface condition deteriorates and friction decreases. According to a study performed at an actual crossing, traffic light signalization results in a decrease in saturation flow; for example, when the road surface is frozen, this value decreases by 48% of the reference conditions involving dry asphalt; these reductions need a 107% increase in cycle time. (32).

13.location and width of crosswalk,

At signalized crossings, crosswalk width has a direct impact on cycle length and, consequently, mobility levels. The ideal crossing width guarantees the least amount of delay for pedestrians and other users. (33). It is recommended that pedestrian crossings be positioned in accordance with the direction of pedestrian streams and as near to the edge of the nearby road as is practical. This emphasizes the necessity of crosswalks at intersections. If a crossing must be repositioned from the edge of the intersection due to right-turners on all-vehicle lanes, at least five to six meters must remain (34).

The demand for crossing pedestrians in some signalized crosswalks may differ greatly between the two directions, making pedestrian crossing time greatly influenced by the interaction of crossing pedestrians. Thus, the movement of the left-turning automobiles also had a big impact (35).

In the Polish city of Gdynia, the behavior of both pedestrians and drivers at the signalized crossing was examined. The gathered video assisted in identifying variables including pedestrian volumes, age groupings (children, teens, adults, and the elderly), the average time it takes to cross the street, and the time it takes for a pedestrian to enter the crosswalk while the green light is on. The outcome displays the pace at which a person crosses the crosswalk. The median speed of all pedestrians examined was 1.32 m/s, with men being the fastest (1.41 m/s) and elderly individuals being the slowest (0.88 m/s) (36).

14. Vehicle composition.

It has been demonstrated that the most sensitive factor affecting the saturation flow is the composition of cars in the traffic stream. Additionally, because there are both fast-moving and slow-moving vehicles in the traffic stream, extremely poor lane discipline is usually observed in a highly diverse traffic situation at signalized junctions in urban settings. In particular, when the proportion of 3Ws and 2Ws rises, the saturation flow per standard width decreases (37).

Vehicle size affects headways during saturated flow, according to measurements made between cars being released from a wait at a signalized urban intersection. the shortest headways discovered when there are two little cars in front and behind each other. Small and full-sized cars have similar headways, but as the traffic stream gets closer to unrestricted flow, the differences disappear. For the first cars in a discharging line, the headway difference is particularly notable. Up until at least the sixth car in the line, average headways for little cars are noticeably shorter than those of full-sized cars. A traffic flow increase of 10 to 15% can be achieved at signalized metropolitan junctions with a fleet of little automobiles compared to a fleet of full-sized cars; the magnitude of the increase depends on how long the effective green period is for each cycle. Smaller cars have a bigger impact on intersection capacity the more turns that are made (38).

In general, signalized crossings affect the efficiency of urban traffic networks. The saturation flow rate is crucial to the layout and functionality of signalized junctions. The majority of transportation organizations do not gather data from the field, despite the significance and use of saturation flow rate. Rather, they employ values recommended by the Highway Capacity Manual (HCM), which may not be appropriate for all cities worldwide. Different locations have different saturation flow rates. As a result, applying the number recommended by HCM may overestimate or underestimate the true local saturation flow rate. This could result in an inaccurate assessment of the intersection's performance and capacity (2) .

Therefore, as we observed from those literatures HCM estimations may result in less accuracy for our case. It is designed with the developed nations standard and may not reflect our complicated behavior and movement of pedestrians. Saturation flow and passenger car unit (PCU) have a major impact on a signalized intersection's operation, capacity, and design. roads in developing countries have crossroads that handle a variety of motorized traffic types as well as pedestrians and other slow-moving traffic. Therefore, in order to assess the overall performance of signalized crossings, saturation flow and passenger car unit (PCU) must be taken into account under mixed traffic scenarios.

In selecting a saturation flow value for use in capacity studies, engineers and planners may find it prudent to collect local data to "spot check" the applicability of the flow rates. Perhaps even more so than with other aspects of traffic engineering, professional judgment is an essential ingredient in capacity analyses (22).

In transportation engineering, the passenger car unit (PCU) is a measurement tool used to accurately measure the traffic volume on highways. Converting a varied traffic flow into a single traffic volume is the main function of the Passenger Car Unit (PCU). It is a measure of how closely a car and traffic flow relate to one another in relation to standards under a certain set of road and traffic conditions (39).

PCU value can be utilized for traffic management, signal design, capacity analysis, saturation flow rate calculation, and traffic flow model development (40). A study done in Addis Ababa shows that PCU methods employed indicates that is more accurate and reliable than which homogenous (1).

The traditional methods for estimating saturation flow rate assumed that the queue discharge headway was relatively constant and that the average headway estimated from the first 4-to-10 or 4-to-12 vehicles was representative of the saturation headway. This means that every vehicle in a stable moving platoon consumes h seconds (37).

The impact of the many elements influencing the flow at intersections must be measured in order to optimize the usage of the current infrastructure. Modeling is one way to accomplish this. The conventional western formulas for estimating the values of saturation flows, lose time, and PCU factors are inappropriate for emerging nations due to fundamental variations in traffic characteristics.

Therefore, an appropriate saturation flow rate depending on local characteristics needs to be established in order to more accurately reflect the current traffic condition. Thus, the purpose of this study is to ascertain the true impact of pedestrians on the capacity of the selected signalized crossings in Addis Ababa.

3. Methods and materials

3.1 Study areas

Ethiopian capital city Addis Ababa, is a diplomatic center and the location of the African Union. With 540 km² of land, it has a 2.5% annual population growth rate, 15% annual urbanization rate, and 25% annual motor vehicle traffic fatalities, of which 88% are pedestrians (41). Despite notable advancements in infrastructure and economic expansion, Addis Ababa continues to face complex transportation issues.

One of Addis Ababa's main transportation issues is traffic congestion. A 2019 analysis by Sitotaw and Tekilu discovered that the overall financial expense of traffic between Megenagna and CMC that is, just eastern parts of the city was 42,897,752.15 Birr with the mean economic loss incurred per kilometer per annum amounted to 9,618,330 Birr (42).

Transportation challenge will be solved through adequate planning, proper management, strong compliance with land use and transport measures. Ethiopian government is doing its best to solve it.

One of the challenging areas in traffic is signalized area and its capacity will be measured through saturation flow analysis which is influenced by numerous elements, one of them is pedestrian movement. In Addis Ababa walking is a major mode of transport and pedestrians affect the movement of vehicles by crossing the road while car green is on.

We chose five signalized junctions in Addis Ababa to investigate how pedestrians affect signal capacity. Jemo Michael, Saris Abo, Ayer Tena, Banko de Roma and Meskel square.

Figure 2Ayertena Signalized Intersection

Figure 3 Jemmo Michael Signalized Intersection

Figure 4 Banco de Roma signalized intersection

Figure 5 St Estifanos Signalized Intersection

Figure 6 Saris Abo Signalized Intersection

3.2 Study variables

3.2.1 Dependent variables

- Through lane Saturation flow rate (Veh/h/ln)

3.2.2 Independent variables

Geometric conditions

- Lane width
- Number of through lane
- approach grade
- configuration and geometry of intersection

Traffic conditions

- Traffic composition
- Number of heavy vehicles
- Green time
- Volume of through movement
- Number of approaching pedestrians
- Number of Illegal crossing pedestrians

3.3 Sample size and sampling technique

There are approximately 98 signalized intersections in the city according to traffic management agency data these are attached on the annex of this thesis work. For this study five intersections in Addis Ababa namely, Jemo Michael, Saris Abo, Ayer Tena, St Estifanos, Banko de Roma intersection were selected based on criteria like, their functional status, four armed/leggedness , high pedestrian flow with high traffic volume, from different directions of the city but with low influence congestion due to commercial and business center, least interference to entry and exit traffic due to parking activities adjacent to a travel lane within 100m of the stop line.

1. Jemo Michael intersection
2. Saris Abo intersection
3. Ayer Tena intersection
4. Banko de roma intersection
5. St Estifanos intersection

3.4 Data collection procedure

In this study, a camera was used to record video of intersections at peak hours and on tall buildings close to the crossroads to gather statistics, information, and count the number of cars and people with manual transcription. The camera was positioned atop the target building ten minutes prior to the commencement of the study period. One hour of peak-hour traffic in the morning and afternoon was recorded and stored for each intersection, and it was guaranteed that the camera would record traffic data at least 100 meters upstream from the intersection stop line. The camera was positioned on a visible height so that the data collector could see the beginning and end of each phase.

The discharge headways of vehicles in line from various cycles throughout morning and afternoon peak hours are computed from the video recording. The video recordings were used to measure the headways during peak morning and afternoon hours. Video cameras and field measurement techniques were used to gather the field data at five intersections. Geometric, traffic, and signal control data were gathered to examine the effect of several factors on the signalized crossings' capacity.

