



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
SCHOOL OF CIVIL AND ENVIRONMENTAL
ENGINEERING

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED
SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA**

By: Michael Amare Mekonnen

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of
the Requirements for the Degree of
Master of Science

In

Road and Transport Engineering

Research Advisor: Bikila Teklu Wodajo (PhD)

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May, 2019

Addis Ababa, Ethiopia

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UNDERTAKING

I certify that research work titled “*Through Traffic Passenger Car Equivalents for Selected Signalized Intersections in Addis Ababa, Ethiopia*” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Date: May, 2019

ABSTRACT

Currently, there are about 34 registered signalized intersections in Addis Ababa. As most of developing countries the capacity and level of service for these facilities is measured using manuals adopted from overseas. Among the overseas manuals the Highway Capacity Manual (HCM 2010) is the most common one. Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. To address such differences HCM(2010) has a conversion to saturation flow rate of signalized intersections in units of passenger cars per hour per lane (pc/h/l_n). Currently, a PCE value of 2.0 is specified for all through heavy vehicles where no distinction is made between trucks, recreational vehicles, buses and other vehicles in the calculation of the adjusted saturation flow rate at signalized intersections.

Traffic and drivers behavior in other countries may be significantly different from the situation in Addis Ababa, Ethiopia. Developing local values will minimize the errors we incur at every step of our capacity analysis due to the use of adopted manual input parameters. In this study the researcher has developed local through traffic passenger car equivalents for small busses, large busses, trucks and truck trailers on selected signalized intersections of Addis Ababa with significant number of heavy vehicles. Using drone technology as a data collection tool and deploying the headway ratio method for determining through traffic PCEs the researcher has come up with new local values. The study showed that the mean local PCEs of Small Busses are 1.49, 1.51, and 1.68 on first (inner), second (middle), and third (outer) lanes respectively. Similarly the mean local PCEs of Large Busses are 1.95, 2.20, and 1.99 on first (inner), second (middle), and third (outer) lanes respectively. Trucks on the other hand have mean local PCE values of 1.62, 1.56, and 1.44 on first (inner), second (middle), and third (outer) lanes respectively. Whereas, Truck Trailers have larger mean local PCE values which are 3.62 and 3.78 on second (middle) and third (outer) lanes respectively. Moreover, on relatively level approaches the PCEs are larger than the PCE values on down and upgrades. While, lane width has low effect on PCEs, approach width has significant effect on PCEs. Similarly, the available green time has direct relationship with the PCE values.

Key Words: Passenger Car Equivalents, Saturation Flow Rate, Signalized Intersections, Headways

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DEDICATION

To my sister, Tigist Kebede Refaw

(This one goes to you)

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ACRONYMS

HCM	Highway Capacity Manual
PCE	Passenger Car Equivalence
PCU	Passenger Car Unit
ERA	Ethiopian Roads Authority
PC	Passenger Car
CEO	Chief Executive Officer
Eng	Engineer
Dr	Doctor
LB	Large Bus
SB	Small Bus
T	Truck
TT	Truck Trailer
FT	First
SD	Second
TD	Third
VT	Vehicle Type
LGP	Lane Group
A.A	Addis Ababa
M	Meter
Ln	Lane
CI	Confidence Interval

CHAPTER 1 INTRODUCTION

1.1 General Background

Major urban junctions are designed as signalized intersections. In fact, traffic lights at junctions are used for improving safety, reducing mean time to cross junctions and consequently increasing capacity. Appearance of different vehicles at junctions has caused many problems for urban traffic engineers and planners. The vehicles are different as far as speed, time headway, dimensions, and size are concerned (Saman Sadeghiyan, 2014).

The important parameters in the planning, design and control of a signalized intersection are saturation flows, lost times and passenger car units (PCU) (Md Hadiuzzaman, 2008).

Moreover in signalized intersection design and traffic operations on roadway facilities, passenger car unit values (PCU) and saturation flows are very important and can vary across cities owing to differences in traffic mix and vehicle characteristics as well as differences in driver behavior, regulation and enforcement. Local values no matter how crude may be preferred (Charles Anum Adams, May , 2014).

Saturation flows however, are influenced by the proportion and type of vehicles in the traffic stream. Therefore, passenger car equivalents (PCE) are usually assigned to various categories of vehicle in order to normalize the saturation flow to the common base of passenger car units per hour (pcu/hr) (Dr Leong Lee Vien, 2006).

When traffic light turns red, a long queue of different vehicles is formed at a junction, which affects traffic flow with respect to their sizes. The space occupied by a heavy vehicle in a lane exceeds a car.

Therefore, based on the weight and effect of each vehicle leaving on traffic flow, it should be changed into a unique unit. The best unit is PCE factor and/or its passenger car unit called PCU. The PCE rate is determined as per a standard car in which the car's PCU is assumed equal to 1. Besides, PCE factor is not a fixed value and it varies from one place to another under the traffic condition of that junction. The concept of PCE is number of vehicles that may be substituted by a special vehicle in a traffic flow without causing any change in the other performance parameters of the flow.

In fact at intersections, vehicles do not follow ordered queue and lane discipline. Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. The problem of measuring volume of such mixed traffic has been addressed by converting different vehicles categories into equivalent passenger cars and expressing the volume in terms of Passenger Car Unit (PCU) per hour (Gowri Asaithambi, 2017).

Several researchers globally , and some local studies have tried to determine local PCE factors considering site specific traffic composition, intersection geometry , whether condition , driver behavior and other important factors. This research tries to generate appropriate local PCE values and to study the relationships of the newly found PCEs with different traffic and geometric parameters of signalized intersections of Addis Ababa.

1.2 Statement of the Problem

The most common method used for analysis of signalized intersections is contained in the Highway Capacity Manual 2010 (HCM). In this method, the base saturation flow rate of a signalized intersection is defined in units of passenger cars per hour per lane (pc/h/ln).

To account for the presence of large trucks in the traffic stream, HCM 2010 includes a Passenger Car Equivalency (PCE) value.

- ✚ Currently, a PCE value of 2.0 is specified for all through heavy vehicles.
- ✚ No distinction is made between trucks, recreational vehicles, buses and other vehicles in the calculation of the adjusted saturation flow rate at signalized intersections.

This adopted single value of PCE may lead designers and planners to over/under-estimate the capacities of signalized intersections in the capital city of Ethiopia, Addis Ababa.

1.3 Hypothesis and Research Questions

1.3.1 Hypothesis

With the Student's T-test distribution hypothesis test for the sample mean (μ) when the population standard deviation (σ) is unknown will be done. The null hypothesis for this research is that the Passenger Car Equivalence (E_T) factors for different vehicle categories

in Addis Ababa equals to 2 and the alternate hypothesis will be the Passenger Car Equivalence (E_T) factors are different from HCM value of 2.

H_0 : Passenger Car Equivalence (E_T) for different vehicle categories in A.A, $\mu = 2$

H_1 : Passenger Car Equivalence (E_T) for different vehicle categories in A.A, $\mu \neq 2$

$$t \approx \frac{\bar{x} - \mu}{s/\sqrt{n}}, \text{ with d.f.} = n-1 \dots \dots \dots \text{Eqn -1.1}$$

1.3.2 Research Questions

- ✚ What are the local through traffic PCE values for selected signalized intersections in Addis Ababa for different vehicle categories?
- ✚ Does the local through traffic PCE values significantly differ from HCM (2010) suggested value?
- ✚ How can these local through traffic PCE values affect the capacity analysis of signalized intersections of the City?
- ✚ Which population parameters have the highest effect on the determination of local through traffic PCE values?

1.4 Objective of the Study

1.4.1 General Objectives

Estimate local PCE values in mixed traffic and check whether the PCE value adopted from other countries manuals will describe the situation in our country and insight the effect of the adopted PCE value for local analysis use.

1.4.2 Specific Objectives

- ✚ To determine appropriate local through traffic PCE values of different categories of vehicles for use in signalized intersections analysis in Addis Ababa.
- ✚ To compare and contrast the newly found local through traffic PCE values with the HCM 2010 PCE value of 2 and local studies.

- ✚ To study the effect of geometric parameters (longitudinal grade, lane width, number of lanes, lane group) and Traffic parameters (Heavy vehicle percentage) of intersections on local through traffic PCEs.
- ✚ To show the impacts of the gap on the analysis of local signalized intersections in Addis Ababa City.

1.5 Scope and Limitation of the Study

1.5.1 Scope of the Study

The scope of the study covers determining local through traffic Passenger Car Equivalence (E_T) factors for different vehicle categories at signalized intersections in Addis Ababa and compare the new values with the existing HCM (2010) Manual Passenger Car Equivalence (E_T) value of 2. Also, the study will model the relationship of local through traffic PCEs with geometric and traffic parameters of signalized intersections in the city.

1.5.2 Limitation of the Study

- ✚ This research focuses only on through passenger car equivalents.
- ✚ Only Certain Vehicle Types and Geometric Parameters will be used for the selected intersections.
- ✚ The study does not consider weather and road surface conditions.
- ✚ Three wheelers, Bicycles and Motor Cycles are not incorporated in this study.
- ✚ Due to budget and other constraints data for each pre-timed intersection was collected for only 2:30 hrs.

1.6 Research Challenges

- ✚ Although data collection using drones produces a high quality aerial video, it has drawbacks for continuous video recording applications. One drone is capable of recording only 18 minutes continuous video with fully charged battery. To capture 2:30 hour continuous video it required three drones and three extra batteries which was challenging during the data collection process. Also, finding camera professionals who have drones and are willing to take videos using drones in city areas was difficult.
- ✚ There is no grounding rule which prohibits or allows the use of drones in city areas. The researcher has tried to get permits for the data collection even though there was

no responsible governmental organization who is willing to take the risks. The bureaucracy is tedious and time consuming which makes the data collection schedule late.

- ✚ The other main challenge for the research was video data extraction. To extract time headway data the existing softwares are expensive and the video was extracted manually. It took about two months to extract all the videos manually which was tedious and tiresome.

1.7 Contribution and Impact of the Study

- ✚ The research may contribute to the efforts made to use locally developed values for analysis and design of different infrastructures.
- ✚ It may add value to previously accomplished studies in similar specific concerns by using more accurate data collection technology and analysis methods.
- ✚ Previous work by (Girum Tamene, 2016) on Addis–Adama Expressway tried to find PCEs for Buses and Trucks as one vehicle class and the study was devoted to only Freeways. Another Study on signalized intersections by (Bogale Shiferaw, 2015) was conducted using other country’s vehicle classification and with analysis Technique called synchronous Regression. Therefore, this study has a unique contribution by using our country’s vehicle classification and tried to find PCEs for different vehicle types by applying the most appropriate and recommended analysis methods.
- ✚ Also it may show policy makers, research institutions and different stake holders of the transportation sector how much variation will be added to our design and analysis due to the use of adopted values from other countries.
- ✚ Similarly, it will rise the motive to do such ‘a calibration of local parametric values’ type of researches for future fellow researchers.
- ✚ Finally, results may be applicable for real world use with the help of similar studies and approval of respective authorities.

1.8 Organization of the Study

The research paper is organized in five main chapters. Chapter one covers an introduction, statement of the problem, hypothesis and research questions, general and specific objectives of the study, scope and limitations of the study, research challenges and

contribution and impact of the study. Chapter two contains literature review with specific components such as introduction, passenger car equivalence, most common analysis methods, studies around the globe, and recent local studies. Chapter three deals with research methods, materials and procedures in general. Chapter four discusses about the analysis process and explains findings of the research. The last Chapter is chapter five which contains conclusions based on the research findings plus recommendations based on core results of the study.

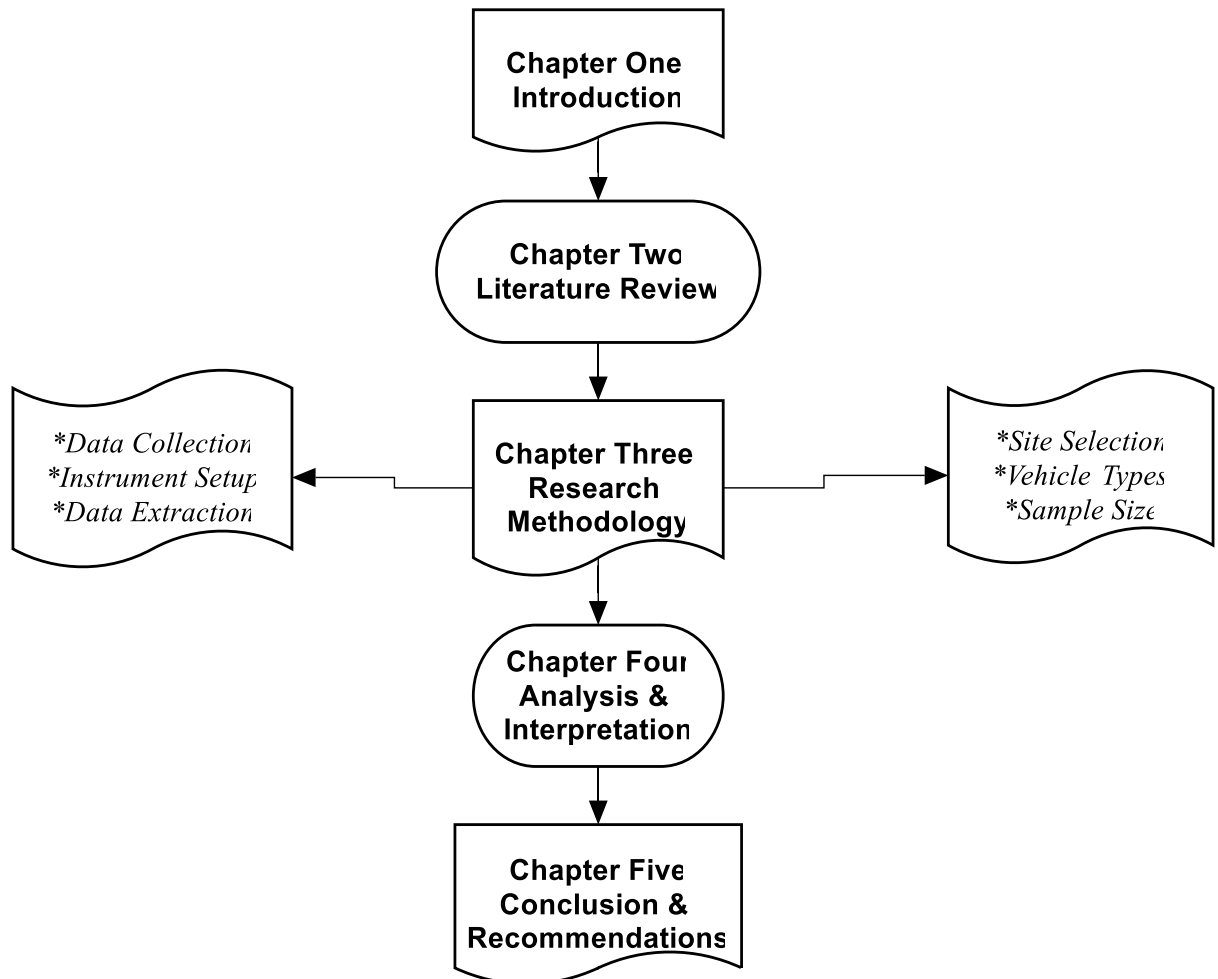


Fig 1.1: Organization of the study

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In different countries researchers have tried to develop local passenger car equivalence factors using different analysis methods. The next section of this paper tries to assess and explore what others study and find out on their specific researches. The review is presented in such a way that *Section 2.2* discusses about the importance of passenger car equivalence. *Section 2.3* highlights the most common analysis methods. *Section 2.4* of the review part tries to skim different studies around the globe. The final section that is *Section 2.5* referred recent local studies in relation to the current topic.

2.2 Passenger Car Equivalence

Signalized intersections play a critical role in the smooth operation of both arterial and urban streets, where traffic movement in different directions meets together. Signalization is a traffic control strategy to ease the competition by providing right of way in a cyclic manner to conflicting traffic at intersections (Prof. Shrinath Karli, November, 2016).

At intersections, vehicles do not follow ordered queue and lane discipline. Different vehicle types occupy different spaces on the road, move at different speeds, and start at different accelerations. The problem of measuring volume of such mixed traffic has been addressed by converting different vehicles categories into equivalent passenger cars and expressing the volume in terms of Passenger Car Unit (PCU) per hour (Gowri Asaithambi, 2017).

In signalised intersection design and traffic operations on roadway facilities, passenger car unit values (PCU) and saturation flows are very important and can vary across cities owing to differences in traffic mix and vehicle characteristics as well as differences in driver behaviour, regulation and enforcement. Local values no matter how crude may be preferred (Charles Anum Adams, May, 2014).

2.3 Most Common Analysis Methods

A) Multiple Linear Regression Method

According to (Parvathy R, 2013) this method, classified vehicle counts are started after 3 sec. of green initiation (startup lost time is about 2-4 sec for the selected intersections).

