DEVELOPMENT OF PASSENGER CAR EQUIVALENT FOR SIGNALIZED INTERSECTIONS (BASED ON A STUDY CONDUCTED AT SELECTED FOUR SIGLALISED INTERESECTIONS OF HAWASSA CITY, ETHIOPIA)

M.Sc. THESIS

THOMAS BEZABIH BASHE

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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THOMAS BEZABIH BASHE

Advisors

PROF. J.P. NARAYAN
KIBKAB WUBE

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We, the undersigned, members of the Board of Examiners of the final open defense by **Thomas Bezabih** have read and evaluated his/her thesis entitled **"DEVELOPMENT OF PASSENGER CAR EQUIVALENT FOR SIGNALIZED INTERSECTION (BASED ON A STUDY CONDUCTED AT SELECTED FOUR SIGLALISED INTERESECTIONS OF HAWASSA CITY, ETHIOPIA)"** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DECLARATION

I hereby declare that this MSc thesis dissertation is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis / dissertation have been duly acknowledged.

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LIST OF ACRONYMS

$\frac{v}{c}$ ………………………. Volume to Capacity ratio

ERA……………………… Ethiopian Road Authority

HCM ………………………...Highway Capacity Manual

HV………………………. Heavy Vehicle

LOS………………………. Level of Service

PC or p ………………………Passenger Car

PCE………………………. Passenger Car Equivalent

PCU ………………………..Passenger Car Unit

TRB ………………………. Transport Research Board

b……………………………. Bajaj/Auto Rickshaw

HV/hv………………………. Heavy Vehicle

LDV…………………………. Light Duty Vehicle

M/m…………………………. Motorcycle

RTMS ………………………. Remote Traffic Microwave Sensor

ABSTRACT

The number of passenger cars displaced in a traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions is called Passenger Car Equivalent, Highway Capacity Manual (2010), where estimating it was the basic objective of this dissertation with all other vehicle categories available at signalized intersection of Hawassa City, Ethiopia. Data was collected from four signalized intersections using digital video recorder which is followed by extraction of the time headway. An analytical model was developed to simulate headway values based on total travel time and vehicle type. This model was used to estimate headways of Motorcycle, Auto rickshaw, Passenger cars, Light Duty Vehicle and Heavy Vehicles which are then used to estimated PCE of each vehicle group. Time headway ratio method was chosen for the analysis and estimation of PCE, for it was found to be utilizing such a dynamic characteristic of traffic stream (i.e. headway) which is able to explain driver behavior, roadway surroundings, traffic volume and speed characteristics through a single parameter. The PCE factors of Motorcycle, Auto rickshaw, Light Duty Vehicle and Heavy Vehicle are found to be 0.552, 0.701, 2.004 and 2.967 respectively. The PCE factor value of Motorcycle used by the local standard book, Ethiopian Road Authority, Geometric Design Manual (2013) is less than half of the calculated finding of the study; similarly, for Auto rickshaw the ERA provision is slightly larger than half of the calculated value of this study. The absence of PCE for Light Duty Vehicle and Heavy Vehicle groups and deviation of PCE factors for the remaining vehicle groups from this study result indicates a significant quantity of calculations involving PCE, such as saturation flow rate and thus influences the design of signalized intersections. Finally, it is suggested that the values obtained in this study can be used as a guideline in the design and analysis of signalized intersections in Hawassa City as well as in Ethiopia.

Key Words: Passenger Car Equivalent, Signalizes Intersections, Traffic, Roadway.

1. INTRODUCTION

1.1. Background

It is common to see a diversity of traffic, especially here in developing countries, ranging from human and animal drawn and non-standard carriages, outdated and old model slow moving cars to the latest brand vehicles which are used to transport goods and people from place to place. This heterogeneous traffic stream, compromised traffic lane discipline and a considerable behavioral change of drivers of different types of vehicles have posed an unprecedented problem. This assortment, according to Anthony I., 2004, influences the analysis of trip assignment in travel demand modeling, traffic volume estimation, capacity and level of service determination, lane requirements, and determining the effect of traffic on highway operations.

Highway capacity is expressed in passenger cars per hour per lane. A uniform measure of vehicles is thus necessary to assess the different types on common basis; and it is here where the idea of passenger car unit came to being and developed. Muhammad, A., 2013, defined a Passenger Car Unit as a measure of the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single standard passenger car.

The impact of heavy vehicles on multi-lane highways was established for the first time in the 1950 Highway Capacity Manual (HCM). But the term “Passenger car equivalent” was first introduced in HCM, 1965, to define the effect of trucks and buses in the traffic stream. It was defined as “the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions” (Muhammad, A., 2013). And later editions of Highway Capacity Manual (HCM) showed a slight modification of definition; “The number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions", (HCM, TRB, 2010). But this definition of PCE was for relatively homogeneous traffic conditions (only bus, car and trucks) prevailing in developed countries and PCE values relay on a limited field database and extensive simulation runs based on this information, and according to Umama, A., 2010, they were calibrated on steady-flow traffic operations. This is where I get the initiative to work on recalibrating PCE values with due consideration of local roadway, traffic and control conditions.

Therefore, this study about Passenger Car Equivalents (PCE) at signalized intersections will be carried out in Hawassa city. It also comes as a complement to a previous study in Addis Abeba – Adama expressway on PCE values of trucks and buses.