For one week working days in the month of September, from Monday through Friday, continuous images of the traffic flow were captured during the peak morning hours of 8:00 am to 9:00 noon and the afternoon peak hours of 3:00 pm to 4:00 pm. A total of 374 cycles about 10 hours were recorded and 320 cycles were considered for analysis. The remaining cycles were discarded because of very short queues less than seven vehicles, and traffic flow disturbances and interferences

In this study, we considered three lane and four lane road per direction. The number of through lane of these roads is different. For four lanes two of them are for through movement one for left and one for right turn movements in one direction and for three lane the lanes are arranged as one for through movement one for left turn and one for right turn movement. Standard width of one lane is 3.5m.

The lane groups considered for the data collection were through only lane a total of 28 data collection spots had assessed from the five junctions. The following materials were used during data collection.

3.5 Data analysis

In this study we tried to correlate the capacity with the influencing pedestrian flow by generalizing the group movement of pedestrian and vehicles. The number of vehicles and pedestrians crossing illegally during green phase for vehicles had been extracted from the video by manual counting.

A multiple regression model was used to assess saturation flow when there are unauthorized pedestrian crossings. One soft computing technique that was applied in several fields, including intersection capacity estimation, was regression analysis. The creation of equations with dependent and independent variables is the methodology's basic foundation.

This study determines the capacity of the signalized junction by considering several criteria, such as vehicle mix, signal timing, effective green time, and pedestrian.

The regression technique is also used to examine a number of contributing parameters that impact saturation flow. However, the saturation flow prediction model is developed employing numerous influencing parameters according to traffic and geometric situations using multiple line regression.(4) .

The best regression model between pedestrian flow and equivalent vehicle flow was determined to be the linear model, which also happens to be more compatible with another research (6). Using SPSS software, the correlation matrix and ANOVA test were used to identify the important factors and Modeling was done for through lane saturation flow rate using IBM SPSS modeler.

3.6 Ethical consideration

When conducting research, a number of crucial rules and procedures must be adhered to. These include the freedom from harm and the rights to privacy, self-determination, anonymity, and confidentiality (43).

Prior to data collection, a formal letter from Addis Ababa University was given to the appropriate and interested entities like the Addis Ababa Transport Management Authority, the Addis Ababa Transport Bureau, AACRA and ERA.

4 Analysis and result

At the chosen intersections different parameters including width, grade, number of pedestrians, traffic volume, traffic composition, speed and clearance time data from different approaches of the signalized intersection were collected.

Data on signal timing, including cycle duration and vehicle clearing time at each signal phase at various approaches to the signalized intersections, was gathered manually concurrently. Based on observed data, the vehicles are classified into six categories: Passenger car, pickup and LC, mini bus, standard bus, small truck (2 axels) and medium truck(3axels)/heavy good vehicles.

Vehicle classification was done Based on Ethiopian Road Authority pavement design manual volume 1-2013 and a study done on urban traffic flow modeling in Addis Ababa. Accordingly, Vehicles of length less than 6 m considered as small 6-9 as medium and 9- 12 as big vehicles and according to their overall weight in tone vehicles with less than 4 tone are considered as small 4-11 as medium and 11-16 and above as heavy vehicles. In terms of passengers they carry, passenger car and taxi 2-7 passengers , minibus 12 passengers and heavy vehicles freight transport (44).

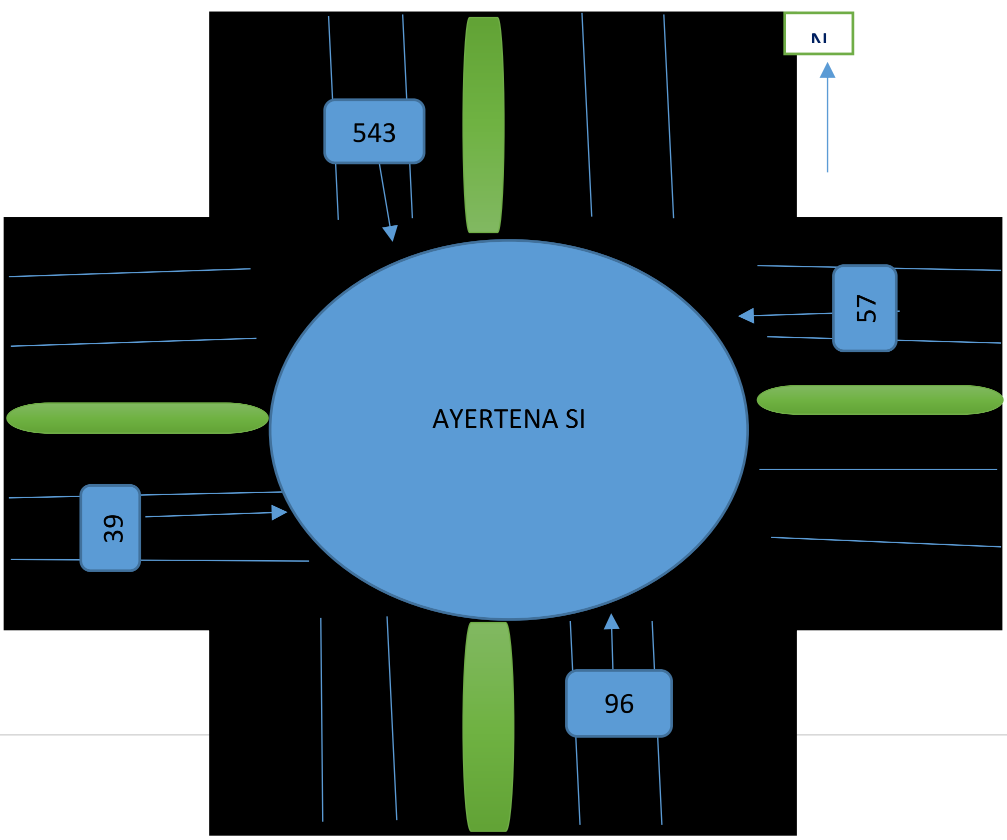

Figure 7ayertena signalized intersection with its respective number of vehicles in through lane

From analysis of field data, the following vehicle distribution in each direction and percentage lane traffic data had obtained (table 1). The cycle time and green time is for all lane movements since vehicles from one direction released equally during data collection. The total number of vehicles in through, left and right lanes are also presented in table 2 below.

Table 1 traffic lane distribution

Intersection	Approach from	Cycle Time (Sec)	Green time (Sec)	% of cars	% Left Turning traffic	% through traffic	% Right Turning traffic
Ayertena SI	East	203	67	28.5	20	61	19
	West	200	56	20.5	27	58	15
	North	205	45	30	36	55	9
	South	211	49	21	21	14	65
St. Estifanos SI	East	206	53	22	18	78	4
	West	206	55	29	16	53	31
	North	200	58	21	16	73	11
	South	201	55	28	53	39	8
Saris Abo SI	East	156	75	38	26	61.5	12.5
	West	212	71	40	9.5	80	11.5
	North	153	15	6	9	18	73
	South	158	35	16	61	22	17
Banko de Roma SI	East	200	42	25	59	21	20
	West	197	41	10	51	34	15
	North	188	65	52	31	38	31
	South	201	50	13	37	52	11
Jemo Michael SI	East	213	74	25	12	77	11
	West	215	68	29	23.5	65	11.5
	North	211	38	19	29	44	27
	South	212	70	27	57	36	7
		3948	1082				

Table 2 Total vehicle distribution in lane

	Ayertena	estifanos	saris	Banko D	Jemo M	tot	%	average
left	870	1824	614	3066	1547	7921	31.5	1320
through	1599	4053	1530	2653	2788	12623	50	2104
right	816	978	405	1788	663	4650	18.5	775
	3285	6855	2549	7507	4998	25194		

Since traffic is heterogeneous type, physical characteristics are different, operating conditions are different and poor lane discipline, we have to convert the data to PCU using equivalence factor. PCU, which is generally a conversion factor for different vehicle types with respect to their impact on capacity in comparison to a passenger car, is the number of passenger cars that a truck or bus can displace in the traffic flow under the current road and traffic conditions, as stated in the highway capacity manual.

A total of 25194 vehicles were recorded and out of the 25194 vehicles that were recorded, 48% were passenger cars, 32% were taxis, 12% were buses, and 8% were trucks. Motorcycles and non-motorized vehicles were not included because they make up a very small portion of the total vehicle composition.