The saturated green time is regressed against the number of each category of vehicles crossing the stop line during the saturated green time, assuming a linear relationship between the variables. The general form of equation is given below.

$$T = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 \dots \dots \dots \text{Eqn-2.1}$$

Where,

T= saturated green time (sec),

a₀= y-intercept,

a₁= coefficient of car,

a₁, a₂, a₃, a₄, a₅= coefficient for different types of vehicles

x₁, x₂, x₃, x₄, x₅ = number of vehicles of each category in time T.

Following the synchronous regression method site-specific PCU values were obtained for each type of vehicle.

$$\text{Passenger car unit of vehicle type } PCU_i = a_i / a_1 \dots \dots \dots \text{Eqn-2.2}$$

Where, a_i = regression coefficient for a particular type of vehicle

B) Increased Delay Method

In this method PCE values for large vehicles are estimated as a unit value plus the ratio of the increased delay due to the presence of large vehicle in the queue to the base delay of a passenger car when the queue is composed of all basic vehicles or passenger cars (Md. Mizanur Rahman, 2015).

$$\boxed{PCE_{LVj} = 1 + (d_{LGj}/D_o)} \dots \dots \dots \text{Eqn-2.3}$$

Where:

PCE_{LVj} = Passenger car equivalents for a large vehicle at jth queue position

d_{LGj}= increased delay due to the large vehicle at jth queue position

D_o = base delay of a passenger car when all the queued vehicles are passenger car

C) Flow Rate Method

(Lee, et al., July, 2010) determined PCUs of motorcycles at the beginning of a green period. Motorcycles' PCUs were estimated by the flow rate method, the equation of which is shown below:

$$\boxed{pcu_i = \frac{1}{p_i} \left(\frac{Q}{q_m} - 1 \right) + 1} \dots\dots\dots \text{Eqn-2.4}$$

where :

pcu_i : the PCU value of vehicle type i,

Q :the saturation flow rate,

q_m : the mixed flow rate, and

p_i : the proportion of vehicle type i in the mixed traffic.

D) Headway Ratio Method

Headway defined as “the time between two successive vehicles as they pass a point on the roadway, measured from the same common feature of both vehicles (for example, the front axle or the front bumper” (HCM ,2010).

In this method, headways of the vehicles crossing the stop line of the intersection are used to calculate the PCE values. The following condition should be satisfied to calculate the PCE values by the headway ratio method (Gowri Asaithambi, 2017).

$$\boxed{h_{c-c} + h_{x-x} = h_{c-x} + h_{x-c}} \dots\dots\dots \text{Eqn-2.5}$$

Where,

h_{c-c} = Average headway of a car followed by a car;

h_{c-x} = Average headway of a car followed by a type x vehicle;

h_{x-c} = Average headway of a type x vehicle followed by a car;

h_{x-x} = Average headway of a type x vehicle followed by a type x vehicle.

Hence, the PCU is calculated using:-

$$\boxed{PCU_{(x-x)} = \frac{h_{A(x-x)}}{h_{A(c-c)}}} \dots\dots\dots \text{Eqn-2.6}$$

Where,

$(h_{A(c-c)})$ = Adjusted Mean headway of a car followed by a car;

$(h_{A(x-x)})$ = Adjusted Mean headway of a type x vehicle followed by a type x vehicle.

Eventhough there are many methodologies for determination of passenger car equivalents (PCEs), (Kanakabandi Shalin, 2014) states that headway ratio method is the most commonly used method for measuring PCEs at signalized intersections.

2.4 Studies Around the Globe

(Charles Anum Adams, 2014) studied PCEs for Motorcycles, Tricycles, and Buses/trucks in Ghana, Temale city considering two signalised intersections representing urban traffic flow condition by means of video recording data collection technique. Using multiple linear regression analysis technique he has found that motorcycle PCEs of 0.3 and 0.38, tricycle PCEs of 0.75 and 0.67, Bus/Truck PCEs of 1.52 and 1.68 at Barclays Bank and Agric intersections respectively.

(Ye. Fornalchyk, 2015) come up with a study of determining PCEs assuming changes of dynamic properties of vehicles and the growth of their cumulative operational kilometers. Taking cargo-carrying vehicles and buses with speed range of 0.25-3.5 m/s² with the help of VISSIM traffic simulation software he has found PCEs from 1.35-4.14 for different signalised intersections.

On other study in india, Chennai city (Gowri Asaithambi, 2017) has tried to estimate PCEs at signalised intersections for non-lane based mixed traffic using microscopic simulation model for various combinations of vehicular composition, volume levels and road width. Finally he tried to come up with a multiple linear regression model with PCE as dependent variable plus traffic composition and road width as independent variables.

$$PCU_i = a_i + b_{1i}TV + b_{2i}.TW + b_{3i}.Car + b_{4i}.AUTO + b_{5i}.HV + b_{6i}.RW \dots \dots \dots \text{Eqn-2.7}$$

Where: PCU_i – PCU value of the vehicles of class i;

TV – traffic volume in vph;

TW – the proportion of two-wheelers in %;

Car - the proportion of cars in %;

AUTO – the proportion of auto-rickshaws in %;

HV – the proportion of heavy vehicles in %;

RW – the road width in m; b_{1i} , b_{2i} , b_{3i} , b_{4i} , b_{5i} , b_{6i} coefficients corresponding to the independent variables.

(A. A. Obiri-Yeboah, April,2014) evaluated PCEs for medium cars and trucks within Kumasi Metropolis,Ghana at eleven different signalised intersections by underscoring the aim of developing local PCEs and with the use of headway ratio method.He has found PCEs for medium cars 1.65 and 1.35 ,PCEs for trucks 3.05 and 2.25 with and without roadside friction respectively.

In (2006) ,Dr Leong Lee Vien, has discussed the effect of PCEs on the estimation of saturation flows using the audio cassette recording equipment as a data collection instrument.The five vehicle classes he distinguished at 64 Malaysian signalised intersections were:-

Class 1: Passenger cars including taxis, small vans and utilities

Class 2: Lorries with 2 axles and mini buses

Class 3: Trailers with more than 2 axles

Class 4: Buses

Class 5: Motorcycles

According to his data ,“On the average, the traffic flow consists of 60% cars, 30% motorcycles, 5% respectively for lorries and buses and 1% trailers”. This led him to find saturation flows in pcu/hr much larger than the Malaysian HCM (2006) values. As the percentage of motorcycles in the traffic flow go beyond 50%, the percentage drop in saturation flows in pcu/hr is more than 50%. This is mainly due to the impact of the motorcycle PCE value which is less than 1.0. Nevertheless, if the percentages of heavy vehicles were high, the saturation flows in pcu/hr will increase because the PCE values for heavy vehicles are more than 1.0.Based on this logical speculation he showed the relationship of PCEs and saturation flow in pcu/hr.

(Ahmed Anwaar, October, 2011) used the lagging headway to determine PCEs for single unit trucks and combination trucks on basic freeway sections in India. He implemented

three-stage-least-squares (3SLS) regression to generate a model that predicts lagging headways and expanded it to predict lagging headways for each of the nine vehicle-following combinations .Finally he has calculated PCEs as the ratio of the lagging headway of each truck class to that of PC and found 1.3689 and 1.3828 for Single unit trucks and 1.6548 and 1.6443 for combination trucks using three equation three-stage-least-squares (3SLS) and nine equation three-stage-least-squares (3SLS) respectively.

In Dhaka, (Md Hadiuzzaman, 2008) on his study of saturation flow model at signalized intersection for non-lane based traffic tried to determine passenger car equivalents simultaneously. He and his colleagues used synchronous regression method to develop local passenger car equivalents. Also ,the study tried to incorporate lane changing driver behaviors.

After finding local PCE values the researchers have tried to develop models for different vehicle classes for non-lane based traffic.

(LEE, et al., July, 2010) used flow rate method to determine motorcycle passenger car equivalence values at the beginning of green period and in saturation flow states in Central London. The flow rate method calculates PCU values using the difference of the flow rates caused by the presence of a certain vehicle type. The flow volumes for calculating the PCUs were obtained by using a microscopic traffic simulation model.The researcher has found motorcycle PCEs with range of 0.16-0.38 and 0.4-0.61 for beginning of green periods and saturation flow states respectively.

(A.P.Cuddon, 1990) in coloboration with Monash University tried to study the effect of heavy vehicles on saturation flows at signalized intersections.The researchers highlight that heavy vehicle equivalents should be used with care because the underlying proportions of each vehicle type in the traffic stream has a significant effect on the magnitude of the heavy vehicle equivalence.The researchers tried to incorporate 71 sites throughout Melbourne and has used the headway ratio method as an analysis tool.The headway ratio method is briefly described in the research methods part of this paper.

They come up with PCE values of 1.68 ,2.22 and 1.97 for heavy vehicles on through lanes, exclusive left turn lanes and exclusive right turn lanes respectively.

(Cesar J. Molina, May, 1987) with the help of Texas State Dept. of Highways and Public Transportation tried to develop passenger car equivalence for trucks traveling

straight through a level, signalized intersections based on vehicle type and position of vehicle in queue. The study tried to determine PCE of truck based on the total delay it inflicts on all the vehicles traveling behind it. They have found PCE values of 1.7 for light trucks and 3.7 for heavy trucks .

(H. Nassiri, 2017) developed delayed base passenger car equivalence factors for Iran fourteen signalized intersection approaches. Delay based passenger car equivalence has the following form:-

$$d_m = V_m \cdot \sum_{i=1}^n d_{mi} \cdot P_{im} \quad \text{..... Eqn-2.8}$$

$$d\text{-PCE} = 1 + \frac{d_m - d_0}{P_H \cdot d_0} \quad \text{..... Eqn-2.9}$$

Where d_m : is the average delay of approach m,

V_m is traffic volume of approach m,

d_{mi} is the delay of movement i in approach m,

P_{im} is the percentage of movement i in approach m,

d_0 is the basic delay, and

P_{Hi} is the proportion of heavy vehicles i in traffic flow.

According to the study ,the estimated PCE values range from 1.07 to 2.07 for general condition and from 1.15 to 1.65 for one movement at approach. Similarly, for approaches with two and three movements, the PCE varies from 1.07 to 1.99 and from 0.76 to 3.6, respectively.

(Parvathy R, 2013) on his study development of new PCE values and effect of length of passenger cars on PCEs considered two sites in India. The headway method and the regression method were used as analysis tools. Results showed PCEs ranging from 0.45-0.5, 0.83-1, 2.23-4.5, 1.28-1.5, 2.1-3 for Motorcycle, Auto rikshaw, Trucks, Light commercial vehicles and Buses respectively.

(Sarraj, 2014) on his study of Passenger Car Equivalents at Signalized Intersections for Heavy and Medium Trucks and Animal Driven Carts in Gaza, Palestine, used headway ratio method in three signalized intersections. Based on the research he concludes that in Gaza City, PCE values at traffic signals were found to be 2.23, and 1.43 for heavy and medium trucks, respectively. However PCE value for animal driven carts was found to be 1.51.

In Yokohama city of Kanagawa prefecture of Japan (Md. Mizanur Rahman, 2015) tried to measure Passenger Car Equivalents (PCE) for large vehicles at seven signalized intersections. “This study introduces a new method for estimating passenger car equivalents (PCE) for large vehicle at signalized intersections based on increased delay caused by the large vehicle. In this study PCE values for large vehicles are estimated as a unit value plus the ratio of the increased delay due to the presence of large vehicle in the queue to the base delay of a passenger car when the queue is composed of all basic vehicles or passenger cars.” (Md. Mizanur Rahman, 2015). According to the study , PCE value for large vehicle decreases as position of large vehicles in the queue increases. PCE value (for 20% large vehicles) is maximum 1.317 when large vehicle’s position in the queue is first and second, and this value is 1.062 when large vehicle’s position in the queue is nine and ten. Also, (for 30% large vehicles) maximum PCE value is 1.368 and minimum PCE value is 1.066 and this occurred when larger vehicle’s position is first-second-third and eight-nine-ten in the queue respectively. PCE value for large vehicle decreases as position of large vehicles in the queue increases. Large vehicle has a very little impact on the PCE value when it stands at the end of the queue. There is a big difference in PCE value for same percentage of large vehicles due to the change of the position of the large vehicles in the queue. PCE value increases as percentage of large vehicles in the queue increases.

(Saman Sadeghiyan, 2014) on his comparative evaluation of passenger car equivalent factors for different vehicles at traffic-lighted Gorgan junctions based on time headway, found PCEs with values ranging 0.4-0.45, 1.86-1.9 and 2.8-3.12 for Motorcycles , Pickups and Buses respectively.

A study on Lamar–Barton Springs and the Martin Luther King Jr.–Interstate 35 Frontage Road intersections in Austin, Texas (Shabih, 2000) used headway ratio method and resulted in Small Sport Utility Vehicles PCEs of 1.07,0.96 and 1.08 for through, left

turning and right turning lanes respectively. Similarly, he has discovered Large Sport Utility Vehicles PCEs of 1.41, 1.06 and 1.19 for through, left turning and right turning lanes respectively.

2.5 Recent Local Studies

(Bogale Shiferaw, 2015) developed a predictive model for saturation flow rate and estimated passenger car equivalent factors in Addis Ababa on twelve approaches of four signalized intersections with the use of multiple linear regression technique. He has found Minibus PCEs ranging 0.86-1.25, 0.84-1.43, 0.83-1.43, 0.85-1.09 on exclusive through lanes, left turning shared lanes, right turning shared lanes, and exclusive left turn lanes respectively. Also, the study discovered exclusive through lanes, left turning shared lanes, right turning shared lanes, and exclusive left turn lanes Medium Buses/Trucks PCEs ranging 1.28-1.77, 1.34-2.4, 1.68-2.27, and 1.31-1.79 respectively. For Large Buses PCEs range from 1.83-2.82, 2.4-3.38, 2.52-2.83, and 2.23-2.49 on exclusive through lanes, left turning shared lanes, right turning shared lanes, and exclusive left turn lanes respectively.

(Girum Tamene, 2016) tried to estimate passenger car equivalents for basic freeway segments on Addis Ababa – Adama expressway using the equal flow density method. According to the study, when the proportion of trucks and buses is from 10% up to 50%, the Passenger Car Equivalent increases as the proportion of trucks and buses decreases. The major variation observed in lower trucks and buses proportion non-linearly because the interaction between trucks and buses with passenger cars increases. Moreover for trucks and buses proportions from 10% up to 50%, the value of PCE varies in between 1.4 up to 7.8 for upgrade up to 5% which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0. For trucks and buses proportions of 10%, the value of PCE varies with the length of grade in between 5.6 up to 7.8 for 5% upgrade which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0.

CHAPTER 3 RESEARCH METHODS, MATERIALS AND PROCEDURES

3.1 Site Selection

During the data collection there were 34 signalized intersections from which 7 of them are not working and 1 is five legged and not suitable for video recording the approach legs. On selected signalized intersections data were collected for morning peak hours of the day (Time where we can get many vehicles of the desired category and which will significantly show the effect).

The total population of working signalized intersections was categorized into two considering the number of approaches:-

- ✚ 3 three legged
- ✚ 23 four legged

On this paper the researcher has selected 3 four legged and 1 three legged intersections **having significant number of heavy vehicles** with different approach grades, number of lanes, lane width and are connected to heavy vehicle corridors. Considering the **Djibouti Port** as the main entry vessel of the country's import and export trade plus different construction raw material transporter heavy vehicles enter to the city through **Addis Adama Expressway ↔ Tulidimtu ↔ Different parts of Addis Ababa** using different roads linked with the below stated signalized intersections the route is considered heavy vehicle corridor. The selection was done by consulting Addis Ababa Transport Authority Personnel and heavy vehicle drivers who are commuters of the Addis Ababa-Djibouti line.

The intersections were chosen based on the features listed below:-

- ✚ All the intersections had pre-timed signal timing during the time of the survey;
- ✚ The selected intersections represented the typical ones with common vehicular compositions;
- ✚ These intersections were chosen from different locations throughout the city of Addis Ababa to represent intersections with significant number of heavy vehicles and have heterogeneous traffic.



Fig 3.1: Selected pre-timed intersections on revised road network of Addis Ababa

Having the above point in mind, the following signalized intersections were chosen for the study:-

From 3 three legged intersections:

✦ Around Gerji Mebrat Hayl

From 22 four legged intersections:

✦ Around Jemo Michael

✦ Around Lebu Mebrat Hayl

✦ Around Abo Church

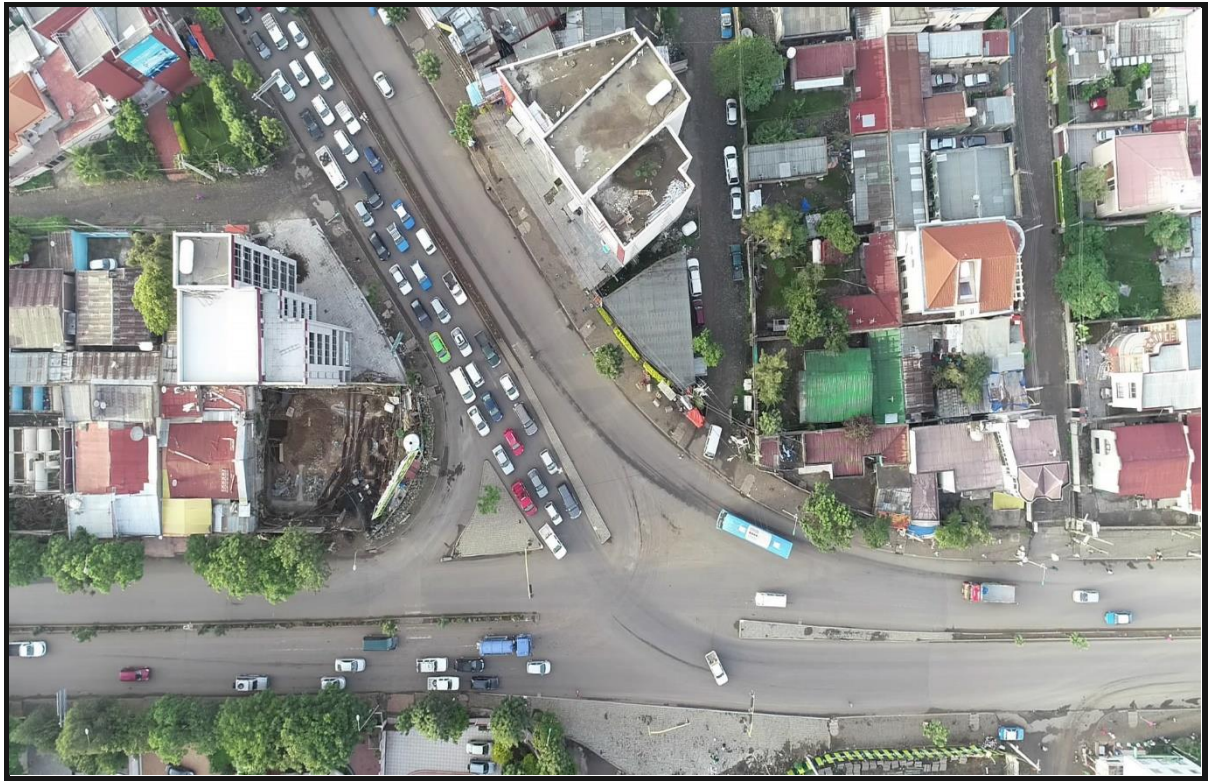


Fig 3.2: Gerji Mebrat Hayl intersection



Fig 3.3: Jemo Michael intersection



Fig 3.4: Lebu Mebrat Hayl intersection

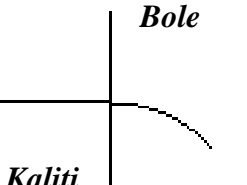
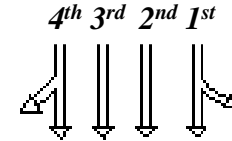
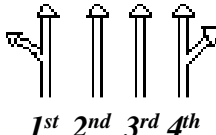
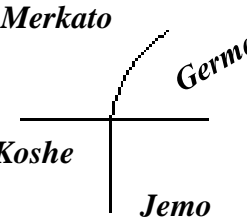
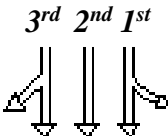
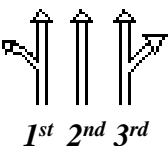
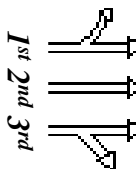
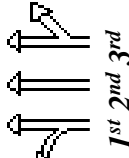
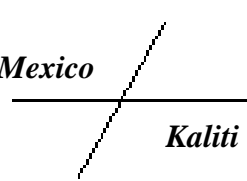
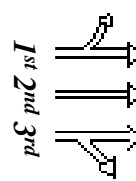
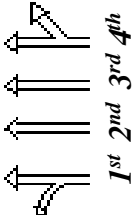
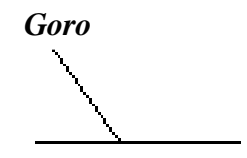
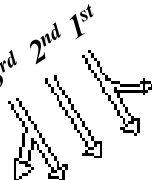


Fig 3.5: Saris Abo intersection

Table 3.1: Summary of Selected pre-timed intersection

Name of Intersection:- <u>GERJI M/HAIL</u>					Lane Width				
Item No	Approach Name	No of Lane	Approach Grade(%)	Green Period	1 st (inner)	2 nd (Middle)	3 rd (Outer)	Total leg Width	
1	Goro-Gerji m/hail	3	-2.49	30	2.6	2.8	3	8.4	
Name of Intersection:- <u>LEBU M/HAIL</u>					Lane Width				
Item No	Approach Name	No of Lane	Approach Grade(%)	Green Period	1 st (inner)	2 nd (Middle)	3 rd (Middle)	4 th (Outer)	Total leg Width
2	Mexico-Lebu	3	2.48	40	4.3	3.45	4.8		12.55
3	Kaliti-Lebu	4	-2.27	40	3.2	2.7	3.4	3.3	12.6
Name of Intersection:- <u>JEMO MICHAEL</u>					Lane Width				
Item No	Approach Name	No of Lane	Approach Grade (%)	Green Period	1 st (inner)	2 nd (Middle)	3 rd (Outer)	Total leg Width	
4	Jemo-Michael	3	2.72	30	3.5	3.57	3.38	10.45	
5	Koshe-Michael	3	-1.26	40	3.8	3.65	3.1	10.55	
6	Merkato-Michael	3	-0.81	46	3.3	3.36	3.2	9.86	
7	German-Michael	3	1.26	40	3.5	3.5	3.3	10.3	
Name of Intersection:- <u>SARIS ABO</u>					Lane Width				
Item No	Approach Name	No of Lane	Approach Grade (%)	Green Period	1 st (inner)	2 nd (Middle)	3 rd (Middle)	4 th (Outer)	Total leg Width
8	Bole-Saris Abo	4	4.24	45	2.7	2.72	2.72	3.44	11.58
9	Kaliti-Saris Abo	4	1.56	45	3.06	2.96	2.93	2.99	11.94

Table 3.2 :Selected Intersections geometry and lane group

Intersections			
<i>Saris Abo</i>			
<i>Jemo Michael</i>			
			
<i>Lebu Mebrathayl</i>			
<i>Gerji Mebrathayl</i>			






From selected Intersections, Lebu Mebrat Hayl at both Bole and Kaliti legs the outer lane is channelized. Similarly, Jemo Michael has two approach legs with outer lanes channelized namely, Merkato and German roundabout approaches. Gerji Mebrat Hayl has channelized outer lane on Goro approach. On the contrary, Saris Abo intersection has no channelized outer lane on all of its approach legs.

3.2 Vehicle Types

The researcher aimed to come up with new PCE values for Small Buses (Class 3) , Large Buses (Class 4), Trucks (Class 5-11) and Truck Trailers (Class 12 & 13) according to the vehicle classification of ERA 2013 manual.




Table 3.3 ERA vehicle classification

(ERA 2013:p.2-3)

ERA VEHICLE CLASSIFICATION					
CLASS	TYPE	AXLES	DESCRIPTION		
1	Car	2	Passenger cars and taxis		Passenger Car
2	Pick-up/4-wheel drive	2	Pick-up, minibus, Land Rovers, Land Cruisers		
3	Small Bus	2	≤ 27 seats		
4	Bus/coach	2	> 27 seats		Trucks and Buses
5	Small truck	2	≤ 3.5 tonnes		

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED
SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA**

(ERA 2013:p.2-3)

ERA VEHICLE CLASSIFICATION					
CLASS	TYPE	AXLES		DESCRIPTION	
6	Medium truck	2 or 3	3.5 - 7.5 tonnes		Trucks and Buses
7	Large 2-axled truck	2	> 7.5 tonnes		
8	3-axled truck	3	*		
9	4-axled truck	4	*		
10	5-axled truck	5	*		
11	6-axled truck	6	*		
12	2-axled trailer	2	*		
13	3-axled trailer	3	*		
14	Unknown vehicle type				

* Not needed for definition

3.3 Headway Data Sample Size Determination

3.3.1 Sampling

For this study the researcher aimed to use Simple Random Sampling to determine required headway combination samples from each of the above signalized intersections with heterogeneous vehicular composition. (A.P.Cuddon, 1990) on his study tried to study effect of heavy vehicles on saturation flows at signalized intersections and found standard deviations for ranging from 0.3-0.7 it will be reasonable to assume a population standard deviation of 0.5 for headway studies.

For 95 % level of confidence, Margin of Error $E=0.05$, and standard deviation $\sigma =0.5$ the minimum number of headways required for the study will be:-

$$n = \left(\frac{z_c \sigma}{E} \right)^2 \dots \dots \dots \text{Eqn -3.1}$$

$$= (1.96 * 0.5 / 0.05)^2$$

$$n = \underline{\underline{385}} \text{ Headways}$$

The researcher has used 7563 Headways (leader-follower combinations) from all four sites which is much greater than the required amount of sample size.

3.4 Research Materials

3.4.1 Data Collection

A) Primary data

- + Accurate identification of the intersections on field visual inspection.
- + Signal time data for each intersection and approach leg on field survey.
- + Measurement of the existing intersection approaches :-
 - ✓ Longitudinal grade using level (%)
 - ✓ Lane width using steal tape (m)
 - ✓ Approach width using steal tape (m)
 - ✓ Count number of lanes manually (numbers)

✚ Traffic Video data on selected intersections for a predetermined time interval recorded to get the required traffic data:-

- ✓ Headway(sec)
- ✓ Vehicle classification(category)

B) Secondary Data

- ✚ Identify the existing geometric and layout arrangements of the project area.
- ✚ Refer revised road network of Addis Ababa for Heavy vehicle corridor selection.
- ✚ Highway Capacity Manual (HCM 2010).
- ✚ Ethiopian Roads Authority Manual (2013).
- ✚ Addis Ababa City Roads Authority Manual.

3.4.2 Data Collection Time

Traffic data for each leg of individual intersections was collected from 6:30 AM-9:00 AM local time in the morning peak hour .It took four days from May 29, 2018 to June 5, 2018 to collect the data from four selected signalized intersections.

3.4.3 Data Collection Dates

Data were collected on week days from Tuesday to Friday considering the morning peak hours.

3.4.4 Instruments and Setup

Video data were taken from above to have clear aerial view of vehicles as they pass the stop line using the latest technology *Phantom IV Drones* having HD Camera capable of recording videos at 100 fps. The drone camera will be setup at the center of the intersections around 120 feet from ground to get full coverage of the approach legs and the stop line at the same time as shown in the figure to simplify the use of *manual data extraction* methods after the data collection.



Fig 3.6: Phantom IV Drone with HD Camera

3.4.5 Manual Data Extraction

For manual data extraction the following was done:-

- ✚ Hit Film Express 2017 video player with time display of precision level of three micro seconds was used to increase the data accuracy especially for headway data extraction.
- ✚ During data extraction a sticker mark was placed at the entry leg stop line to show the exact point of stop lines where the original stop line marks are faded at the data collection sites.
- ✚ To measure individual vehicle headways the sticker mark at the entry leg stop line will be used. The Video will be played with slow motion and as the leader vehicle's front bumper passes the sticker mark the time for the front vehicle (T1) will be recorded on a spread sheet .Similarly as the follower vehicle's front bumper passes the sticker mark the time (T2) will be recorded.
- ✚ With the help of a spreadsheet application the above data are recorded according to each leader-follower pair category in the data extraction table. Then the time headway for each case can be found using:

$$H_i = T_2 - T_1 \dots \dots \dots \text{Eqn -3.2}$$

- ✚ Vehicle count according to each vehicle category within respective lanes.

3.4.6 Software Packages Used

- ✚ Microsoft Office 2013
- ✚ Minitab 18 statistical software
- ✚ AutoCAD Civil 3D 2013
- ✚ Click Chart flow chart builder
- ✚ HitFilm Express 2017 Video Composing Software

3.4.7 Excluded Cases

The following cases were excluded from the analysis to actually determine discharge headways at signalized intersections:-

- ✚ The first three vehicles discharging from the queue.

- ✚ Vehicles impeded by pedestrians or turning vehicles.
- ✚ Platoons within which vehicles did not stop before entering an intersection.
- ✚ Platoons with turning vehicles.
- ✚ Instances where the traffic was not working.
- ✚ Signal Cycles in which traffic accident occurred.
- ✚ Weaving vehicles (lane changing) at intersection entrance.

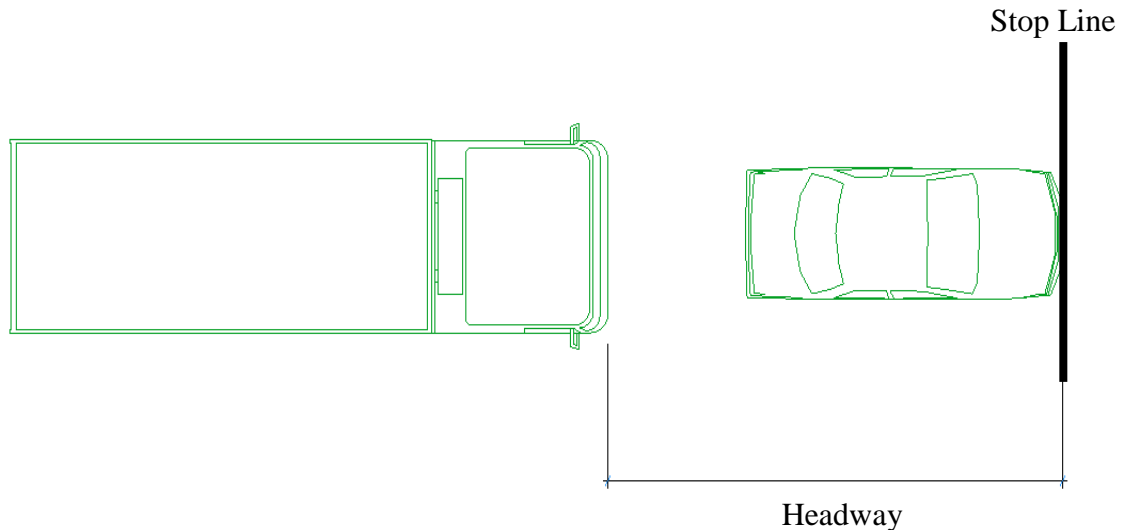


Fig 3.7: Typical Individual Vehicle Headway

3.5 Analysis Methodology

3.5.1 Headway Ratio Method

In different countries couple of researchers used variety of analysis methods to determine local PCE values .The most common methods for PCE determination are the regression method and headway ratio method. But according to (Dr Leong Lee Vien, 2006) the saturation flow rate based on PCE of the headway ratio method predicts better than the saturation flow rate based on PCE of regression analysis.

Therefore, on this study the researcher has used the headway ratio method as primary method of analysis to determine through passenger car equivalents on selected signalized intersections in Addis Ababa.

As (A.P.Cuddon, 1990) discusses the headway ratio briefly, the following condition should be satisfied in order to calculate PCEs using this method:-

$$\boxed{h_{c-c} + h_{x-x} = h_{c-x} + h_{x-c}} \dots\dots\dots \text{Eqn-4.1}$$

Where,

h_{c-c} = Average headway of a car followed by a car;

h_{c-x} = Average headway of a car followed by a type x vehicle;

h_{x-c} = Average headway of a type x vehicle followed by a car;

h_{x-x} = Average headway of a type x vehicle followed by a type x vehicle.

For those headway samples that do not exactly fulfil the independence condition, a corrective factor needs to be applied. The corrective factor (C) using the least square method is given by:-

$$C = \frac{abcd(w - x - y - z)}{abc + abd + acd + bcd} \dots\dots\dots \text{Eqn-4.2}$$

Where,

a = Number of headways for car following car;

b = Number of headways for car following type x vehicle;

c = Number of headways for type x vehicle following car;

d = Number of headways for type x vehicle following type x vehicle;

w = Mean headways for car following car;

x = Mean headways for car following type x vehicle;

y = Mean headways for type x vehicle following car;

z = Mean headways for type x vehicle following type x vehicle.

The adjusted mean headways for a car following a car:-

$$h_{A(c-c)} = U - \frac{C}{\text{No. of headways car following car}} \dots\dots\dots \text{Eqn-4.3}$$

Where,

$h_{A(c-c)}$ = Adjusted mean headways for car following car;

U = Uncorrected mean headway;

C = Correction factor

The adjusted mean headways for vehicle type x following vehicle type x can be represented :-

$$h_{A(x-x)} = U - \frac{C}{\text{No. of headways vehicle type x following vehicle type x}} \dots\dots\dots \text{Eqn -4.4}$$

Where, $h_{A(x-x)}$ = Adjusted mean headways for vehicle type x following vehicle type x.

Hence, the PCU is calculated using:-

$$\boxed{PCU_{(x-x)} = \frac{h_{A(x-x)}}{h_{A(c-c)}}} \dots\dots\dots \text{Eqn -4.5}$$

Where,

$h_{A(c-c)}$ = Adjusted Mean headway of a car followed by a car;

$h_{A(x-x)}$ = Adjusted Mean headway of a type x vehicle followed by a type x vehicle.