Table 3 distribution by vehicle type

	AYERTENA	ESTIFANOS	SARIS	BANKO D	JEMO	SUM
HT	180	90	275	214	170	929
MT	188	376	574	864	185	2186
BUS	90	140	213	321	120	884
MB	186	411	628	546	320	2092
TAXI	1056	2335	343	2225	1681	7640
PC	1585	3503	515	3337	2522	11462
TOTAL	3285	6855	2549	7507	4998	25194

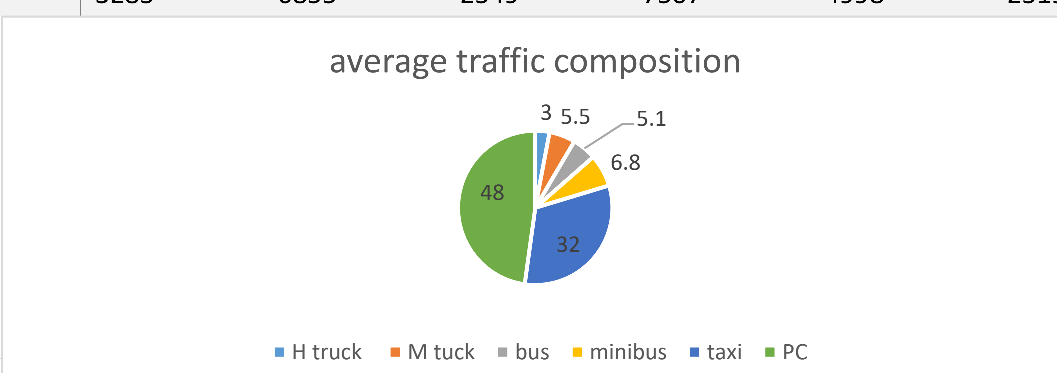

Figure 9 average traffic composition pi-chart

4.1 Development of Passenger Car Unit (PCU)

PCU values have been calculated using a variety of methods, and researchers have typically proposed a static unit for each vehicle. Nevertheless, it's possible that dynamic PCUs accurately depict mixed traffic flow scenarios (4) and it transform a mixed traffic flow into an equivalent passenger car flow (45).

For a variety of factors related to the length, acceleration, deceleration, and maneuverability of HGVs, their presence in the traffic stream reduces a highway's capacity. Increased headways indicate the effect of HGV length, which lowers capacity. Furthermore, HGVs are less able to accelerate and decelerate, which increases their harmful effects at lower speeds and in upgrading portions. Consequently, the average PCE values ought to be greater than those of a single-passenger vehicle. (46).

Saturation flows from various locations with varying traffic compositions are compared using generic units known as Passenger Car Units (PCU), rather than actual vehicles. These units represent the amount of space that various vehicle types take up, measured in relation to a passenger automobile (47).

The Passenger car unit or Passenger car equivalent is a unit which is adopted for traffic volume and traffic capacity measurement. It is computed by considering passenger car as a standard vehicle. The knowledge of passenger car unit of vehicles is important for various purposes such as design of a road section, traffic operation on the road, management of traffic etc. (48).

The study done on estimation of PCU of various categories of vehicles based on the dynamic properties of vehicles which is speed of the vehicle found that the PCU values of different type of vehicle are different for different volume of traffic due to the dynamic characteristics (48).

According to a study by Al-obaedi and Jalal Taqi Shaker, the equivalency factors for the same site varied considerably depending on the pace of the traffic. However, it was demonstrated that the length differences between vehicles and HGVs had an impact on this fluctuation with traffic speed. Additionally, the obtained PCEs values were somewhat lower under normal traffic conditions and higher than those suggested by the highway capacity manual during crowded conditions (46).

At certain intersections, the PCU equivalents for motorcycles, buses, commercial vehicles, and light vehicles differed from those determined by Webster and Cobbe. The results of this study demonstrated a noteworthy distinction. Driver behavior, traffic composition, and other environmental factors could be the cause of this (49).

According to a Nigerian study that examined the effectiveness of PCU values for various vehicle types in traffic situations, traffic volume and queue length rise as long and heavy vehicles share a lane. The headway method of estimating is more beneficial in PCU analysis, according to the study's testing of multiple PCU techniques (50)(39).

Six vehicle types were chosen for this study from the thirteen categories of vehicles listed in the Ethiopian Road Authority Pavement Design Manual Volume 1 because of the good mix of these vehicle types on the road. (51). A study done in Addis Ababa by Tadiyos Marie also classified as follows (52,53):

Table 4 length width and area classification of vehicle types

Vehicle type	PC	Taxi	minibus	Standard bus	Medium truck	Heavy truck
Length	3.2	4.6	4.6	7.7	6.6	11.5
Width(m)	1.7	1.8	1.9	2.2	2.2	2.7
Projected area(m2)	5.44	8.28	8.74	16.94	14.52	31.05

Over the past few decades, a number of approaches have been put forth to estimate suitable PCUs (see, for example, Werner and Morrall, 1976; Chandra et al., 1997; Chandra and Kumar, 2003; Minh and Sano, 2003; Srikanth and Mehar, 2017)(12) Walker's method, Headway method, multiple linear regression method, Simulation method, Density method (used by HCM). Out of the available methods, the one proposed by Chandra is the most suitable for mixed traffic condition, traffic with high heterogeneity, and in the conditions where vehicles do not follow lanes strictly. The Method adopted in this thesis work to generate a model equation to calculate PCU is Speed-Area method which is developed by Dr. Satish Chandra, according to Chandra's method PCU of any vehicle category can be found by using the following formula (48)(54).

$$PCU = \left(\frac{Vc}{Vi}\right)/\left(\frac{Ac}{Ai}\right)$$

Where V is mean speed and equals to distance/ time

Vc = average speed of standard car

Vi = average speed of vehicle type i

Ac = projected area of the standard car

Ai = projected area of vehicle type i

A vehicle's average speed can be calculated by measuring its journey time over a 100-meter span. The average speed was measured at 15-minute intervals. Because some vehicles go more quickly than others, different vehicle types have varying speeds. By examining the speeds of several vehicle kinds at various intervals, the variation in each vehicle's speed has been ascertained.

Table 5 average speed data of vehicles in their classification at the intersection area

.

Time of the day	*VHT*	*VT*	*VB*	*VMB*	*VTx*	*VPC*
3:00-3:15	36	40	42	45	51	60
3:15-3:30	33	36	36	40	45	51
3:30-3:45	22.5	30	45	33	60	45
3:45-4:00	30	33	40	36	51	51
AVG speed (km/h)	30	34	41	38	52	52

VHT = speed of heavy vehicle(km/h)

VT = speed of truck (km/h)

VB= speed of bus (km/h)

VMB= speed of medium bus (km/h)

Vtx = speed of taxi (km/h)

VPC = speed of passenger car (km/h)

AVG Speed = average speed(km/h)

Table 6 PCU and adjusted number of vehicles at intersections

Intersections	parameters	H truck	M tuck	bus	minibus	taxi	PC	Adjusted number of vehicles per lane
Ayertena	% vehicle	5.5	5.7	2.7	5.7	32.1	48.3	
	#vhcl	88	91	44	91	513	772	
	pcu	5.58	2.95	5.2	1.8	1.5	1	
	adjested	491	268	229	164	769	772	2694
St. estif	% vehicle	1.3	5.5	2	6	34	51	
	#vhcl	53	223	81	243	1378	2067	

	pcu	6.74	4.46	5.31	1.95	1.43	1	
	adjested	357	994	430	474	1971	2067	6293
Saris	% vehicle	10.8	22.5	8.4	24.7	13.5	20.2	
	#vhcl	165	344	128	378	207	309	
	pcu	5.86	4.75	5.16	1.73	1.57	1	
	adjested	967	1634	660	654	325	309	4549
Banko deroma	% vehicle	2.8	11.5	4.3	7.3	29.6	44.5	
	#vhcl	74	305	114	193	785	1180	
	pcu	6.19	4.38	5.86	1.92	1.62	1	
	adjested	458	1336	668	371	1271	1180	5284
Jemo M	% vehicle	3.4	3.7	2.4	6.4	33.6	50.5	
	#vhcl	95	103	67	178	937	1408	
	pcu	6.10	3.91	4.75	1.69	1.28	1	
	adjested	580	403	318	301	1199	1408	4209

Compared to medium Trucks, buses were shown to have a greater impact on the amount of space needed. Their practice of stopping at or close to intersections to do business may be the cause of this. It is evident that the optimal PCUs have pushed the curve quite near to the ideal one. This indicates that the traffic mix has been successfully brought pretty close to a stream of passenger automobiles using the ideal PCU values (13).

The PCU of different vehicle types has been found to alter linearly with increases in traffic volume and v/c ratio, but exponentially with changes in traffic composition. The developed mathematical models can depict how it changes with different volume levels, compositions, and volume to capacity ratios (55).