But this basic headway ratio method has some drawbacks when we put it to real world practice. According to this method there should be at least two X-X headways to enable the adjustment factor. This may not happen at some locations and specific lane groups and it prohibits the lane wise analysis.

Considering the above limitation, (A.P.Cuddon, 1990) studied different cases that breach the independent condition and compared the adjusted and unadjusted headways to arrive at a conclusion that the headway adjustment can be removed and derived a new equation of determining PCEs.

$$\boxed{e_x = \frac{\bar{h}_{c_x} + \bar{h}_{x_c} - \bar{h}_{c_c}}{\bar{h}_{c_c}}} \dots\dots\dots \text{Eqn -4.6}$$

The values we get from this equation are known as inferred PCEs since we don't directly use X-X headways. Using this simplified equation lane wise PCE determination is possible since minimum sample size of X-X headways is no more a problem.

3.5.1.1 Analysis Procedures:-

- ✚ Filter the extracted inter vehicular time headway data for outliers and inappropriate data sets using Mini Tab Statistical software package and remove unwanted data.
- ✚ Calculate the average time headways for each leg and respective lane group for each leader-follower vehicle categories within a given time interval.
- ✚ Check if the precondition is fulfilled according to equation *Eqn-4.1* if not, make adjustments according to equations *Eqn-4.3* and *Eqn-4.4*.
- ✚ Then calculate PCEs for each vehicle category using equation *Eqn-4.6*.
- ✚ Finally, study different relationships of PCEs with different Traffic and geometric parameters using the newly found locals PCE values and interpret the results.

3.6 Research Methods

3.6.1 Research Procedure

The research begins by studying about through traffic passenger car equivalents. To do so, related articles and journals were reviewed in order to understand with which parameters does PCEs correlated. On top of that, input parameters for the study were identified.

After the input parameters identification the next step was selecting appropriate method of data collection strategies. The only way for accurate traffic data collection which suits demands of the researcher was aerial video. Such type of video enables to exactly capture the effect of vehicle sizes. Drone Technology was used to comply with the required video footage and quality.

Geometric and site specific data was surveyed on site with the help of steel tapes, level, stop watch and other tools. Furthermore, secondary data was collected from different respective authorities.

Once all the data was collected, the next stage requires processing of raw data for analysis purpose. Extraction of headway data from videos, filtering and screening of outlier data sets from extracted data was carried out.

Simultaneously with the data processing, write-up of related literatures was on progress. Besides, Different aspects of headway ratio method and scenarios which may challenge the analysis remained under investigation.

Subsequently, through traffic passenger car equivalents were determined using the headway ratio method for all desired vehicle categories. Then, the results were summarized for analysis and interpretation.

Finally, conclusions and recommendations based on the research findings were suggested at the end of the document.

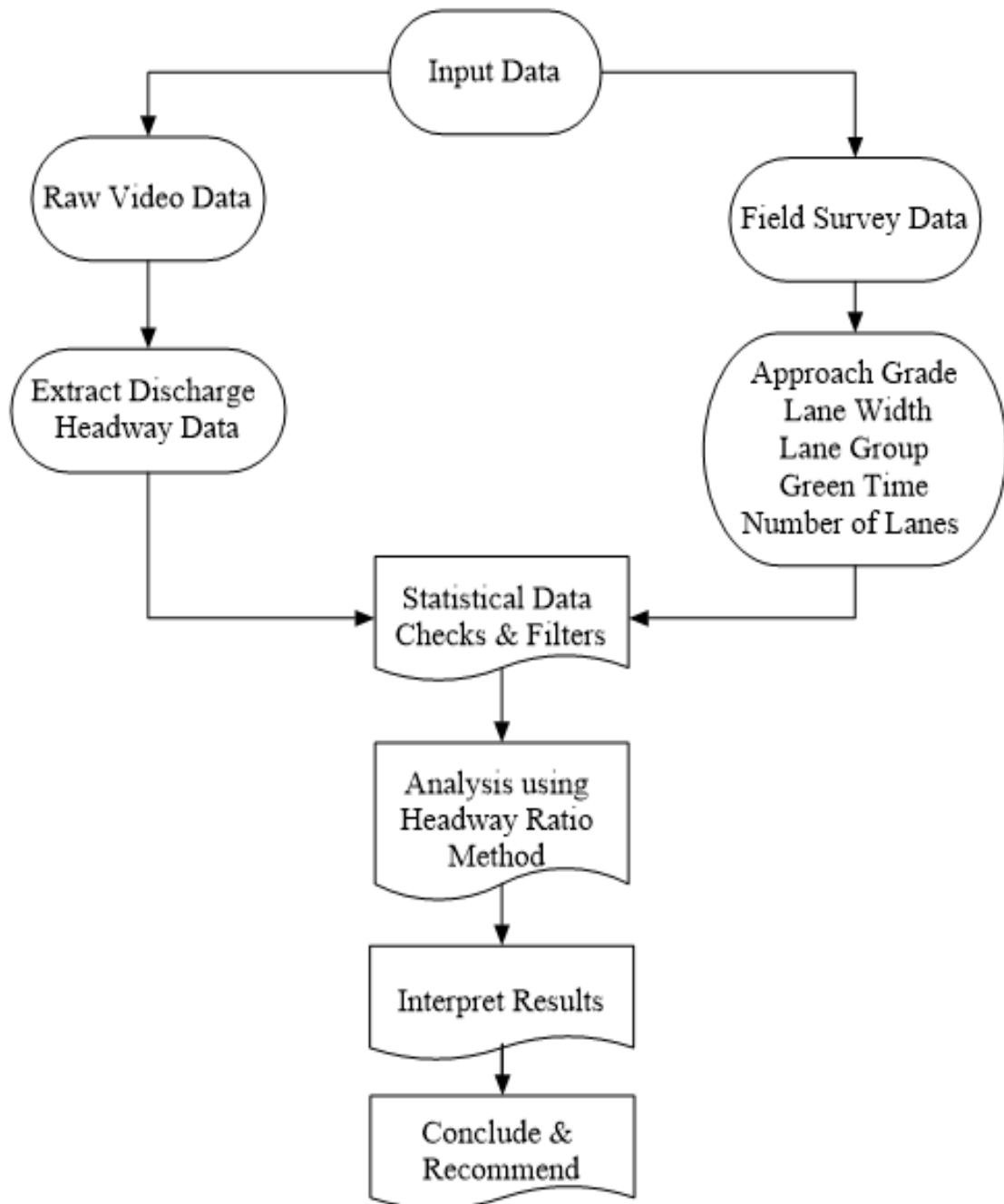


Fig 3.8: Research Procedure

CHAPTER 4 RESULTS & DISCUSSION

As discussed in methodology part, the headway ratio method requires leader-follower combination of each vehicle category with passenger cars. On top of that, it is recalled that total of 7563 Headways (leader-follower combinations) were extracted lane wisely.

To simplify the lane wise analysis the individual headways were collected in the following form on approach individual lanes:-

h_{c-c} = individual headway of a car followed by a car;

h_{c-x} = individual headway of a car followed by a type x vehicle;

h_{x-c} = individual headway of a type x vehicle followed by a car;

These individual headways were then aggregated and average headway values as indicated in **Appendix A** determined for each leader-follower combination of vehicle category *X* with passenger cars within respective lane groups. Headway ratio method outputs are presented in summarized form in **Table 4.1** .

Through traffic passenger car equivalents for nine approach legs of four signalized intersections determined and discussed in this section.

In the first part of **chapter 4** relationship of through traffic passenger car equivalents with lane group, lane width, approach width, green time and approach longitudinal grade is discussed.

Both tabular and graphical analysis method was used to present the findings in understandable way. Some statistical tests were also applied to compare and contrast variations within the findings and with some recent local study.

Then, a hypothesis test to compare the local through traffic passenger car equivalence values with the HCM(2010) suggested value was done.

THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA

Table 4.1 Passenger Car Equivalents at Every Location

Passenger Car Equivalents at Every Location Within Each Lane Group														
Intersection Name	Approach Leg	Vehicle Type	Approach Longitudinal Grade (%)	Green Time (sec)	Approach Width(m)	No. of Lanes	Lane Width(m)				PCEs within Each Lane Group			
							1st	2nd	3rd	4th	1st	2nd	3rd	4th
Saris Abo	Bole	SB	4.24	45	11.58	4	2.7	2.72	2.72	3.44	–	1.265	1.506	
		LB									–	2.806	1.703	
		T									1.884	1.523	1.589	
		TT									–	3.727	–	
	Kaliti	SB	1.56	45	11.94	4	3.06	2.96	2.93	2.99	1.465	1.120	1.800	
		LB									2.084	2.859	1.948	
		T									1.581	1.542	1.135	
		TT									4.039	5.243	4.435	
Jemo Michael	Jemo	SB	2.72	30	10.45	3	3.5	3.57	3.38	–	1.285	–	1.632	
		LB									–	1.842	1.696	
		T									1.530	1.465	1.588	
		TT									–	–	–	
	Koshe	SB	-1.26	40	10.55	3	3.8	3.65	3.1	–	1.728	1.348	1.792	
		LB									–	1.651	2.002	
		T									1.853	1.406	1.434	
		TT									–	–	–	

THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA

<i>Passenger Car Equivalents at Every Location Within Each Lane Group</i>														
Intersection Name	Approach Leg	Vehicle Type	Approach Longitudinal Grade (%)	Green Time (sec)	Approach Width(m)	No. of Lanes	Lane Width(m)				PCEs within Each Lane			
							1st	2nd	3rd	4th	1st	2nd	3rd	4th
Jemo Michael	German RBT	SB	1.26	46	10.3	3	3.5	3.5	3.3	-	-	1.450	1.597	
		LB									-	1.449	-	
		T									-	1.416	1.343	
		TT									-	3.207	-	
	Merkato	SB	-0.81	40	9.86	3	3.3	3.36	3.2	-	-	1.430	1.610	
		LB									-	2.259	1.762	
		T									-	1.503	1.224	
		TT									-	-	-	
Lebu Mebrat Hayl	Mexico/Sarbet	SB	2.48	40	12.55	3	4.3	3.45	4.8	-	-	1.723	1.923	
		LB									-	2.199	2.320	
		T									-	1.663	1.426	
		TT									-	3.072	3.130	
	Kaliti	SB	-2.27	40	12.6	4	3.2	2.7	3.4	3.3	1.097	1.637	-	
		LB									1.619	2.334	-	
		T									1.396	1.810	-	
		TT									-	2.853	-	
Gerji Mebrat Hayl	Goro	SB	-2.49	30	8.4	3	2.6	2.8	3	-	1.904	2.105	1.591	
		LB									2.151	2.388	2.505	
		T									1.505	1.678	1.802	
		TT									-	-	-	

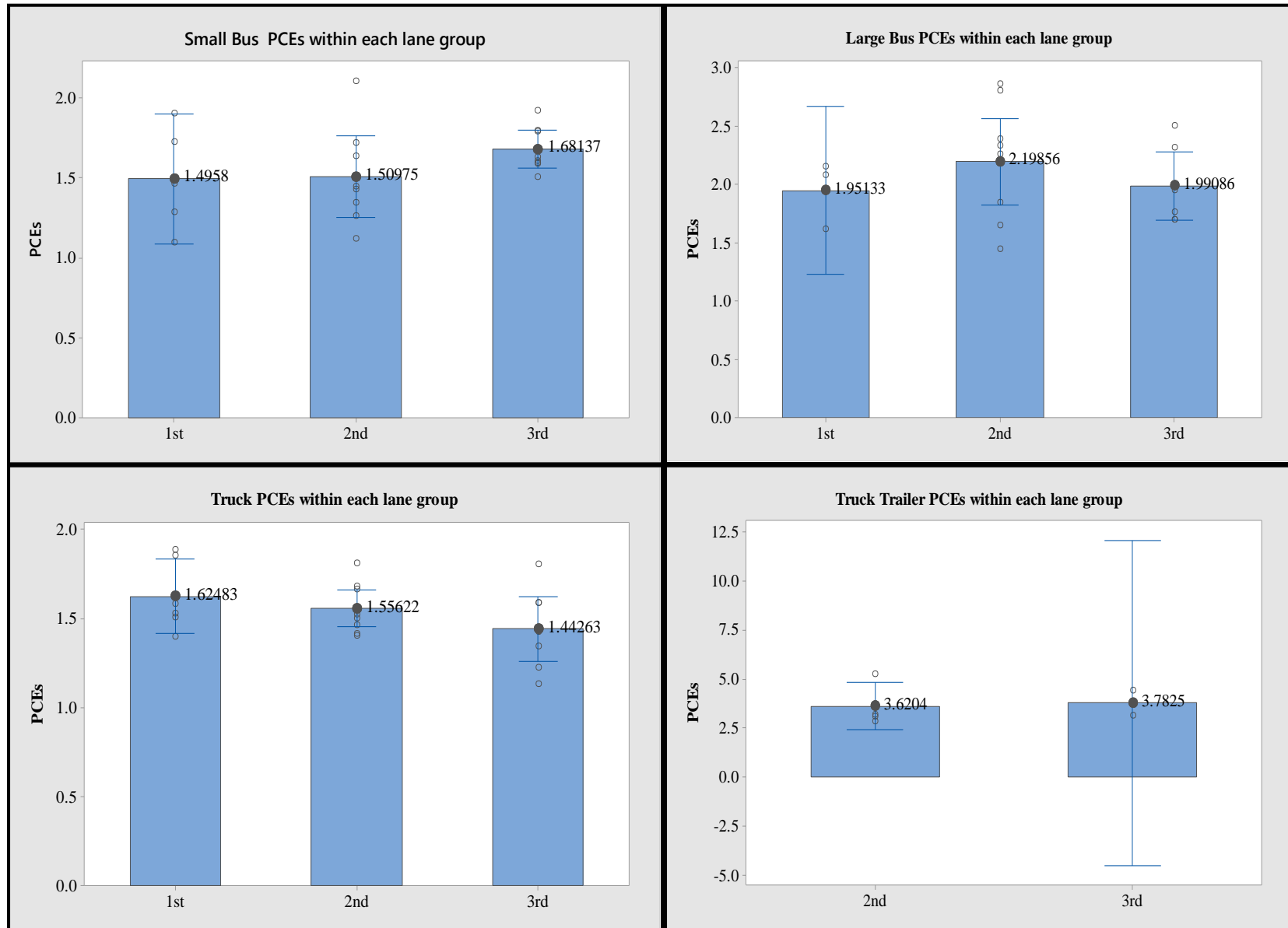


Fig 4.1 :Interval Plot of PCEs Vs Lane Group

The researcher has tried to study the effect of lane group on through passenger car equivalence of different vehicle categories. *Fig 4.1* graphically visualizes how lane group affects local PCEs using mean values as reference. For Small Buses PCE values in the first (inner) and second (middle) lane are more or less similar whereas PCE values in third (outer) lane are a little bit higher. This may be due to side traffic friction and pedestrian interference on the outer lanes.

For large Buses, PCE values in the first (inner) and third (outer) lanes are smaller than PCEs in the second (middle) lane. This may be due to the larger size of Large Buses which make drivers careful when they are in the second (middle) lane. Drivers carefulness will make headways larger which leads to larger PCE values.

With Similar assumption, Trucks have larger PCE values in the first (inner) and second (middle) lanes than the third (outer) lane. Drivers of these vehicles will tend to decrease speed when they are in inner lanes than outer lanes for better carefulness. Consequently, headways at inner lanes will decrease and headways at outer will increase. This makes through PCEs of Trucks larger at inner lanes and smaller on outer lanes.

On the other hand when we look at Truck trailers, they do have a little bit larger PCE values in third (outer) lanes than in second (middle) lane. Larger size of truck trailers combined with traffic side friction may have caused this results.

To strengthen the above points the researcher has used individual value plots for three of the vehicle classes contained in the study. *Fig 4.2* shows two scenarios namely PCEs by lane group (LGP) broken down by vehicle type (VT) and PCEs by vehicle type (VT) broken down by lane group (LGP).

The first case shows how each vehicle type's PCE values behave on first (FT), second (SD), and third (TD) lane groups. Whereas, the second case shows how different vehicles PCE values vary within similar lane group. It is evidently shown that (overall score by vehicle type) large busses have highest local through traffic PCE values, small busses the second and trucks have the least local through traffic PCE values.

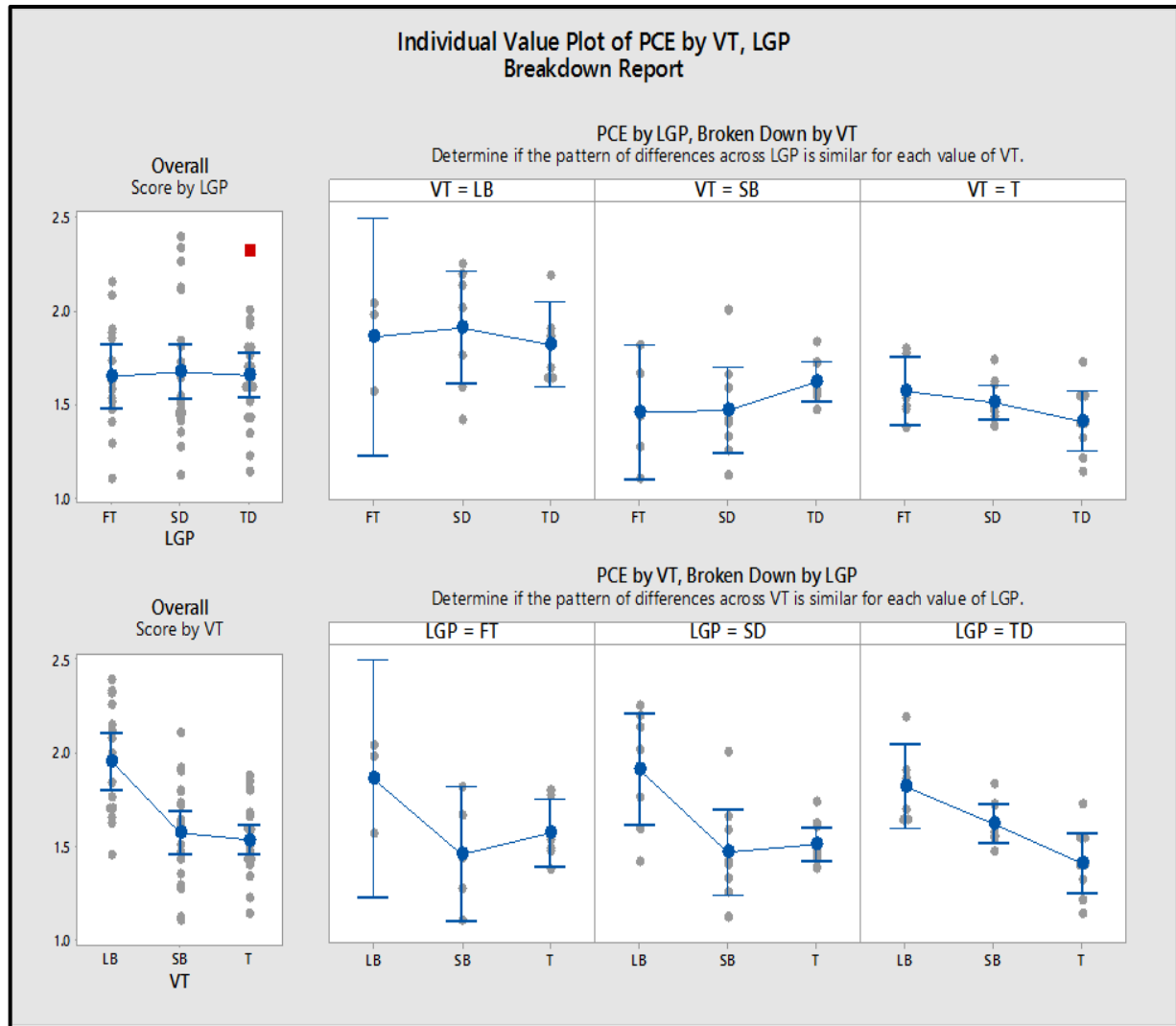


Fig 4.2: Individual plot of PCEs of different vehicle categories in every lane group

Fig 4.3 clearly shows comparison of PCEs between different vehicle categories. It is evidently shown that local through traffic PCEs of Truck Trailers are the largest, local through traffic PCEs of Large Buses are the second largest and local through traffic PCEs of Small Buses are third. Also, the graph shows that local through traffic PCEs of Trucks are the smallest from the rest.

Vehicle type directly relates to operational efficiency, size, vehicular load, horse power and other technical characteristics of each vehicle category. Truck Trailers are large in size and usually they carry heavy loads which makes them slower and inefficient when it comes to traffic operations. Large Buses also share most characteristics of truck trailers even though

they are smaller in dimensions. Small Busses and Trucks have more or less similar size but exercise different operational efficiency and usually Trucks transport heavier loads than small busses. But, Trucks and Small busses have better operational efficiency than Truck Trailers and Large Busses.

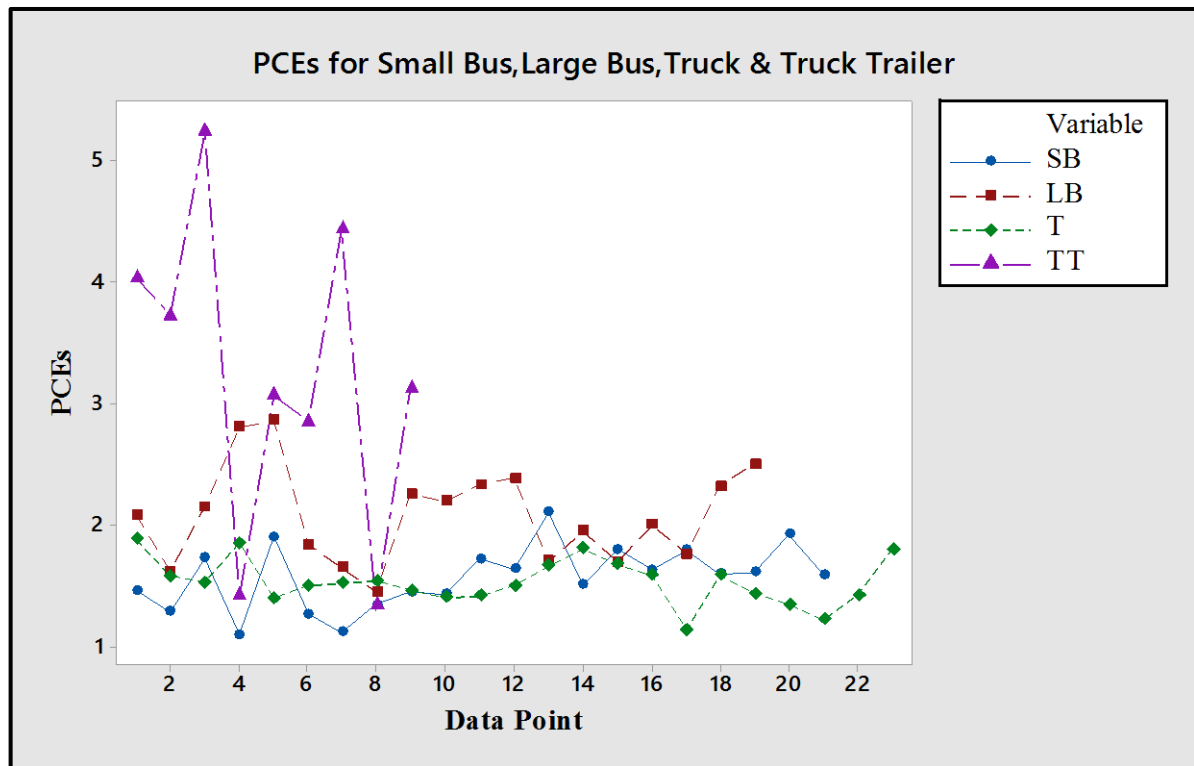


Fig 4.3: PCEs for different vehicle categories

Such technical performance issues of vehicles directly relate to passenger car equivalents. As the vehicle is inefficient when it compared to passenger cars, the headway between that vehicle and passenger car before/after it will increase. Similarly, when a vehicle has better performance compared to a passenger car before/after it, the gap (time headway) decreases.

To clearly show the gap between different vehicle categories the researcher has used individual value plot of large bus, small bus and trucks. **Fig 4.4** can explain how vehicle type affects local through traffic PCE values. Therefore, it can be said that Truck Trailers have large local through traffic PCE values and Trucks on the other side possess smaller local through traffic PCEs due to the reasons stated in the above paragraphs.

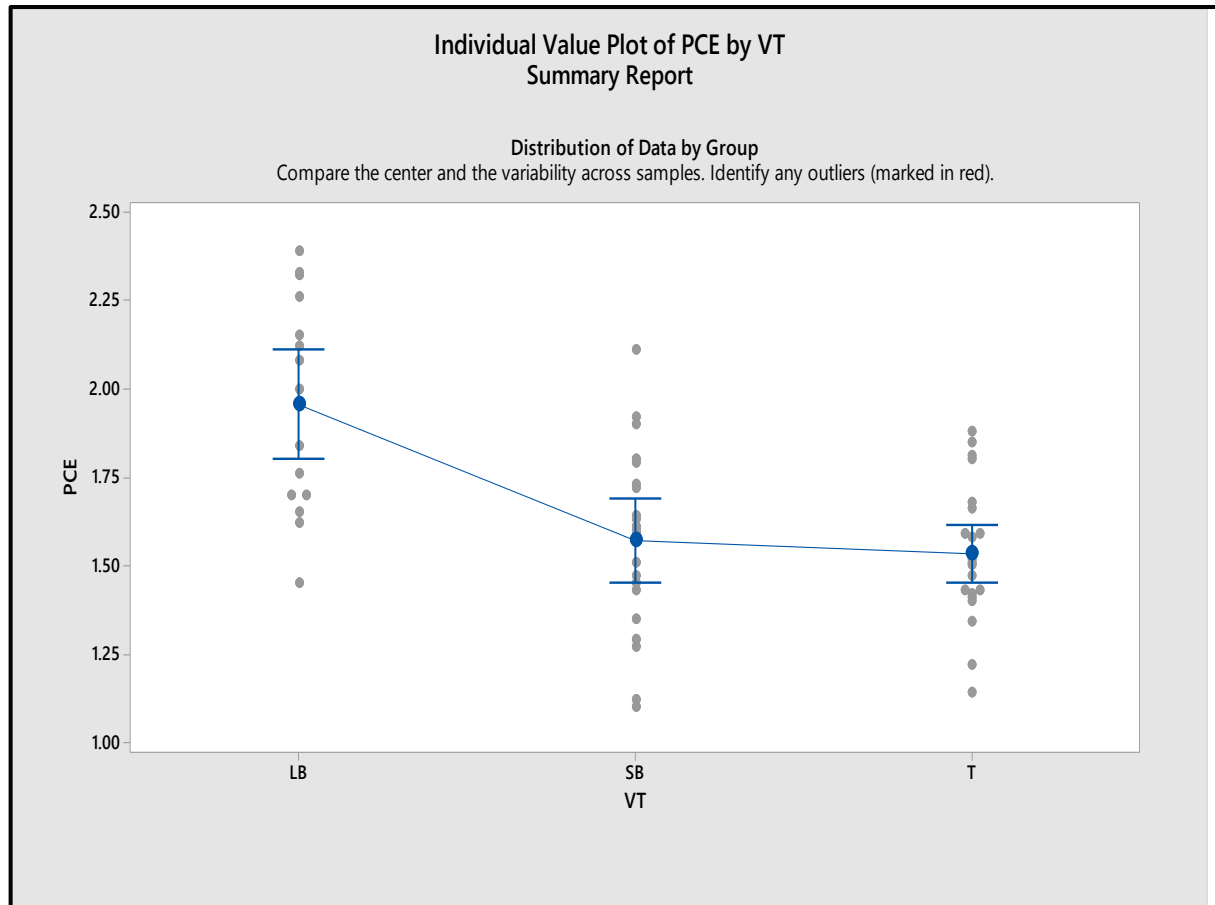


Fig 4.4: Individual value plot of PCEs for different vehicle categories

In order to check the difference of PCEs between different vehicle categories the *Mann Whitney Test* was done and presented below in *Table 4.2*.

Table 4.2 Mann Whitney Test-Test for difference of Medians

	Null hypothesis	$H_0: \eta_1 - \eta_2 = 0$	95 % CI
	Alternative hypothesis	$H_1: \eta_1 - \eta_2 \neq 0$	
Parameter	PCEs	W-value	p-value
	LB-SB	139.5	0.021
	LB-T	143	0.002
	LB-TT	122	0.04
	SB-T	202.5	0.337
	SB-TT	148	0.013
	T-TT	154	0.014
Vehicle Type			Comment
			Significantly Different
			Significantly Different
			Significantly Different
			Not Significantly
			Significantly Different
			Significantly Different

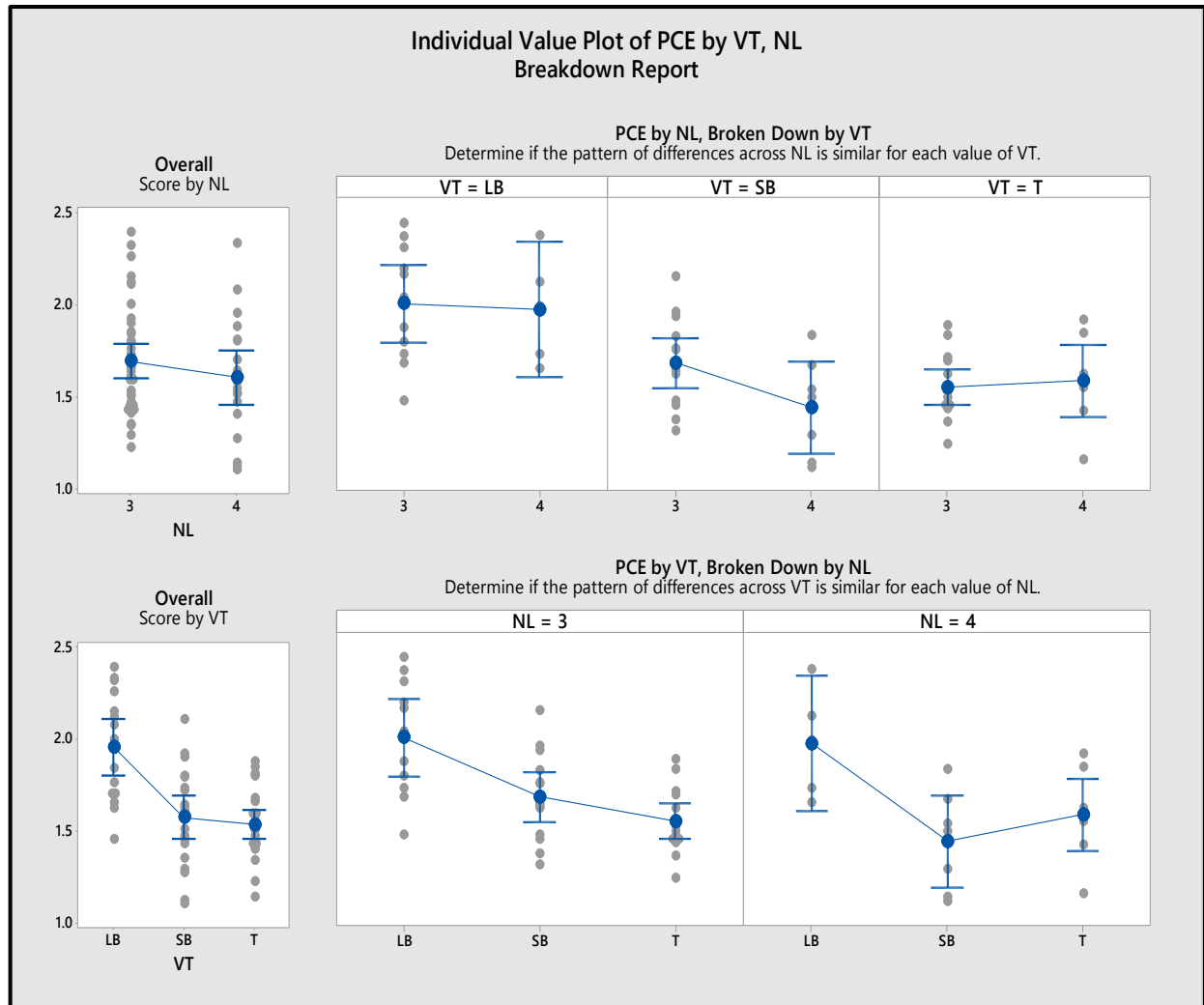


Fig 4.5: Individual value plot of PCEs by vehicle type and number of lanes

When we look at the relationship of local through traffic PCEs and number of lanes, it is visibly shown in **Fig 4.5** that at signalized intersections with small number of lanes large buses have the highest, small busses the second and trucks have the least local through traffic PCE values.

As the number of lanes increases from 3 to 4, small busses entertain the least, trucks the second and large busses the highest local through traffic PCE values. This results implies that small busses will speed up when the number of lanes increases at signalized intersections which decreases headways. Trucks on the other side have larger local through traffic PCEs at intersections with larger number of lanes than at intersections with small number of lanes.

Referring *Fig 4.6* PCE versus approach longitudinal grade plot we can see the impact of approach grade on PCEs. On relatively level approaches ($-2 < 0 < 2$) % the local through traffic PCEs are larger than the local through traffic PCE values on down (< -2) % and upgrades (> 2) %. On level approaches vehicles will speed up, there is no need of carefulness and operational capability issue of heavy vehicles does not exist which leads to larger headway values. In other words, the gap between vehicles is larger which leads to larger local through traffic PCE values on those approaches.