A study done on Determination of Passenger Car Unit for Urban Roads in Addis Ababa (56) develop a linear regression model

$$PCU = a + b(10^{-x})Q$$

Where, PCU=passenger car unit

a = constant, y intercept

b = coefficient,

Q = traffic volume in veh/hr

The values of the constants and coefficients for each category of vehicles are presented in the table as follows:

Table 6. Values of Constants Obtained From Regression Analysis.

Types of vehicle	Four lane				Six lane			
	a	b	x	Ad.R^2	a	b	x	Ad.R^2
Big car	1.26	1.36	4	0.94	1.36	1.15	4	0.95
minibus	1.37	1.73	4	0.89	1.39	1.88	4	0.91
Truck	4.3	6.06	4	0.92	4.6	2.64	4	0.97

Table 7 comparison of arthemetic PCU Value with a previous model in addis ababa

	SI	a	10^{-x}	b	Q	PCU model result PCU=a+b(10^{-x})Q	Arithmetic PCU result	% variation
heavy truck	Ayertena	4.3	0.0001	6.06	1599	5.27	5.58	5.57
	Estifanos	4.3	0.0001	6.06	4053	6.76	6.74	0.24
	Saris	4.3	0.0001	6.06	1530	5.23	5.86	10.79
	Banko D	4.3	0.0001	6.06	2653	5.91	6.19	4.56
	Jemo M	4.3	0.0001	6.06	2788	5.99	6.1	1.81
minibus	Ayertena	1.37	0.0001	1.73	1599	1.65	1.8	8.52
	Estifanos	1.37	0.0001	1.73	4053	2.07	1.95	6.21
	Saris	1.37	0.0001	1.73	1530	1.63	1.73	5.51
	Banko D	1.37	0.0001	1.73	2653	1.83	1.92	4.74
	Jemo M	1.37	0.0001	1.73	2788	1.85	1.68	9.89

4.2 Calculating the saturation headway

The duration that passes between consecutive cars passing the stop line can now be used to characterize the vehicle headways. The initial headway will be the amount of time it takes for the first car's back wheels to cross the stop line. The second headway is the distance between the back wheels of the first car crossing the stop line and the back wheels of the second car crossing it (57)

At saturation flow, vehicles depart at equal headways of 1/s. It is advantageous to split the signal cycle into a "effective green time," when the departure rate is s, and a "effective red time," when no departures take place, in order to account for this assumption of equal departure headways. This idea is helpful as capacity and effective green time are directly correlated (22).

Usually, field observations of the time that passes between the fourth and tenth to twelfth vehicles in a line are used to estimate saturation headways (58). It has been noted that the final few cars in a lengthy line may exhibit elongated or compressed headways. Vehicles that tailgate to gain passage during the phase change interval typically exhibit constrained headways.

On lengthy lines of through traffic, elongation may be seen because, by the time cars reach the stop line, their speeds may have risen above 40 mph. This results in longer headways, which can be caused by conservative drivers creating wide gaps by driving more slowly or by drivers increasing their spacing for safety. The discharge process of each lane is impacted by the wider spacing since it also makes drivers more likely to switch lanes (58)

The last headway was compared with the average headway of the queue, excluding H4, and the results of a t-test show that the observed last headway was not significantly different from the previous average headway. The HCM, which essentially makes the assumption that the saturation headway remains constant until the end of a standing queue, is consistent with these results (58).

Preliminary investigation revealed that Addis Ababa's queue discharge flow is highly variable and does not reach a constant value. Even during queue discharge, there are significant time headways of up to 6 seconds because of variations in acceleration behavior and slow-responding traffic (44).

To determine the rate of saturation flow Firstly record when the front axle of the fourth car passes the stop line. Second, a record of the final car in line is also made. Thirdly, the fourth and final vehicle's time lag is computed. Fourth, we may calculate saturation headway by dividing the time lag by the number of cars. Lastly, the time reciprocal of the saturation headway is the saturation flow rate (23).

Table 8 sammpletravel time record for headway analysise

		ayertena SI		St Estifanos SI		saris abo SI		banko de roma SI		Jemo M SI	
Laps between		time	cumulative	time	cumulative	time	cumulative	time	cumulative	time	cumulative
green time	vehicle 1	6.11	6.11	5.17	5.17	7.59	7.59	8.49	8.49	11.37	11.37
vehicle 1	vehicle 2	1.94	8.05	1.4	6.57	3.42	11.01	3.07	11.57	2.12	13.49
vehicle 2	vehicle 3	2.34	10.4	1.27	7.85	2.95	13.96	2.35	13.93	1.71	15.21
vehicle 3	vehicle 4	2.72	13.13	2.39	10.24	2.59	16.56	3.76	17.7	2.17	17.38
vehicle 4	vehicle 5	1.73	14.86	1.62	11.87	2.45	19.01	2.34	20.04	2.78	20.17
vehicle 5	vehicle 6	1.98	16.85	1.51	13.38	2.68	21.7	2.71	22.76	2.35	22.52
vehicle 6	vehicle 7	2.07	18.92	1.76	15.15	1.48	23.18	2.49	25.26	2.4	24.93
vehicle 7	vehicle 8	1.65	20.58	2.43	17.58	2.7	25.88	2.36	27.65	2.2	27.13
vehicle 8	vehicle 9	2.65	23.23	2.41	20	1.82	27.71	2.17	29.82	1.89	29.02
vehicle 9	vehicle 10	2.29	25.53	1.96	21.97	2.29	30.01	3.09	32.91	1.81	30.84
vehicle 10	vehicle 11	3.14	28.67	2.04	24.01	2.2	32.21	2.96	35.88	2.31	33.15
vehicle 11	vehicle 12	2.33	31.01	2.2	26.22	2.26	34.48	2.78	38.66	2.71	35.87
vehicle 12	vehicle 13	2.76	33.78	2.99	29.22	2.7	37.18			2.24	38.12
vehicle 13	vehicle 14	1.98	35.76	2.79	32.01					2.2	40.32
vehicle 14	vehicle 15	2.34	38.1	2.51	34.52						
vehicle 15	vehicle 16	2.17	40.27								

Traffic engineers place a great deal of attention on entering headway since it is closely related to other operational metrics at signalized intersections, including saturation flow rate, starting delay, and lost time. In determining the capacity of the junction under investigation and the current saturation flow, it is a crucial metric (30).

Saturation headways were tracked starting when the fourth car in line's rear axle passed the stop line. When the back axle of the last car in line, which had been stopped at the beginning of the green phase, reached the stop bar, the total amount of time that had passed was then determined.

The headway is the amount of time that passes between subsequent vehicles that cross the stop line. The delay between the green light turning on and the first car's front wheels crossing the stop line is known as the first headway. The time difference between the first and second cars to pass the stop line is known as the second headway. The model assumes that the headway stabilizes after a few vehicles. This constant headway, represented by the letter "h," is known as the saturation headway. This continuous headway usually happens when the 4^{th} or 5^{th} car passes the stop line (45).

Headways are calculated as follows (23)(30)(3).

$$h = \frac{(Tn - T4)}{N - 4}$$

where,

Tn = Time taken for the rear axle of the final vehicle on the green phase to cross the stop line (sec),

T4 = Time taken for the 4th vehicle on the green phase crossed the stop line (sec), and

N = number of vehicles line up on the green phase.

Table 9 sample headway formulation

intersection	approach	cycle	T4 (Sec)	Tn (SEC)	N	headway
	West	1	10.24	34.52	15	2.21
St. estifanos	East	2	16.26	54.79	22	2.14
	North	3	17.04	47.08	18	2.15
	South	4	11.16	44.01	18	2.35

From 28 through lanes, 320 average headways were captured in total.