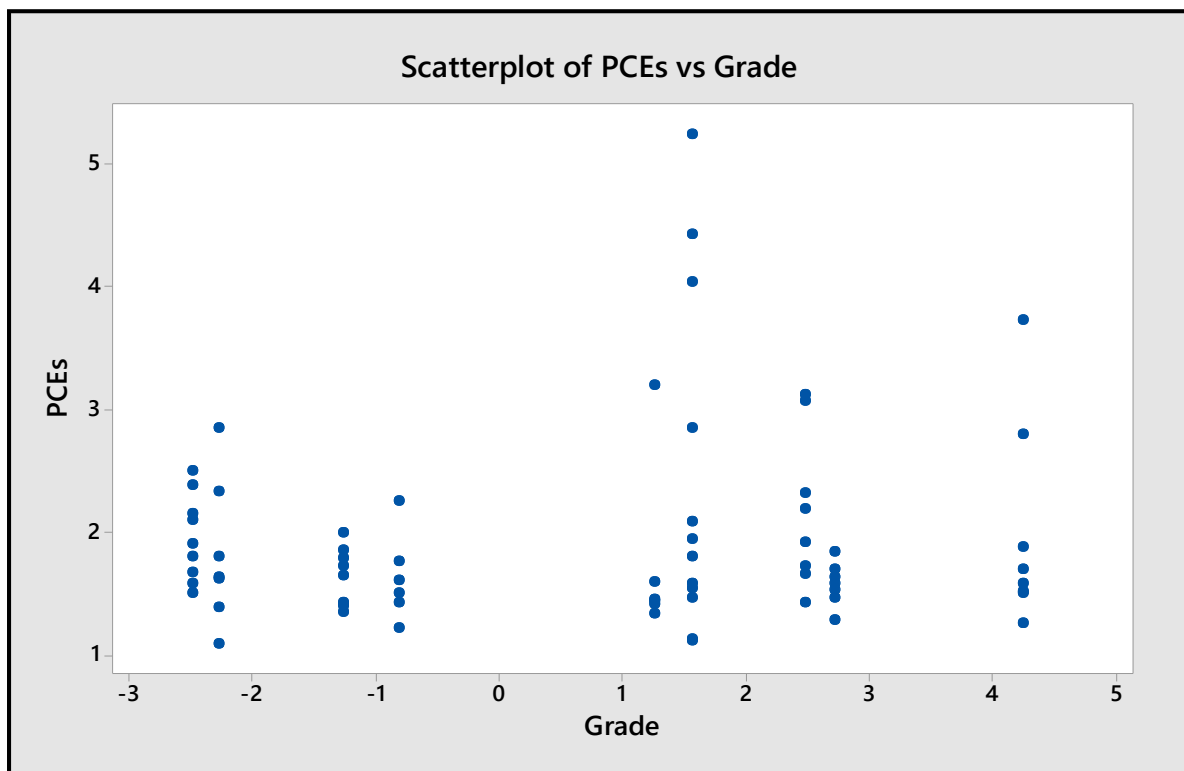


Fig 4.6 Scatter Plot of PCEs Vs Approach Longitudinal Grade

On the contrary side, on up and down graded approaches vehicles will be closer one another due to the operational inefficiency of larger vehicles and drivers are careful on sloppy roads. Therefore, local through traffic PCEs on such approaches are smaller.

On the other side, when we look at scatter plot of PCEs versus lane width (*Fig 4.7*), on lane widths from 2.5-4.0 meters most of the local through traffic PCEs are from 1-3 implying that the local through traffic PCEs are somehow similar in small to medium lane widths. Also, there are some larger values of local through traffic PCEs (3-5.5) due to larger local through traffic PCEs of Truck trailers on narrower lanes for sake of low speed

and carefulness. On larger lane widths (4.5-5.0 meters) local through traffic PCEs are somehow similar to local through traffic PCEs on small and medium lane widths. We can say that lane width has low effect on local through traffic PCEs.

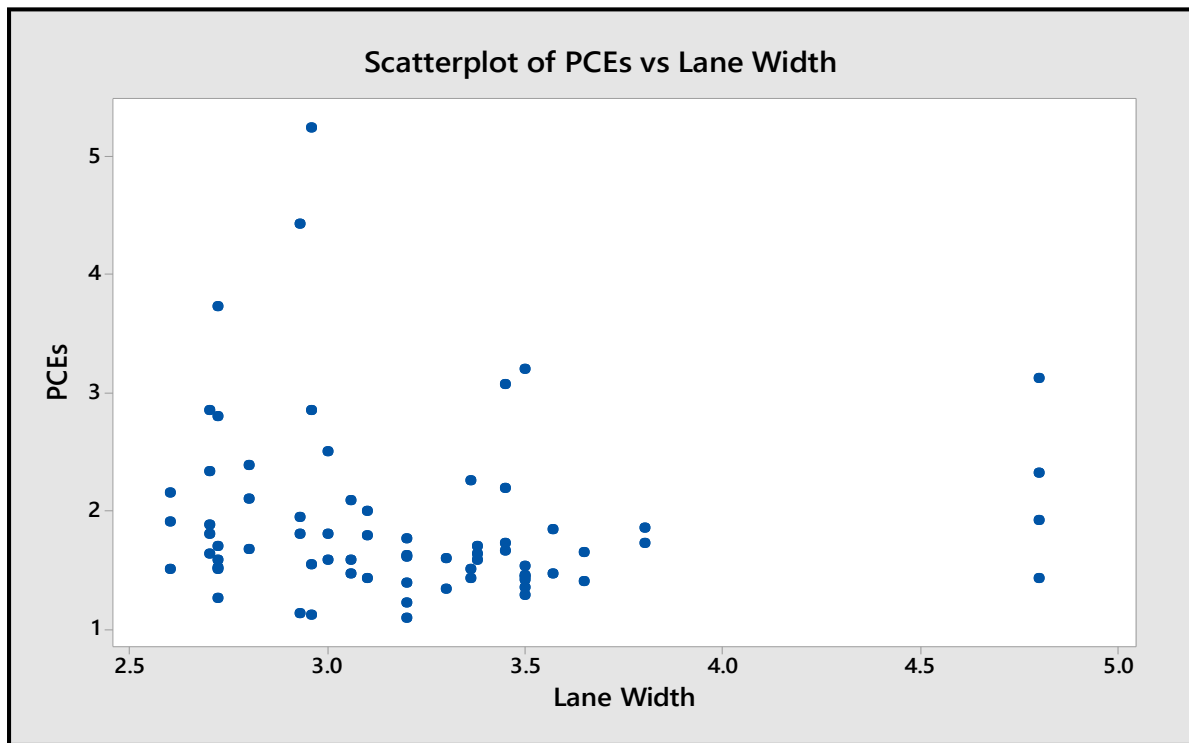


Fig 4.7 Scatter Plot of PCEs Vs Lane width

Similarly, when we look at scatter plot of PCEs versus approach width (*Fig 4.8*) it is clearly shown that for approach widths ranging 8-11 meters local through traffic PCEs are lower than local through traffic PCEs on approach widths ranging from 11-13 meters. On wider approaches drivers are free and there is enough space which makes vehicles to speed up and experience higher inter vehicular headways. Passenger cars will pass the intersections with short fraction of seconds and the gap between them and larger vehicles will be significant. This makes local through traffic PCEs on wider approaches larger and on local through traffic

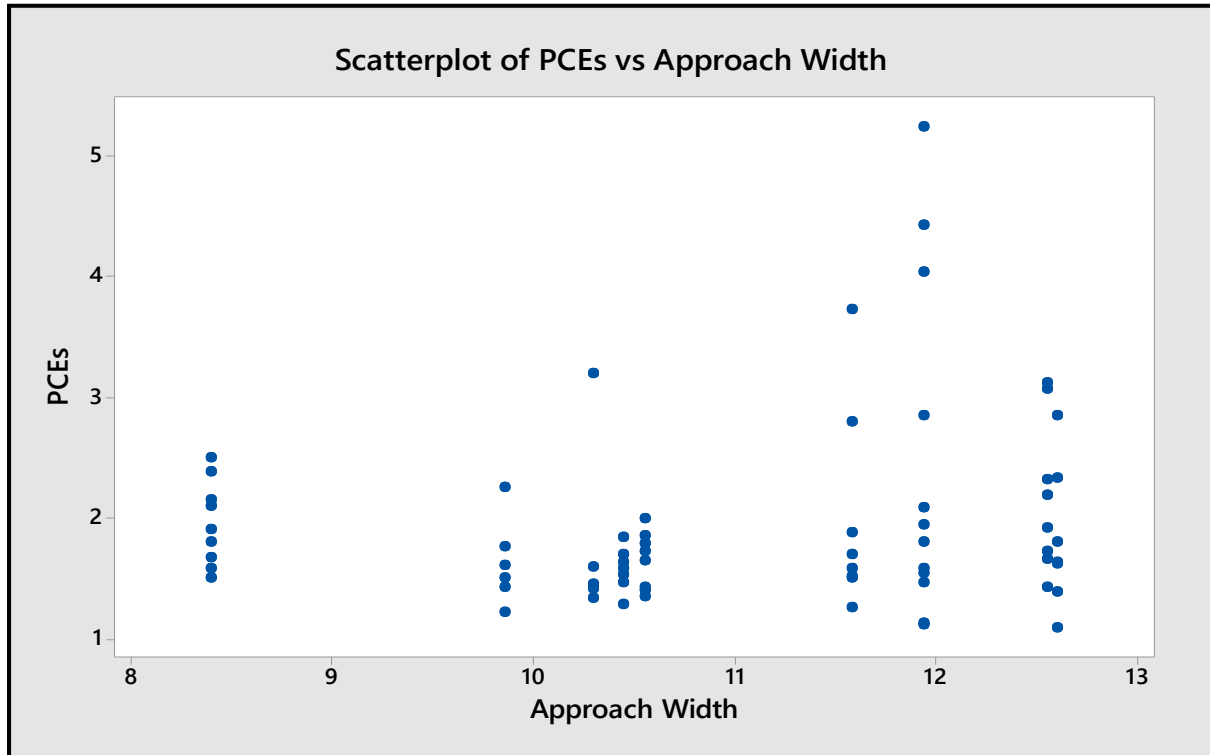


Fig 4.8 Scatter Plot of PCEs Vs Approach width

PCEs on narrower approaches smaller. On narrower approaches drivers are panic to pass the intersection as soon as the traffic light turns green. While on wider approaches they are somehow relaxed and assume the green time is adequate to pass the intersection without any panic.

Lastly, the scatter plot of PCEs versus green time (*Fig 4.9*) clarifies the impact of green time on local through traffic PCEs. As we can see from the graph when the available green time is small drivers are more alert to use the available green time and they drive fast which makes local through traffic PCEs smaller. Nevertheless, when there is larger green time drivers do not panic to pass the lights, they are relaxed which in return makes inter-vehicular headways to be larger. In other words, larger headways cause larger local through traffic PCEs.

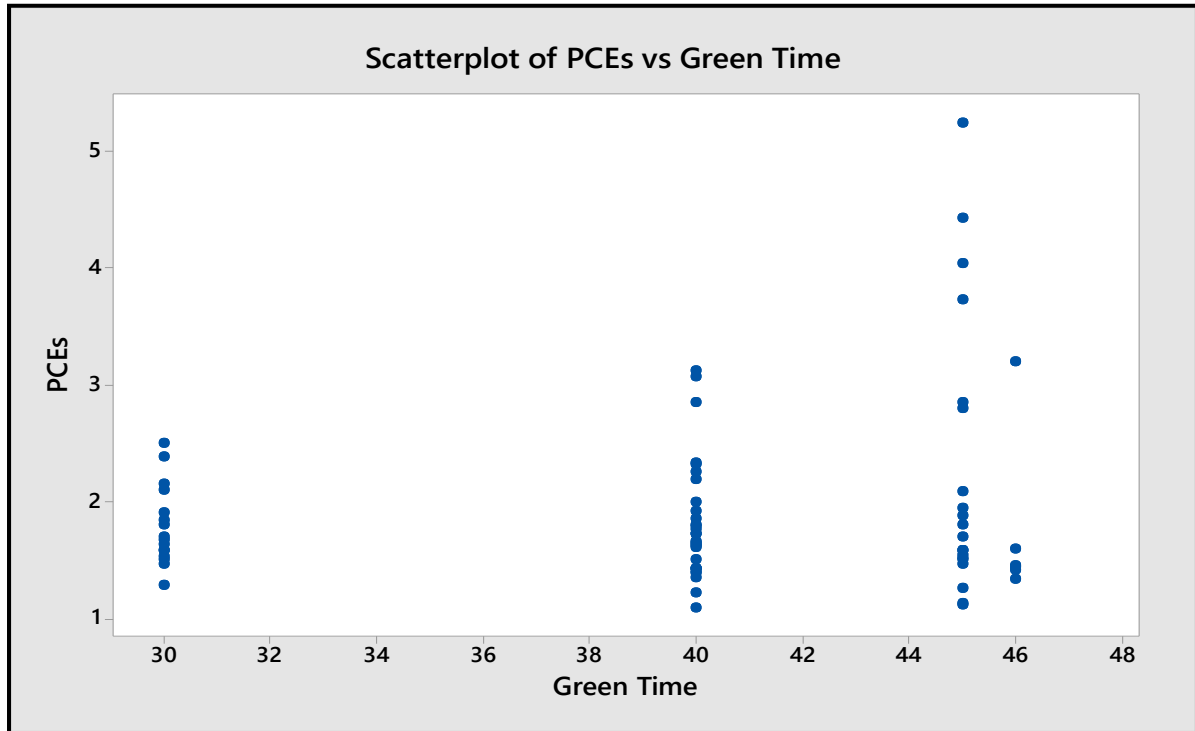


Fig 4.9 Scatter Plot of PCEs Vs Green Time

4.1 Hypothesis Testing

A hypothesis test is rule that specifies whether to accept or reject a claim about a population depending on the evidence provided by a sample of data.

For this paper the researcher has used two sided hypothesis that is the alternate hypothesis claims local through PCE values are significantly different from HCM (2010) value of 2.

On this study the researcher has used a significance level of 0.1 where the null (H_0) and alternate (H_1) hypothesis are:-

H_0 : Passenger Car Equivalence (PCE) for different vehicle categories in A.A, $\mu = 2$

H_1 : Passenger Car Equivalence (PCE) for different vehicle categories in A.A, $\mu \neq 2$

$$t \approx \frac{\bar{x} - \mu}{s/\sqrt{n}} \dots\dots\dots Eqn 4.7$$

Where: \bar{x} =sample mean
 μ =population mean
 s =sample standard deviation
 n =sample size

Table 4.3: Summary of hypothesis test results Minitab 18 outputs

Vehicle Type	Mean	St Dev	SE Mean	90% CI for μ	T-Value	P-Value
Small Bus	1.5718	0.263	0.0574	(1.4728, 1.6708)	-7.460	0.000
Large Bus	2.083	0.3978	0.0913	(1.9248, 2.2412)	0.910	0.375
Truck	1.5346	0.1892	0.0394	(1.4669, 1.6023)	-11.800	0.000
Truck Trailer	3.667	0.875	0.331	(3.024, 4.309)	5.040	0.002

Interpreting the p-value

The results show that for **Small Buss, Truck and Truck Trailer** we have enough evidence for rejecting the null hypothesis (H_0) since we do have $\alpha < p$ -value. Therefore, with 90% level of confidence we can say that the local PCE values are different from HCM (2010) value of 2. For **Large Bus** we do have $\alpha > p$ -value, Therefore, we fail to reject the null hypothesis (H_0), since we do not have enough evidence to reject the null hypothesis of the local PCE values are equal to HCM (2010) value of 2. So, for large bus the HCM (2010) PCE value can be used for local analysis purposes. Therefore, there is no need of local PCE value for large buses.

Hence, the study has met the hypothesis for three vehicle types namely **Small Buss, Truck and Truck Trailer** having different PCE findings from currently used HCM (2010) and it could be useful for local application purposes. On the other side, **Large Bus** local PCE values generated from this study are almost the same as HCM (2010) value of 2 implying that we can use the existing manual value of 2 for local use.

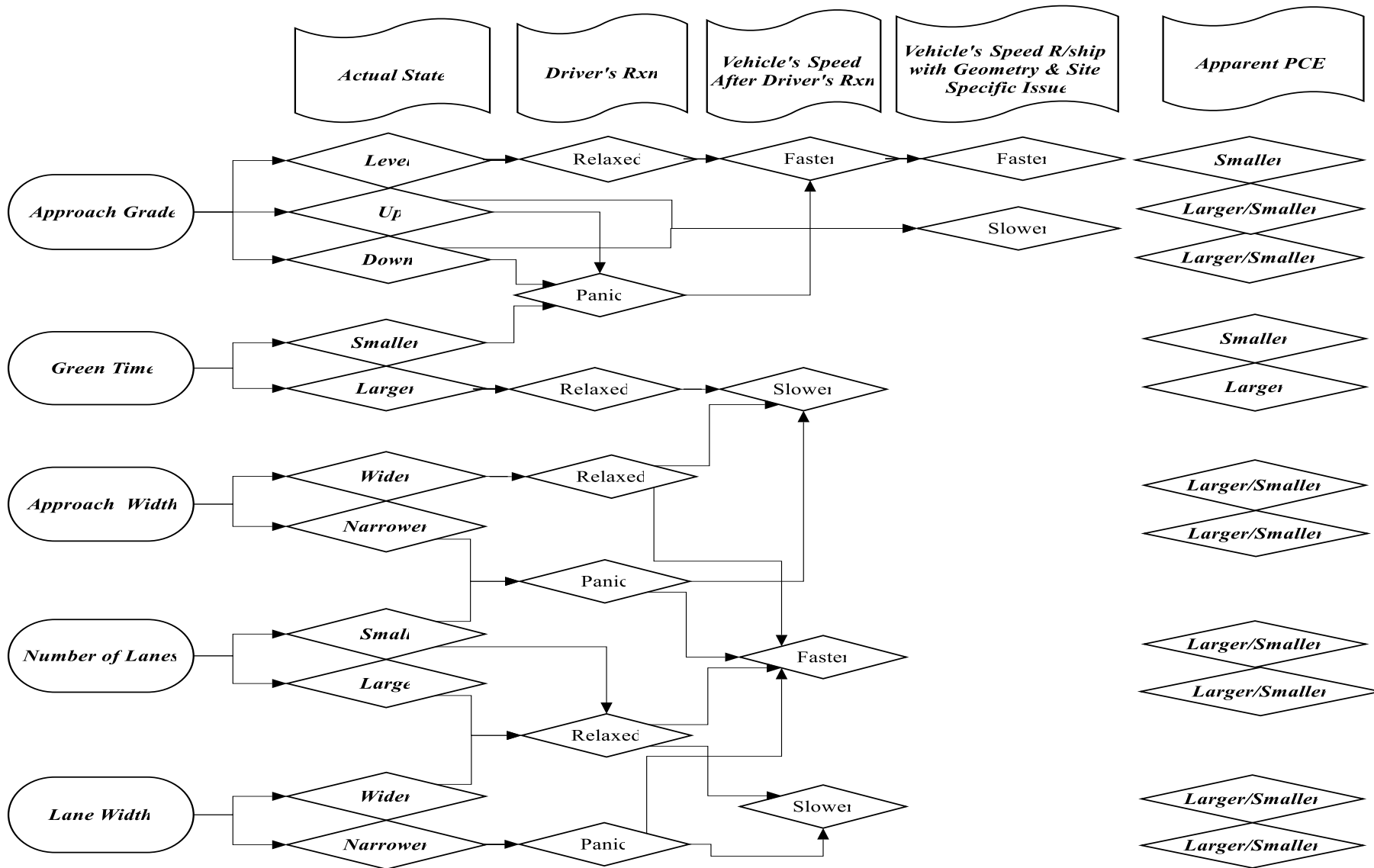


Fig 4.10: Flow chart of possible relationship of PCEs with Geometric Parameters

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- ✚ The hypothesis test clearly shown that for *Small Buss, Truck and Truck Trailer* we have enough evidence for rejecting the null hypothesis (H_0), since we do have $\alpha < p$ -value. Therefore, with 90% level of confidence we can say that the local PCE values are different from HCM (2010) value of 2. For *Large Bus* we do have $\alpha > p$ -value, Therefore, we fail to reject the null hypothesis (H_0), since we do not have enough evidence to reject the null hypothesis of the local PCE values are equal to HCM (2010) value of 2. We can conclude that the local PCE values are different from HCM (2010) value of 2 for many of vehicle categories in Addis Ababa, Ethiopia.
- ✚ According to the study, the mean local PCEs of Small Busses are 1.4958, 1.5097, and 1.6814 on first (inner), second (middle), and third (outer) lanes respectively. Similarly the mean local PCEs of Large Busses are 1.9513, 2.1986, and 1.9909 on first (inner), second (middle), and third (outer) lanes respectively. Trucks on the other hand have mean local PCE values of 1.6248, 1.5562, and 1.4426 on first (inner), second (middle), and third (outer) lanes respectively. Whereas, Truck Trailers have larger mean local PCE values which are 3.6204 and 3.7825 on second (middle) and third (outer) lanes respectively.
- ✚ The results indicate that PCEs in middle lane are somehow larger than PCEs in first (inner) and third (outer) lanes for Small Buses and Large Buses. Trucks on the other side have the largest PCE values on the first (inner) lane while, Truck Trailers exhibit the largest PCEs on third (outer) lane.
- ✚ Even though, proportion of Truck Trailers is small in Addis Ababa, they do have the largest PCE values. They are large in size, have low operational efficiency, and lack dynamic characteristics of small vehicles. On the contrary, large buses have significant proportion and due to similar characteristics as Truck Trailers they possess the second largest local PCE values. Small Busses and Trucks have more or less closer values of local PCEs. This may be due to the similarities in size and operational efficiency of the two vehicle categories.

- ✚ The results show that on relatively level approaches the PCEs are larger than the PCE values on down and upgrades. Whereas, on up and down graded approaches vehicles will be closer one another due to the operational inefficiency of larger vehicles and drivers are somehow careful on sloppy roads. Therefore, PCEs on such approaches are smaller.
- ✚ For lane widths from 2.5-4.0 meters the PCEs are from 1-3 indicating that the PCEs are somehow similar in small to medium lane widths. Moreover, there are some larger values of PCEs (3-5.5) due to larger PCEs of Truck trailers on narrower lanes for sake of low speed and carefulness. On larger lane widths (4.5-5.0 meters) PCEs are somehow similar to PCEs on small and medium lane widths. We can say that lane width has low effect on PCEs.
- ✚ For approach widths ranging 8-11 meters PCEs are lower than PCEs on approach widths ranging from 11-13 meters. On wider approaches drivers are free and there is enough space which makes vehicles to speed up and experience higher inter vehicular headways. Passenger cars will pass the intersections with short fraction of seconds and the gap between them and larger vehicles will be significant. This makes PCEs on wider approaches larger and on PCEs on narrower approaches smaller. On narrower approaches drivers are panic to pass the intersection as soon as the traffic light turns green. Therefore, they do not leave any space and drive head to head to properly utilize the green period which makes the time headway too smaller, resulting in small PCE values on narrow approaches.
- ✚ Similarly, when the available green time is small drivers are more alert to use the available green time and they drive fast which makes PCEs smaller. Nevertheless, when there is larger green time drivers do not panic to pass the lights, they are relaxed which in return makes inter-vehicular headways to be larger .In other words, larger headways cause larger PCEs.

5.2 Recommendations

- ✚ Since local PCE values are different from HCM (2010) value of 2, we should give due attention on using local values in capacity analysis and design of traffic infrastructures no matter how the values seem crude.
- ✚ Traffic parameters in developed countries and in developing countries vary due to many reasons. Therefore, developing local traffic parameters will increase the efficiency in capacity and level of service analysis of our infrastructures. It is advisable to conduct researches focusing on local value calibrations. Universities and institutions should pay due attention to use such types of research findings for practical applications instead of putting them on shelves.
- ✚ It would be recommendable to select representative signalized intersections considering traffic composition, pavement distress, geometric features, whether and other important parameters as selection criteria plus collecting considerable traffic data for longer time interval. Such enriched data with the help of advanced data extraction technique will ease the analysis process and can produce more reliable PCE values.
- ✚ The research has used the most advanced technology to capture areal video data which may show fellow researchers new way of data collection instrument for traffic studies. Hence, upcoming researchers and scientists in traffic engineering area can use drones for studies that may require high quality areal pictures.
- ✚ Addis Ababa is the capital city of Ethiopia and head quarter of African Union requiring the most interchangeable traffic on a daily basis. To make this happen professionals in this area should strive to check every input parameters in our analysis and design which are basically adopted from foreign countries. Respective government authorities should fund researches to develop manuals that incorporate local scenarios.
- ✚ Software Engineers and other Information Technology professionals with the help of Traffic Engineers can contribute to different traffic engineering related problems. Using image processing technique, video data extraction softwares can be developed which will improve and ease the data extraction challenge to much extent.

- ✚ There is poor inventory of existing traffic infrastructures which the researcher has noticed during data collection stage of the research. Organizations or fellow researchers can contribute by doing a periodic inventory of existing infrastructures in the city and putting it in organized data base system. This will help planners, researchers and others who want to access the data for different purposes.
- ✚ Most of the signalized intersections in Addis Ababa now a days are changed from roundabouts to reduce accidents, minimize traffic jams and to improve efficiency. Even though, the aim is good the intersections have significant visible geometric design defects which impacts traffic studies and the existing traffic on those areas. Therefore, respective traffic agencies should give due attention when they try to change roundabouts to signalized intersections.
- ✚ Upcoming researchers can study passenger car equivalence factors for other movement types and they can get better results by focusing on small number of signalized intersections while considering longer time interval which may enrich the data quality and magnifies the qualities of Headway Ratio method.

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APPENDIX A - HEADWAY DATA

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Table A.1-A.9: Inter-vehicular Departure Headway Data

Intersection Name	Approach Leg	Descriptive Statistics	C-C Lane Group			C-SB Lane Group			SB-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Saris Abo	Bole	Min	1.07	1	1	–	0.1	2.57	1.54	1.73	1.67
		Max	3.34	3.1	3.07	–	2.63	2.7	2.86	3.33	3.67
		Mean	2.1843	1.9216	2.0702	–	1.7988	2.635	2.2	2.5545	2.5529
		Std. Deviation	0.48592	0.46463	0.47974	–	1.00475	0.09192	0.93338	0.48252	0.65232
	Kaliti	Min	0.77	0.6	0.97	1.8	1.6	1.6	2.33	2.1	2.17
		Max	3.5	3.6	3.1	3	2	3.57	3.1	3	4
		Mean	2.162	2.0811	2.0425	2.52	1.8	2.69	2.81	2.612	3.03
		Std. Deviation	0.53535	0.5221	0.44913	0.57619	0.28284	0.77836	0.41869	0.44802	0.68086

Intersection Name	Approach Leg	Descriptive Statistics	C-LB Lane Group			LB-C Lane Group			C-T Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Saris Abo	Bole	Min	–	2.8	1.53	–	1.77	3.2	2.3	1.44	1.87
		Max	–	7.07	1.71	–	3.7	4.5	3.8	3	2.4
		Mean	–	4.4567	1.62	–	2.8575	3.9767	2.99	2.1914	2.0925
		Std. Deviation	–	2.29012	0.12728	–	0.88081	0.68603	0.61628	0.42466	0.22559
	Kaliti	Min	2.5	3.3	2.5	3.4	2.67	2.54	2	1.2	1.3
		Max	4.4	4.43	3	3.6	6.3	4.2	3.8	4.4	2.9
		Mean	3.15	3.7433	2.8075	3.5175	4.2883	3.2133	2.65	2.4819	2.0708
		Std. Deviation	0.87369	0.60302	0.22111	0.09946	1.55754	0.56958	0.54737	0.88939	0.48562

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	T-C Lane Group			C-TT Lane Group			TT-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Saris Abo	Bole	Min	1.9	0.86	2	–	3.55	–	–	4	–
		Max	4.2	4.07	5.2	–	5.6	–	–	5.4	–
		Mean	<i>3.31</i>	<i>2.6561</i>	<i>3.2667</i>	–	<i>4.55</i>	–	–	<i>4.5325</i>	–
		Std. Deviation	0.87101	0.69334	1.70098	–	1.48492	–	–	0.66249	–
	Kaliti	Min	2	1.67	2	5.63	5.07	1	4.63	5.5	10.1
		Max	3.6	4.5	2.63	5.63	5.07	1	5.6	10.6	10.1
		Mean	<i>2.931</i>	<i>2.809</i>	<i>2.29</i>	<i>5.63</i>	<i>5.07</i>	<i>1</i>	<i>5.265</i>	<i>7.9217</i>	<i>10.1</i>
		Std. Deviation	0.45271	0.76052	0.1927	–	–	–	0.43776	1.88659	–

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	C-C Lane Group			C-SB Lane Group			SB-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Jemo Michael	Jemo	Min	0.94	0.8	1	1.5	1.24	2.4	1.93	1.93	1.5
		Max	3.2	3.07	3.37	1.76	1.77	2.4	3.6	1.93	4.03
		Mean	1.8997	1.8394	1.9622	1.63	1.54	2.4	2.71	1.93	2.765
		Std. Deviation	0.48509	0.45965	0.5251	0.18385	0.21335	–	0.84042	–	1.78898
	Koshe	Min	1.2	1.03	1.13	2	1.16	1.33	2	1.7	1.8
		Max	2.6	3.23	3.3	3.14	3.87	4.14	2.7	3.13	3.73
		Mean	1.8711	1.9674	1.9633	2.7333	2.2023	2.6163	2.45	2.4179	2.8644
		Std. Deviation	0.35013	0.48377	0.54259	0.49758	0.78578	1.04956	0.31091	0.5091	0.69083
	German RBT	Min	–	1.2	1.2	–	2.07	1.87	–	1.97	2.33
		Max	–	3.34	3.3	–	2.9	5	–	3.33	3.6
		Mean	–	2.075	2.3308	–	2.468	3.0388	–	2.6162	3.015
		Std. Deviation	–	0.45834	0.51014	–	0.37904	1.06385	–	0.47244	0.45663
	Merkato	Min	–	1	1.3	–	1.94	1.73	–	1.4	2.3
		Max	–	3.27	2.74	–	3.1	3.87	–	3	2.87
		Mean	–	1.94	2.0568	–	2.65	2.7825	–	2.064	2.585
		Std. Deviation	–	0.49692	0.32875	–	0.47166	1.16038	–	0.67133	0.40305

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	C-LB Lane Group			LB-C Lane Group			C-T Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Jemo Michael	Jemo	Min	1.77	1.73	2.67	–	1.67	2.44	1.17	1.73	1.5
		Max	1.77	2.23	2.67	–	4.97	2.8	3.7	3.2	3.53
		Mean	1.77	1.98	2.67	–	3.2467	2.62	2.506	2.4295	2.515
		Std. Deviation	–	0.35355	–	–	1.65488	0.25456	0.67329	0.43686	1.43543
	Koshe	Min	–	2.4	1.9	–	1.6	2.83	1.8	1.37	1.56
		Max	–	2.77	2.4	–	3.27	5.44	2.97	3.94	3.24
		Mean	–	2.6233	2.18	–	2.5925	3.7138	2.4067	2.4083	2.3883
		Std. Deviation	–	0.19655	0.21679	–	0.7058	0.91556	0.4848	0.72262	0.58533
	German RBT	Min	–	1.44	–	–	2.83	–	–	1.2	1.83
		Max	–	2.7	–	–	3.2	–	–	4.2	3.1
		Mean	–	2.0675	–	–	3.015	–	–	2.4404	2.5267
		Std. Deviation	–	0.51519	–	–	0.26163	–	–	0.73002	0.52785
	Merkato	Min	–	1.64	1.9	–	2.37	2.27	–	1.47	1.53
		Max	–	4.4	2.9	–	4.5	5.27	–	3.5	2.93
		Mean	–	2.8117	2.4	–	3.5111	3.28	–	2.2682	2.2852
		Std. Deviation	–	1.05274	0.70711	–	0.7299	1.72346	–	0.54697	0.56864

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	T-C Lane Group			C-TT Lane Group			TT-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Jemo Michael	Jemo	Min	1.74	1.47	1.66	-	-	-	-	-	-
		Max	2.83	2.73	4.27	-	-	-	-	-	-
		Mean	2.3	2.1053	2.5625	-	-	-	-	-	-
		Std. Deviation	0.32077	0.38233	0.93651	-	-	-	-	-	-
	Koshe	Min	2.26	1.67	2.1	-	2.27	-	-	3.4	-
		Max	4.37	3.2	2.9	-	2.27	-	-	5.6	-
		Mean	3.014	2.3246	2.39	-	2.27	-	-	4.5667	-
		Std. Deviation	0.84133	0.38133	0.32302	-	-	-	-	1.10604	-
	German RBT	Min	-	1.17	2.7	-	2.83	-	-	4.1	-
		Max	-	3.9	3.93	-	5.6	-	-	4.14	-
		Mean	-	2.5729	2.935	-	4.61	-	-	4.12	-
		Std. Deviation	-	0.64463	0.64292	-	1.54477	-	-	0.02828	-
	Merkato	Min	-	1.63	2.2	-	5.5	-	-	-	-
		Max	-	3.5	2.4	-	5.5	-	-	-	-
		Mean	-	2.588	2.2883	-	5.5	-	-	-	-
		Std. Deviation	-	0.55564	0.07757	-	-	-	-	-	-