4.3 Calculating the saturation flow rate in a through movement

Hellendoorn, J Zegeye, S K Zwarteveen, and J W. conducted urban traffic flow modeling in Addis Ababa and found that the corridor's saturation flow rate for straight-through traffic was 1522 PCU/h, while the corresponding PCU values for minibuses and heavy vehicles were 0.90 and 1.09, respectively. The aggressive driving of minibuses results in low time headways and, consequently, low PCU values, as evidenced by their low PCU value, which is comparable to the mean of the saturation flow range for developing countries (44). A study done in china also shows 1535 pc/h/ln of the through lane saturation flow rate (14).

$$S = \frac{3600}{h}$$

where: s = Saturation flow rate (vehicle/hour)

h = Saturation headway (second)

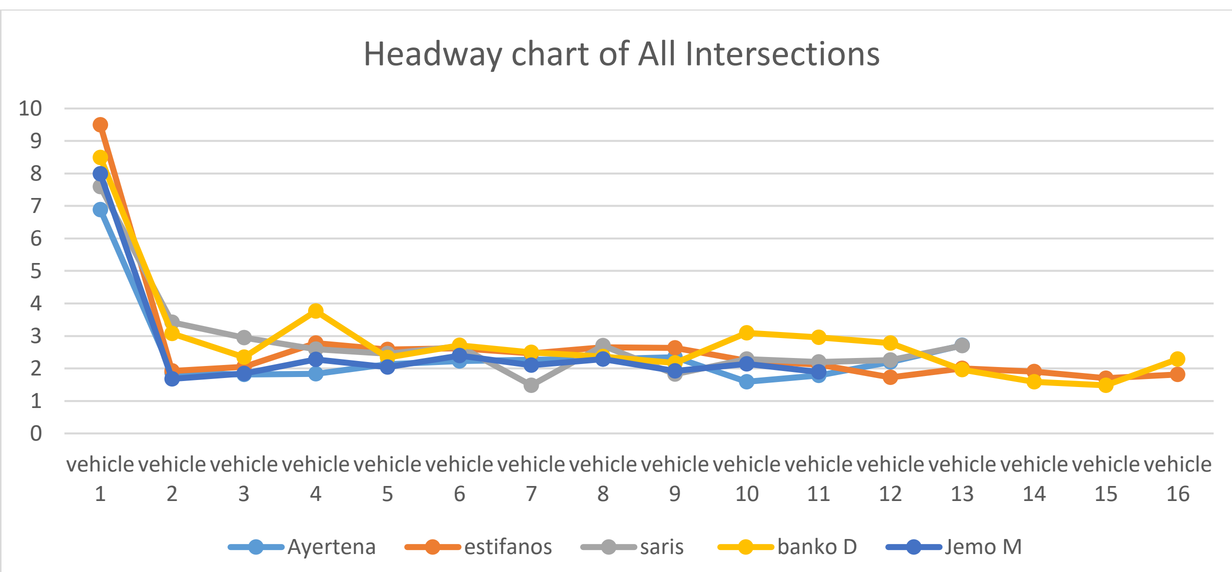

Figure 10 Headway chart of All Intersections

Table 10 Table summarizing saturation flow rates

From all the 28 data collection spots and the 320 cycles studied we summarized the headway and saturation flow of each intersection as follows:

	Ayertena	Estifanos	Saris	Banko	Jemo M
Headway	2.31	2.16	2.53	2.37	2.46
SFR	1558	1667	1423	1519	1463

Very often we are interested to know what association, if any, exists between two variables. One way to determine this is to calculate what is called the correlation coefficient, a commonly used index which measures the degree of association between two variables. Pearson correlation

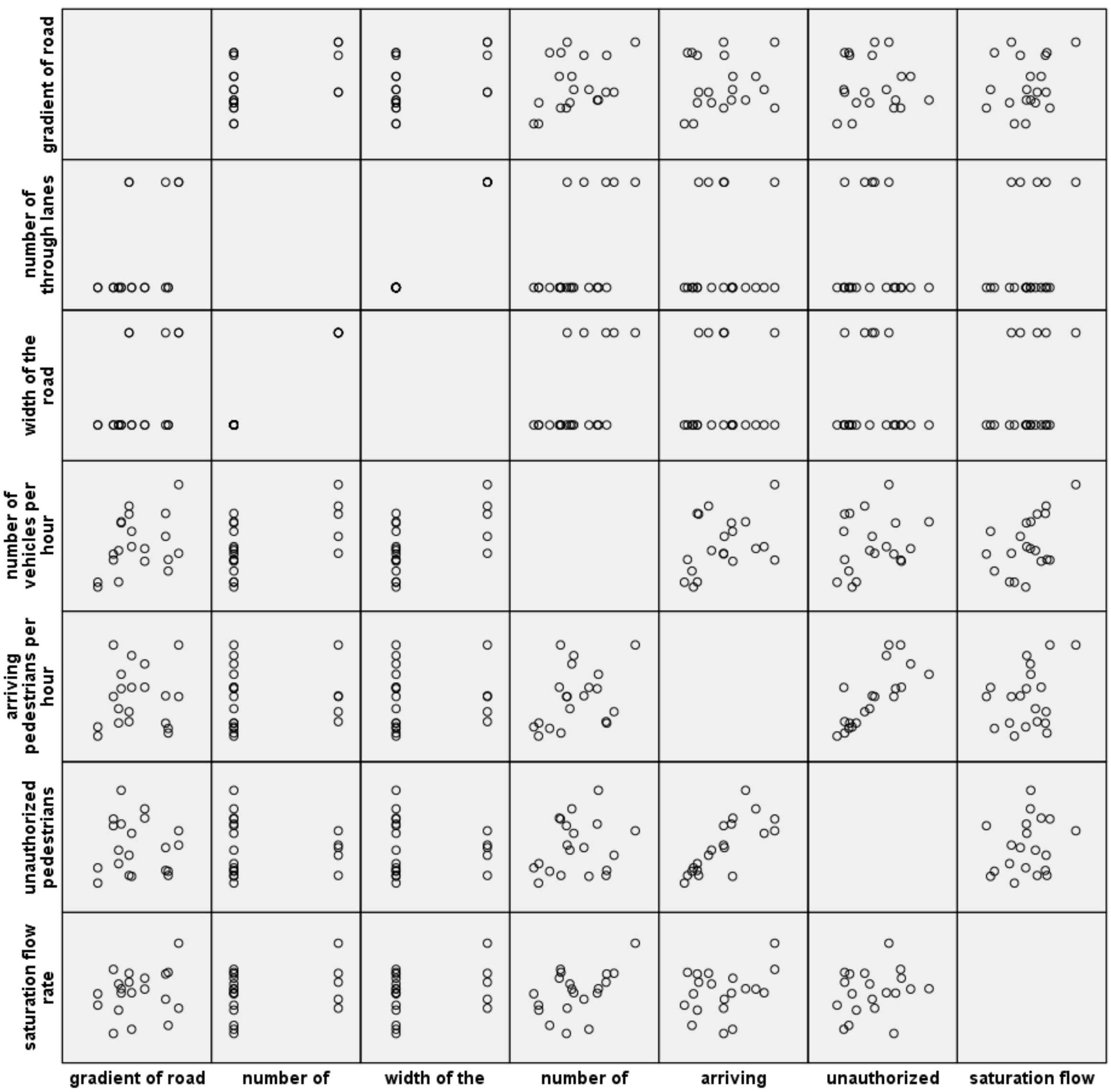

Figure 11 correlation of factors

The hypothesis test done with chi-square test shows that we have to reject the null hypothesis and accept the alternative hypothesis for the following variables: grade, number of through lane, width of road, and number of arriving pedestrians. Here in hypothesis testing summary the number of vehicles are not significant variables and it shows accepting the null hypothesis.

Table 11 tables showing hypothesis test result

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of grade scale occur with equal probabilities.	One-Sample Chi-Square Test	.022	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of number of through lanes occur with equal probabilities.	One-Sample Chi-Square Test	.025	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of width of the road occur with equal probabilities.	One-Sample Chi-Square Test	.025	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of arrivingpedestrians occur with equal probabilities.	One-Sample Chi-Square Test	.047	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of numberofvehicles occur with equal probabilities.	One-Sample Chi-Square Test	.449	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Bivariate analysis shows that number of vehicles and numbers of illegal pedestrians have an effect on saturation flow analysis

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1473.723	48.720		30.249	.000
	number of vehicles per hour	.159	.066	.493	2.404	.027

a. Dependent Variable: saturation flow rate

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1461.264	58.627		24.925	.000
	illegal pedestrians	1.386	.647	.451	2.141	.046

a. Dependent Variable: saturation flow rate

Table 12 summary of bivariate analysis

R.No	Independent variable	Pearson coefficient	P-Value
1.	grade	0.231	0.326
2.	Width	0.270	0.249
3.	lanes	0.270	0.249
4.	Vehicles	0.493	**0.027✓**
5.	Arriving pedi	0.318	0.172
6.	Illegal pedi	0.451	**0.046✓**
7.	Cycle time	-0.067	0.780
8.	Green time	-0.056	0.815
9.	Red time	-0.017	0.944
10.	Number of cycles	0.020	0.932

✓ Variables with p-value less than 0.5

Multiple variables analysis shows the following result

R.No	Independent variable	Pearson coefficient	t	p-value
1.	gradient	-0.099	-0.453	0.660
2.	Width	-0.242	-1.076	0.305
3.	Vehicles	0.996	3.350	**0.006✓**
4.	Arriving pedi	0.173	0.554	0.590
5.	Illegal pedi	0.275	0.893	0.391
6.	Cycle time	-1.583	-1.489	0.165
7.	Green time	-0.848	-3.284	**0.007✓**
8.	Number of cycles	-1.524	-1.403	0.188