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	C-C Lane Group			C-SB Lane Group			SB-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Lebu Mebrat Hayl	Mexico/Sarbet	Min	–	0.9	0.87	–	1.5	1.3	–	2.33	1.43
		Max	–	2.73	3.33	–	3.07	5.53	–	3.33	4.97
		Mean	–	1.7714	1.9657	–	2.1667	3.0183	–	2.657	2.7269
		Std. Deviation	–	0.40033	0.52123	–	0.4725	0.97745	–	0.33592	0.81136
	Kaliti	Min	0.77	0.73	–	1.63	1.2	–	1.73	0.87	–
		Max	3	2.77	–	1.93	4.53	–	2.67	2.93	–
		Mean	1.8865	1.7106	–	1.7565	2.4223	–	2.2	2.0893	–
		Std. Deviation	0.46587	0.40434	–	0.19092	0.8975	–	0.66468	0.53377	–
Gerji Mebrat Hayl	Goro	Min	1.07	1.03	1.2	2.57	3.4	1.7	3.63	2.9	1.93
		Max	3.83	3.57	3.2	3.87	3.4	4.07	4.03	3.8	3.43
		Mean	2.3988	2.2148	2.1081	3.1367	3.4	2.6669	3.83	3.4767	2.795
		Std. Deviation	0.53328	0.50207	0.4076	0.66583	–	0.70705	0.2	0.50063	0.38355

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	C-LB Lane Group			LB-C Lane Group			C-T Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Lebu Mebrat Hayl	Mexico/Sarbet	Min	–	1.63	1.3	–	2.13	2.13	–	0.97	1.1
		Max	–	4.6	5.8	–	3.73	4.87	–	4.43	3.97
		Mean	–	2.74	3.35	–	2.9267	3.176	–	2.4151	2.4
		Std. Deviation	–	0.80462	1.37351	–	0.45714	0.69771	–	0.74639	0.79003
	Kaliti	Min	2.2	0.97	–	2	1.67	–	1.37	1.3	–
		Max	2.63	4.33	–	3.33	4.63	–	4	4.7	–
		Mean	2.415	2.5922	–	2.525	3.1117	–	2.2469	2.4804	–
		Std. Deviation	0.30406	0.72486	–	0.61245	0.73162	–	0.71993	0.74053	–
Gerji Mebrat Hayl	Goro	Min	2.83	3.03	2.23	4	0.97	2.8	1.67	1.33	1.33
		Max	3.47	4.77	6.03	5.13	5.2	5.1	3.33	4.37	3.8
		Mean	3.1075	3.9	3.5421	4.45	3.6036	3.8465	2.4782	2.745	2.5118
		Std. Deviation	0.32786	1.23037	1.01802	0.4809	1.2578	0.69313	0.58539	1.01633	0.92523

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA,
ETHIOPIA**

Intersection Name	Approach Leg	Descriptive Statistics	T-C Lane Group			C-TT Lane Group			TT-C Lane Group		
			1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Lebu Mebrat Hayl	Mexico/Sarbet	Min	–	1.5	1.57	–	1.1	2.9	–	3.67	4.4
		Max	–	3.47	3.07	–	4.67	4.27	–	5.17	4.97
		Mean	–	2.3021	2.3689	–	2.8963	3.4333	–	4.3175	4.685
		Std. Deviation	–	0.46296	0.37529	–	1.32171	0.73364	–	0.50045	0.40305
	Kaliti	Min	1.67	0.93	–	4.17	2.6	–	–	2.6	–
		Max	3.27	3.87	–	5.23	3.57	–	–	4.7	–
		Mean	2.2727	2.3271	–	4.7	3.0588	–	–	3.532	–
		Std. Deviation	0.5016	0.62021	–	0.74953	0.3054	–	–	0.84301	–
Gerji Mebrat Hayl	Goro	Min	2.1	2	3.07	4.27	–	–	7.13	–	–
		Max	5.47	4.47	3.77	4.27	–	–	7.13	–	–
		Mean	3.5311	3.186	3.395	4.27	–	–	7.13	–	–
		Std. Deviation	1.07635	0.80641	0.31316	–	–	–	–	–	–

APPENDIX B-SAMPLE CALCULATION

B.1 Headway Ratio Method Sample Calculation

Inferred headway ratio method has the following equation:-

$$e_x = \frac{\bar{h}_{c_x} + \bar{h}_{x_c} - \bar{h}_{c_c}}{\bar{h}_{c_c}}$$

Where: - e_x = passenger car equivalence for vehicle category i
 h_{c-c} = Average headway of a car followed by a car;
 h_{c-x} = Average headway of a car followed by a type x vehicle;
 h_{x-c} = Average headway of a type x vehicle followed by a car;

Sample Problem 1:-

Site Data:-

Intersection ID: Saris Abo

Vehicle Type: Small Bus

Approach leg: Bole

Lane group: 2nd

Input Average headway leader-follower Data:-

Car followed by Car=1.9216

Car followed by Small bus=2.5545

Small bus followed by car=1.7988

$$e(SB) = \frac{2.5545 + 1.7988 - 1.9216}{1.9216}$$

$$e_{SB} = \underline{\underline{1.26}}$$

Sample Problem 2:-

Site Data:-

Intersection ID: Saris Abo

Vehicle Type: Large Bus

**THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED
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Approach leg: Kaliti

Lane group: 3rd

Input Average headway leader-follower Data:-

Car followed by Car=2.0425

Car followed by Large bus=3.2133

Large bus followed by car=2.8075

$$e(LB) = \frac{3.2133 + 2.8075 - 2.0425}{2.0425}$$

$$e_{LB} = \underline{\underline{1.947}}$$

Sample Problem 3:-

Site Data:-

Intersection ID: Jemo Michael

Vehicle Type: Truck

Approach leg: Jemo

Lane group: 2nd

Input Average headway leader-follower Data:-

Car followed by car=1.8394

Car followed by Truck=2.4295

Truck followed by car=2.1053

$$e(T) = \frac{2.4295 + 2.1053 - 1.8394}{1.8394}$$

$$e_T = \underline{\underline{1.465}}$$

APPENDIX C-LIST OF AVAILABLE PRETIMED INTERSECTIONS

THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA

Table C.1: Existing Pre-timed Intersections in Addis Ababa

No.	Location Name	Left Turn Treatment		Parking		Local Bus Blockage		Channelized		No of Approaches							Working Condition (Working/ Not Working)	No of Lanes	
		Protected	Permitted	Yes	No	Yes	No	Yes	No	Three			Four						
										T	Skewed T	Y	Right Angle	Offset	Oblique	>=5			
1	Megenagna Roundabout	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
2	Ring Road Lebu Mebrathayl	√	-		√		√	√			-	-	-	-	√	-		Yes	3
3	Bole Micheal	√	-		√		√	√			-	-	√	-		-		Yes	4
4	Agona Cinema (Gotera)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
5	Legehar	√	-		√	√	-	-	√		-	-	√	-	-	-	-	Yes	3
6	Bunnana Shay	-	√	-	√	√	-		√		-	-	√	-	-	-	-	Yes	4
7	Mexico Roundabout	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
8	Gerji Mebrathayl	-	√	-	√	-	√	√	-	-	√	-	-	-	-	-	-	Yes	3
9	Around Imperial Hotel	√	-	-	√	-	√	-	√	-	-	-	√	-	-	-	-	Yes	3
10	Cocka Bridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
11	Kolfe 18 Mazoriya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
12	Around Semen Hotel	-	√	-	√	-	√	-	√		-	-	√	-	-	-	-	Yes	3
13	Around Parilament	-	√	-	√	-	√	-	√		-	-	√	-	-	-	-	Yes	4
14	Around National Theater	√	-	√			√	-	√	√						√		Yes	4
15	Around Post Office		√		√		√			√			√					Yes	3
16	Around ETV		√		√		√								√			Yes	3

THROUGH TRAFFIC PASSENGER CAR EQUIVALENTS FOR SELECTED SIGNALIZED INTERSECTIONS IN ADDIS ABABA, ETHIOPIA

No.	Location Name	Left Turn Treatment		Parking		Local Bus Blockage		Channelized		No of Approaches							Working Condition (Working/ Not Working)	No of Lanes
		Protected	Permitted	Yes	No	Yes	No	Yes	No	Three			Four					
										T	Skewed T	Y	Right Angle	Offset	Oblique	>=5		
17	Around Senga Tera (Morgage)		√		√		√		√				√				Yes	3
18	Near Harambe Hotel		√		√		√		√						√		Yes	3
19	Near Shola Market		√		√		√		√	√							Yes	4
20	Around Goma Kuteba		√		√		√	√					√				Yes	4
21	Near Banko Diroma		√	√			√	√							√		Yes	3
22	Near Atlas Hotel		√		√		√	√							√		Yes	3
23	Meskel Square		√	√		√		√							√		Yes	5
24	Near St.Joseph School		√	√		√			√						√		Yes	3
25	Near Lideta Tsebel		√		√		√		√			√					Yes	3
26	To Jomo Ring Road Michael		√		√		√	√							√		Yes	2
27	Kera to Gofa Turn		√		√		√		√				√				Yes	3
28	Near Kera		√		√		√		√				√				Yes	3
29	Kidist Mariam	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
30	Kazanchis Next to Radisson Blue Hotel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	No	-
31	Near Kadisco		√														Yes	3
32	Near Saris Abo Church	√															Yes	4
33	Near Safari		√														Yes	2
34	Salitemihret to Safari		√		√		√		√				√				Yes	3

APPENDIX D -SAMPLE VIDEO DATA EXTRACTION

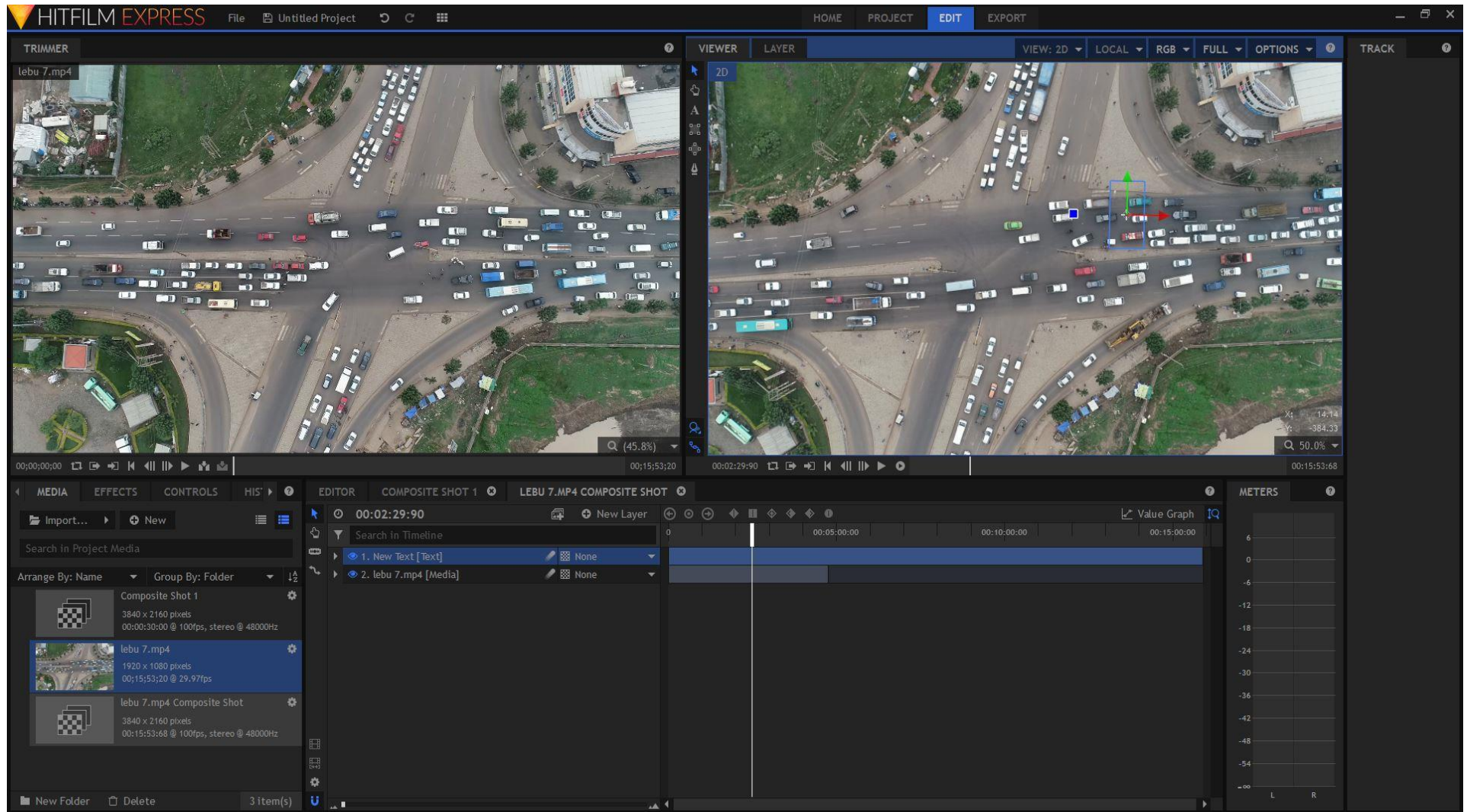


Fig D.1. Full Screen Shot of Video Data Extraction with HitFilm Express 2017(Lebu Mebrat Hayl Intersection)

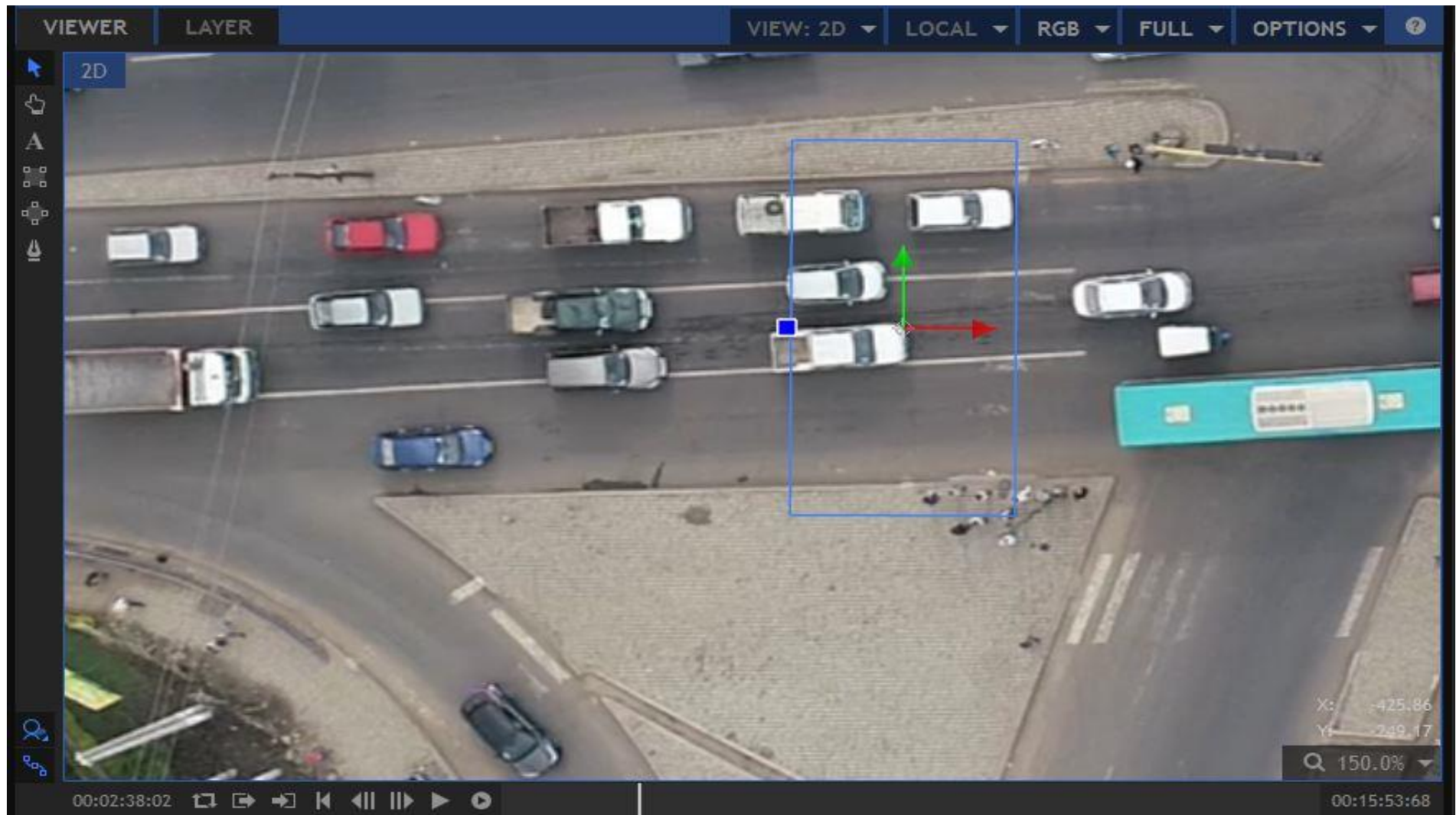


Fig D.2. Zoomed Screen Shot of Video Data Extraction with HitFilm Express 2017(Lebu Mebrat Hayl-Mexico Leg)