✓ Variables with p-value less than 0.5

Table 13multivariate analysis result

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5415.141	2586.511		2.094	.060
	gradient of road	-12.595	27.823	-.099	-.453	.660
	width of the road	-15.326	14.248	-.242	-1.076	.305
	number of vehicles per hour	.321	.096	.996	3.350	.006
	arriving pedestrians per hour	.032	.057	.173	.554	.590
	illegal pedestrians	.845	.946	.275	.893	.391
	cycletime	-10.438	7.012	-1.583	-1.489	.165
	greentime	-6.992	2.129	-.848	-3.284	.007
	numbcycle	-88.098	62.778	-1.524	-1.403	.188

a. Dependent Variable: saturation flow rate

Even though many variables were independent factors while hypothesis testing and bivariate analysis, in multivariate analysis only number of vehicles and green time are associative factors for the significance level of 0.05

Table 14 independent factors analysis result

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1656.421	85.101		19.464	.000
	number of vehicles per hour	.270	.073	.838	3.678	.002
	greentime	-4.673	1.879	-.567	-2.486	.024

a. Dependent Variable: saturation flow rate

Pearson correlation Coefficient shows that arriving and illegal pedestrians have 32% and 45% correlation respectively and Arriving vehicles correlation of 49% at p value of 0.027 with saturation flow rate.

Table 15 Pearson correlation coefficients for significant variables

In bivariate analysis

	SFR	*Vehicles*	*illegal pedi*	*Green time*
SFR	1			
Vehicles	0.493	1		
illegal pedi	0.451	0.380	1	
Green time	-0.056	0.609	0.488	1

The Model will be

SFR=1656.421+0.27NV-4.673Gt

When NV is number of vehicles
Gt is green time

66.7% of the measured productivity can be explained by the established model; the other effects might have been too small to measure in the study's very small sample. However, the model is adapted to offer flow improving solutions since it accounts for the majority of the variance productivity.

This section examines the differences between SFR field data and the present saturation flow rate (SFR) correction model for additional analysis. The following figure was used: The following is the definition of the mean absolute percentage error (MAPE) (23):

$$\mathbf{MAPE} = \frac{1}{N}\left[\frac{Sp - Sadj}{Sp}\right]$$

Where: -

Sadj is adjusted SFR

Sp is observed SFR.

Table 16 MAPE comparison with a previous model and highway capacity manual.

			Sp	Sadj	Sp-Sadj	N	NSp	MAPE	% Variation from HCM
1	Ayertena	East	1592	1471	121	1	1592	7.60	16.21
		West	1654	1471	183	1	1654	11.06	12.95
		North	1621	1498	123	1	1621	7.58	14.68
		South	1472	1498	-26	1	1472	-1.76	22.53
2	St Estifanos	East	1682	1775	-93	2	3364	-2.76	11.47
		West	1631	1775	-144	2	3262	-4.41	14.16
		North	1678	1450	228	2	3356	6.79	11.68
		South	1534	1738	-204	2	3068	-6.64	19.26
3	saris	East	1571	1485	86	1	1571	5.47	17.32
		West	1363	1485	-122	1	1363	-8.95	28.26
		North	1565	1520	45	1	1565	2.87	17.63
		South	1500	1520	-20	1	1500	-1.33	21.05
4	Banko deroma	East	1687	1447	240	2	3374	7.11	11.21
		West	1385	1447	-62	2	2770	-2.24	27.11
		North	1853	1725	128	2	3706	3.45	2.47
		South	1483	1725	-242	2	2966	-8.16	21.95

5	jemmo	East	1594	1495	99	1	1594	6.21	16.11
		West	1569	1495	74	1	1569	4.72	17.42
		North	1704	1504	200	1	1704	11.74	10.32
		South	1339	1504	-165	1	1339	-12.32	29.53

- Model (SFR=990+288TL+8.5SL-26.8G) from A Comparative Study of Operational Performance between Roundabout and Signalized Intersection Using Sidra Software: A Case Study of Addis Ababa City (15)

As the table above shows statistical saturation flow rate deviate from highway capacity manual by 29.53% and with the local study by 12.32% and this shows that studying saturation flow rate at a point is more important than randomly use HCM ideal value.

5 Discussion

This study presents a saturation flow rate analysis of selected Addis Ababa's signalized crossings under mixed traffic situations. In order to collect information on traffic volume and speed on city roads, utilizing a video graphic method, the saturation flow was ascertained. In some metropolitan settings, differences in saturation flow and density may be the cause of the discrepancy in actual traffic handling capacity observed at intersections and on links.

This work investigates the effects of specific parameters and the saturation flow rate at signalized junctions. A saturation flow rate estimation model was developed using the collected field data. Because of their complexity, just some of the relevant factors like approach grade, lane width, and traffic composition are looked at.

Industrialized and developing countries have different characteristics that affect saturation flow levels due to their different traffic cultures. Numerous factors, including as the route, traffic, environment, and control status, affect saturation flow. Numerous parameters need to be carefully taken into account while calculating saturation flow. varying road conditions and traffic patterns are associated with varying saturation flow values, according to research from multiple nations. Different criteria and research show different values, even within the same nation.

The saturation flow rates are affected by the type of vehicle and vary in magnitude with movement. In previous studies, the mobility impact was rarely considered when calculating PCE. In practice, movements which were frequently separated into many lane groups were utilized to determine saturation flow rates. To increase the model's accuracy, various PCE were used for various movements.

Even while this paper just examines a few of the relevant factors, other studies demonstrates that the findings differ from the HCM because of cultural differences and driving behaviors.

It is shown that the saturation flow calculated from the field study is less than the saturation flow calculated using a generalized HCM method, which has a 29.53% error using the Highway Capacity Manual and a 12.32% error when compared to local data. A road and transport engineering project done on saturation flow rate and influencing factors in Addis Ababa also shows a values lower than highway capacity manuals ideal saturation flow rate value. 1462 vehicles per hour per lane for exclusive left lane, 1542 vehicles per hour per lane for through lane, 1492 vehicles per hour per lane for through plus right lane, 1446 vehicles per hour per lane for shared left and through lane. It turns out that the saturation flow per meter width also tends to increase when the percentage of small vehicles rises because of heterogeneity and gap filling, but it tends to decrease as the percentage of cars rises because of rising homogeneity.

Varying vehicle types have varying saturation flow rates, and different maneuvers have different levels of effect. In previous studies, the mobility effect was rarely taken into account while computing PCE. The through and turn movements were frequently separated into different lane groups, and saturation flow rates were computed in practice.

Only the Saris Abo Junction had a countdown timer for cars during the data collection period; the other four intersections lacked either a pedestrian or a car countdown timer. A pedestrian countdown signal (PCS) is intended to give pedestrians extra information at crossings and assist them in making crossing decisions, though the PCS data may also influence drivers' actions when it is visible to them.

During data collection all signal were pre-timed, and regardless of traffic flow, pre-timed traffic lights repeat a predetermined series of phases on a regular basis. Depending on the time of day, such as during peak hours, the phases' duration may vary. Needless delays are one of the disadvantages of using fixed-time signals. Pre-timed signals may cause automobiles to wait at intersections for long periods of time even when there is no traffic since they repeat a predefined, steady cycle.

Self-actuated technologies are getting increasingly sophisticated these days. Depending on whether there are vehicles or pedestrians at a crossing, activated signals may respond. The controllers can change the cycle duration and green times in response to detector activation, as well as the phase order and sequence. Activated control is made up of intervals that are called and extended in response to vehicle detectors. We have to exercise it too.

The existence of CCTV cameras was another aspect of field observation. According to studies, these gadgets give security personnel the ability to monitor traffic in real time and capture video to enhance operations and utilize in the case of an incident or crime. In addition to providing information on traffic flow near the intersection, traffic monitoring cameras can assist minimize accidents in high-accident regions by up to 15–25%. However, at the time of data collection, none of the intersections had operational cameras.

This thesis work findings indicated that pedestrians are not significant factors in through lane saturation flow. Further research should be done on the matter; however, the published research found that pedestrians had the biggest impact on saturation flow in the conflict zone, where there is a higher likelihood of pedestrians and vehicles colliding during turning movements rather than through movement.

6 Conclusion and recommendation

6.1 Conclusion

These recorded saturation flow rates are typically up to 29% lower than the optimal levels recommended by the Highway Capacity Manual (HCM). Number of vehicles and green time of the signals were independent factors. As a result, a combined model incorporating these factors had developed.

In assessing saturation flow, the amount and quality of data that accurately depicts traffic flow across an intersection are critical factors, and the lack of data is one of the main problems, particularly for mixed traffic streams where vehicle behavior is more essential.

Furthermore, a lot of people record videos, which makes it harder to collect and extract data from the material. The uneven distribution and absence of lane-controlled mixed traffic stream can sometimes make it difficult to reliably extract data from the recorded video. As a result, it may be able to collect images of traffic flow in all directions and use contemporary technologies like CCTV to infer the characteristics of each type of vehicle.

Only five junctions were examined in the study, and the findings are based on a very small number of observations made during two hours of the day. Therefore, in order to do additional study in the future, a great deal of data must be gathered and analyzed.

6.2 Recommendation

Using Highway capacity manual ideal saturation flow value over estimate in our condition and whenever we need to know we have to take the real ground data at the spot.

It should be noted that the model was created under particular circumstances and with a particular range of variables (season, traffic, places). If the model is used outside of these parameters, the forecast may be less accurate.

Green time has a stronger effect. Both long and short green times may eventually result in a modest drop-in saturation flow rate and there should be proper green time adjustment in signals or they should be self-actuated.

Additionally, more research should be done on the effect of pedestrian on through lane saturation flow rate.

7 References

1. Hordofa Tullu H, Tucay Quezon E. Determination of Passenger Car Unit for Urban Roads: A Case Study in Addis Ababa. Am J Constr Build Mater. 2021;5(2):57.

2. Elsahly OM, Abdelfatah A. Estimation of Saturation Flow Rate at Signalized Intersections in the UAE. 2023;(February 2021).

3. Chen Y, He Y, Sun X. Impact of Pedestrian Traffic on Saturation Rate of Protected Left-Turn at Urban Intersections. Open J Appl Sci. 2015;05(01):22–31.

4. Mondal S, Gupta A. A review of methodological approaches for saturation flow estimation at signalized intersections. Can J Civ Eng. 2020;47(3):237–47.

5. Indriastuti AK, Priyono EEY. Effect of Pedestrians on the Saturation Flow Rate of Right Turn Movements at Signalized Intersection – Case Study from Rasht City Effect of Pedestrians on the Saturation Flow Rate of Right Turn Movements at Signalized Intersection - Case Study from Rasht .

6. Roshani M, Bargegol I. Effect of Pedestrians on the Saturation Flow Rate of Right Turn Movements at Signalized Intersection - Case Study from Rasht City. IOP Conf Ser Mater Sci Eng. 2017;245(4).

7. Ramireddy S. EFFECT OF PEDESTRIAN CROSSING ON SATURATION FLOW AT SIGNALIZED EFFECT OF PEDESTRIAN CROSSING ON SATURATION FLOW AT INTERSECTIONS IN MIXED TRAFFIC. 2023;(November).

8. Paganini F. Quantifying Saturation Flow of Right Turning Lanes on Intersections. 2017;(July).

9. Analysis MM. HIGHWAY CAPACITY M ANUAL 7th Edition. 2022.

10. Mustaq SN. Literature Review on Saturation Flow at Signalized Intersection under Mixed Traffic Flow Condition. 2017;3(09):450–3.

11. Mondal S, Gupta A. Assessment of saturation flow at signalized intersections : a synthesis of global perspective and future directions. 2020;119(1).

12. Dehghani-Zadeh M, Fallah Tafti M. Estimating saturation flow under weak discipline

traffic conditions, case study: Iran. Arch Transp. 2018;46(2):47–60.

13. Taylor P, Radhakrishnan P, Mathew T V. Transportmetrica Passenger car units and saturation flow models for highly heterogeneous traffic at urban signalised intersections. 2009;(November 2014):37–41.

14. Shang H, Zhang Y, Fan L. Heterogeneous Lanes' Saturation Flow Rates at Signalized Intersections. Procedia - Soc Behav Sci [Internet]. 2014;138(0):3–10. Available from: http://dx.doi.org/10.1016/j.sbspro.2014.07.175

15. Yimer HM, Dugad SB, Gangwar PK, Halefom A. Comparative Study of Operational Performance between Roundabout and Signalized Intersection Using Sidra Software : A Case Study of Addis Ababa City. 2021;(November).

16. Tulu GS, Washington S, King MJ, Haque MM. Why are pedestrian crashes so different in developing countries? A review of relevant factors in relation to their impact in Ethiopia. Australas Transp Res Forum, ATRF 2013 - Proc. 2013;(January).

17. Biswas S, Ghosh I. Estimation of the Passenger Car Unit and Stream Equivalency Factor at Signalized Intersections Under Heterogeneous Traffic Condition. Transp Res Board 96th Annu Meet. 2017;(January 2017):1–17.

18. Turner J, Harahap G. Simplified saturation flow data collection methods. CODATU Vi Conf Dev Plan Urban Transp. 1993;February:1–15.

19. Analysis of Saturation Flow at Signalized Intersection in Urban Area : Surat. 2016;2(12):505–9.

20. Savitha BG, Murthy RS, Jagadeesh HS, Sathish HS, Sundararajan T. Study on Geometric Factors Influencing Saturation Flow Rate at Signalized Intersections under Heterogeneous Traffic Conditions. 2017;83–94.

21. Hadiuzzaman M, Rahman M, Karim MA. Saturation Flow Model at Signalized Intersection for Non-lane Based Traffic. Can J Transp. 2008;2(1):77–90.

22. Stokes RW. Comparison of saturation flow rates at signalized intersections. ITE J (Institute Transp Eng. 1988;58(11):15–20.

23. Wang Y, Rong J, Zhou C, Chang X, Liu S. An Analysis of the Interactions between Adjustment Factors of Saturation Flow Rates at Signalized Intersections. 2020;(X).

24. Mavani AJ, Patel HB. Saturation Flow Rate Measurement on a Four Arm Signalized Intersection of Ahmedabad City. 2016;5(03):298–303.

25. Biswas S, Chakraborty S, Ghosh I. Saturation Flow Model for Signalized Intersection under Mixed Traffic Condition. 2018;

26. Bonneson J, Nevers B, Zegeer J, Nguyen T, Fong T, Institute TT, et al. Guidelines for Quantifying the Influence of Area Type and Other Factors on Saturation Flow Rate. 2005;(January 2005):88p. Available from: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/fdot-do2319-rpt.pdf%0Ahttps://trid.trb.org/view/758083

27. Boumediene A, Brahimi K, Belguesmia N, Bouakkaz K. Saturation flow versus green time at two-stage signal controlled intersections. Transport [Internet]. 2009;24(4):288–95. Available from: https://doi.org/10.3846/1648-4142.2009.24.288-295

28. Shao C, Rong J. Study on the Saturation Flow Rate and Its Influence Factors at Signalized Intersections in China Study on the Saturation Flow Rate and Its Influence Factors at Signalized Intersections in China. 2017;(December 2011).

29. Mukwaya Kampala saaturation flow rate for for through traffic at signalized intersections of kampala.pdf.

30. Ali SAG. Entering Headway for. Transp Res Rec J Transp Res Board. (99):42–7.

31. Sushmitha R, Ravishankar K. Effect of Pedestrian Crossing on Saturation Flow At Signalized Intersections in Mixed Traffic Conditions. Suranaree J Sci Technol. 2021;28(2):1–12.

32. Novikov A, Novikov I, Shevtsova A. Study of the impact of type and condition of the road surface on parameters of signalized intersection. Transp Res Procedia [Internet]. 2018;36:548–55. Available from: https://doi.org/10.1016/j.trpro.2018.12.154

33. Wael K. M. Alhajyaseen, Hideki Nakamura. Design Criteria for Crosswalk Width and

Position at Signalized Intersections. J Civ Eng Archit. 2012;6(7).

34. Guidelines for Traffi c Signals R 1 RiLSA. 2021;

35. Dissertation D. An Estimation Method of Exclusive Left-Turn Lane Capacity Considering the Bi-directional Flow of Crossing Pedestrians at Signalized Intersections. 2021;

36. Oskarbski J, Guminska L, Miszewski M, Oskarbska I. Analysis of Signalized Intersections in the Context of Pedestrian Traffic. Transp Res Procedia [Internet]. 2016;14:2138–47. Available from: http://dx.doi.org/10.1016/j.trpro.2016.05.229

37. Shao CQ, Liu XM. Estimation of saturation flow rates at signalized intersections. Discret Dyn Nat Soc. 2012;2012:1–10.

38. Steuart GN, Shin BY. Effect of Small Cars on the Capacity of Signalized Urban Intersections. Transp Sci. 1978;12(3):250–63.

39. Eya MA, Sinniah GK, Shah MZ, Kamarudin N, Planning R, Teknologi U. Efficiency of Passenger Car Units in Analysing Urban Road Traffic Congestion in Nigeria . 2022;3359:1–10.

40. Raj P, Sivagnanasundaram K, Asaithambi G, Ravi Shankar AU. Review of Methods for Estimation of Passenger Car Unit Values of Vehicles. J Transp Eng Part A Syst. 2019;145(6).

41. Molla D. Addis ababa road safety strategy (2017 - 2030). Addis Ababa Road Saf Strateg. 2017;

42. Gunjo SB, Guta DD, Damene S. Modeling the economic cost of congestion in Addis Ababa City, Ethiopia. Environ Syst Res. 2024;13(1).

43. Cacciattolo M. Ethical considerations in research. Prax English Lang Teach Learn Beyond Bin Res Crit EFL Classrooms. 2015;35(10):55–73.

44. Hellendoorn J, Zegeye SK, Zwarteveen JW. Urban traffic flow modeling in Addis Ababa. 2011;620–5.

45. Ranasinghe W, Bunker J, Bhaskar A. Saturation Headway Variation at a Signalised Intersection Approaches with a Downstream Bus Stop and Bicycle Lane.

2017;(November):1–17.

46. Al-obaedi JTS. Estimation of Passenger Car Equivalents for Basic Freeway Sections at Different Traffic Conditions. 2016;(May):153–9.

47. Journal C. Saturation Flow Model at Signalized Intersection for Non-lane Based Traffic Md Hadiuzzaman, Md Mizanur Rahman and Md Ahsanul Karim. 2008;2(May 2009).

48. Joshi RS, Goliya HS. CAPACITY AND DYNAMIC PCU ESTIMATION OF URBAN ROADS FOR HETEROGENEOUS TRAFFIC : A CASE STUDY IN INDORE CITY. 2021;(May):320–6.

49. Ibrahim M, Kumar KM, Kumar RS. Saturation Flow Concept at Signalized Intersection for Non Lane Based Traffic. Int J Innov Res Sci [Internet]. 2017;6(1):801–8. Available from: https://www.ijirset.com/upload/2017/january/34_1_SATURATION_N.pdf

50. Eya MA, Sinniah GK, Shah MZ, Kamarudin N, Planning R, Teknologi U. EFFICIENCY OF PASSENGER CAR UNITS IN ANALYSING URBAN ROAD TRAFFIC CONGESTION IN NIGERIA . 2022;3359:1–10.

51. ERA. The Federal Democratic Republic Of Ethiopia Ethiopian Roads Authority Pavement Design Manual Vloume I: Flexible Pavements. Pavement Des. 2013;I(March):281.

52. Tadiyos Marie. Travel Speed Using Artificial Neural Network. 2021;

53. Engineering T. ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING PASSENGER CAR EQUIVALENCE UNDER SEVERAL UPGRADE (For Cases under Addis Ababa City). 2023;

54. Chand S, Gupta NJ, Velmurugan S. ScienceDirect ScienceDirect ScienceDirect Development of Saturation Flow Model at Signalized Intersection for Heterogeneous Traffic Development of Saturation Flow Model at Signalized Intersection for Heterogeneous Traffic. Transp Res Procedia [Internet]. 2017;25:1662–71. Available from: http://dx.doi.org/10.1016/j.trpro.2017.05.216

55. Mondal S, Chakraborty S, Roy SK, Gupta A. Estimation of passenger car unit for heterogeneous traffic stream of urban arterials : case study of Kolkata. Transp Lett

[Internet]. 2017;7867(April):0. Available from: http://dx.doi.org/10.1080/19427867.2017.1293313

56. Tullu HH, Quezon ET. Determination of Passenger Car Unit for Urban Roads : A Case Study in Addis Ababa Email address : 2021;5(2):57–63.

57. Al-Mosawi UG, Al-Jameel HA. Estimating Base Saturation Flow Rate for Selected Signalized Intersections in Al-Najaf City. E3S Web Conf. 2023;427:1–7.

58. Li H, Prevedouros PD. Detailed Observations of Saturation Headways and Start-Up Lost Times. 2000;(02):44–53.

8 Annex

Annex 1 observation checklist

1. is there a countdown timer for pedestrian and car?
2. Is the traffic light pre timed or semi actuated or fully actuated?
3. Is there a push button for pedestrian movement?
4. Is there a proper zebra crossing?
5. Is there a camera control?
6. Is there a parking on lane?
7. Is there a special service lane utilization?
8. Is there a work zone around intersection?
9. Is there a bus stop around intersection?
10. Is there a downstream lane blockage?

Annex 2 data summary tool

R/No	Name of Intersection	Road class	Approach from	Grade	Number of lane		Width(m)	Cycle time(S)	Green time(S)	Yellow time(S)	Red time(S)	Vehicle type	Arriving pedestrians /cycle	Waiting pedestrians /cycle	Unauthorized pedestrians /cycle
			East		left turn										
					through										
					right										
					total										
			West		left turn										
					through										
					right										
					total										
			North		left turn										
					through										
					right										
					total										
			South		left turn										
					through										
					right										
					total										
			grand total												

Annex 3 List of signalized intersections in Addis Ababa (Source Traffic Management Authority)

No	Junction name / location
1.	Golf club
2.	Ayer tena
3.	Kokeb Hotel
4.	Jemo Michael
5.	Jemo-1(F)
6.	Lebu(F)
7.	Adey Abeba
8.	Adey Abeba CBE - Saris LRT Station
9.	Matador Addis Tyre
10.	Abo-Roundabout LRT station
11.	Saris Abo(F)
12.	Kadisco(F)
13.	Bole Michael (F)
14.	Bole Brass
15.	Imperial Ring (F)
16.	Bisrate Gebriel
17.	Mekanisa Bridge (Kore MELETEFIA/AMINGO Cafe/T-Junction)
18.	Lideta Tsebel
19.	AU sq.
20.	Tembaho Monopol
21.	Bulgaria Mazoria
22.	ICL Laboratory
23.	Shola-2
24.	Shola-1
25.	British Embassy
26.	Bylere
27.	Tito/Guinea Conakry St.
28.	Holand Embassy
29.	Kolfe 18
30.	Atena Tera
31.	On Dej. Belay Zeleke st, Addisu Gebeya, close to Addisu-gebeya market center
32.	Yohannis
33.	Senegal / Dej Hailesilasie /
34.	Tunenisa Avenue Intersection of Wawel st./ General Wingate st./ Churchill Av.
35.	Tikur Anbesa
36.	ETV
37.	Beherawi(F)
38.	Harambe Hotel(F)
39.	Senga Tera(F)
40.	Goma Kuteba
41.	Amistegna
42.	Lideta Condo
43.	Lideta Land Administration
44.	Koka
45.	Ledeta Church
46.	Mexico Sq Roundabout
47.	Mexico(F)
48.	Commerce
49.	Legehar(F)
50.	St. Joseph(F)
51.	St. Estifanos(F)
52.	Yordanos Hotel/along LRT
53.	Mikey Layland / Namibia / Cape Verde / Ghana Stree
54.	24(F)

55.	Megenagna Roundabout - Adwa Sq
56.	Gurd Shola LRT Station
57.	Wossen (F)
58.	Wossen 02
59.	Wossen Michael
60.	Abem Hotel
61.	St Estifanos/Meskel Square towards Bole Airport
62.	Flamingo/Oromia President Office Bole Road
63.	Shewa Bekery/Shewa Dabo on Bole Road
64.	Sur Construction on Bole Road
65.	Bole Printing Press on Bole Road
66.	Ruwanda / Junction to St.
67.	Michael Church on Bole Road Fantu Supermarket on Bole Road
68.	Millennium Hall on Bole Road
69.	Gerji Mebrathail
70.	Gerji Mebrat Hail Road to Unity University

71.	Jacros (F)
72.	Salitemihret (F)
73.	Figa
74.	Safari (F)
75.	Goro
76.	Lem Hotel along LRT
77.	Haya hulet Meklit Building along
78.	LRT Century Mall along LRT
79.	Salitemihiret church along LRT Station 1
80.	Salitemihiret church along LRT Station 1
81.	Zerihun Building Wuha Limat along LRT
82.	Management Institute along LRT
83.	CMC Michael LRT Station
84.	CMC Michael along LRT Crossing
85.	CMC
86.	CMC Roundabout along LRT
87.	Station 2 Meri along LRT crossing
88.	Ayat LRT Station
89.	St. Mary(F)

90.	Parliament Office
91.	337
92.	Sebategna 1
93.	Abnet Roundabout
94.	Bereberie Berenda
95.	CMC Roundabout along LRT
96.	Station 2 Meri along LRT crossing
97.	Ayat LRT Station
98.	St. Mary(F)