1.2. Statement of the problem

As civilization and globalization strives to bring every part of our world together in all possible means, construction of road infrastructure takes a considerable part. Infrastructure developers; governments and private designers needs the help of professions and scholars in locating the right corner where there is a need of new root alignment, expansion and/or modification of any kind to consider. This comes to reality only through travel demand modeling; through capacity and level of service determination, leading finally to fixing number of traffic lanes requirement, and determining the effect of traffic on highway operations.

According to ERA geometric design manual 2013, traffic volume is one of the basic and foremost design controls and criterions that must be addressed precisely. A standard representation of local vehicles of a particular type under specified roadway, traffic and control conditions is mandatory. There have been researches conducted by different scholars to determine a uniform representation of traffic i.e. PCE or PCU, however, in most cases a relatively homogeneous traffic (car, bus and truck) is considered. In developing countries like Ethiopia, there exist heterogeneous traffic stream resulting due to interference of a significant number of auto rickshaw (Bajaj), motorcycles, non-standard vehicles as well as very old and outdated modes of transport that also includes large freight vehicles. Practically, for design and decision-making purpose, PCE values are cited mostly from other countries highway capacity manuals. That is why we need to adapt accordingly, so that the calculated PCE values reflect the local roadway, traffic and control conditions.

Another reason to conduct this research is that from different studies every country has different traffic flow characteristics and vehicles performance due to this, different studies have got different Passenger Car Equivalent values. Thus, developing these values is essential for the country to design, plan, operate and maintain signalized intersections corresponding to the local traffic stream flow. And also confirms operational improvements resulting from accurate analysis and design of signalized intersections.

In addition, the 2010 HCM directly requests whoever wants to assume PCE values, needs to evaluate its own local values. Furthermore, it is also suggested to continue to update PCE values to account for the ever-changing traffic along with the socio-economic progress of the country in general and special localities like Hawassa in particular.

1.3. Objectives

1.3.1. General Objective

The general objective of this research is to investigate Passenger Car Equivalents for all vehicles under the prevailing roadway and traffic condition of signalized intersections based on a case study conducted at selected four signalized intersections of Hawassa City.

1.3.2. Specific Objectives

The specific objectives of this research are listed as follows;

1. To evaluate the roadway and traffic conditions of the intersections under investigation.
2. To develop the Passenger Car Equivalent values of all vehicles on the selected intersections.
3. To assess the calculated Passenger Car Equivalent with respect to previously conducted similar research findings and practices in developing and developed countries.

1.4. Research questions

Hypothetical research questions that will help respond the objectives of this dissertation are:

Q1. What are the current approaches? Which one fits PCE evaluation at signalized intersections most appropriately?

Q2. What are analysis methods used by ERA manuals, and are we using the latest approaches?

Q3. What are the limitations of PCE of ERA manual, 2013?

Q4. How different are the ERA PCE values from the calculated as well as other studies and practices? Why?

Q5. How are the determining variables of Passenger Car Equivalent affecting the analysis process?

1.5. Scope and Limitation

This research will investigate passenger car equivalents of all vehicle listed in Ethiopian Road Authority, Geometric Design Manual, at signalized intersection's which are found in the city of Hawassa, Ethiopia. Data will also be collected at the above-mentioned locations during saturation flow, which is expected to happen during week days from Tuesday to Friday during morning and before noon rush hours.

In this study, the results depend on set of limitations and criterion in to account on the following:

- Due to financial constraint the video recording was not conducted continuously as it should have been and consider additional variables like onsite vehicle weight
- Vehicle grouping of the national geometric design manual; passenger car and Trucks and Buses was found to be misleading since it comprises a wide range of vehicles.

2. LITERATURE REVIEW

Enormous works have been done on estimation of Passenger car equivalent and capacity of roads in U.S.A. and U.K. The U.S-Transport Research Board (TRB) published Highway Capacity Manuals since 1950 to address the capacity issue. For many years, research publications from the overseas center of the Transport Research Laboratory UK (TRL) formed the basis for design of most transport facilities such as pavements as well as traffic operations on roadway facilities including signalized intersection timing design.

The travel characteristics, road networks and local constraints are very different in the cities of developing countries than those of developed countries. It is therefore necessary to determine the different parameters of traffic movements which are suitable for local urban transport system characteristics. To assess the different types of vehicles on common basis, a passenger car unit or passenger car equivalent (PCE) was developed.

2.1 History of Passenger Car Equivalent

2.1.1 History of PCE in the United States of America

The United States of American, Transportation Research Board's (TRB) first publication of the Highway Capacity Manual 1950, introduced the estimate that, on two-lane highways on level terrain, trucks have the same effect as two Passenger Cars (PC). And according to that same manual this estimate was based on the number of passenger cars passing trucks compared to the number of passenger cars passing passenger cars (Umama, A., 2010).

The term passenger car equivalent (PCE) was first introduced in the 1965 Highway Capacity Manual. PCE for heavy vehicles was defined as “The number of passenger cars displaced in the traffic flow by a truck or a bus, under prevailing roadway and traffic conditions.” Another new concept LOS “Level of Service” was also brought up which was defined in terms of two parameters: operating speed and volume-to-capacity ratio. And PCE in this manual was described for different LOS and provided a range of PCE values for LOS A and relatively same values for LOS B, C, D and E.

The 1985 HCM also related PCE with LOS for two-lane highways but for multilane level freeways a single value of 1.7 for trucks for all LOS was recommended (Al-Kaisy, A., et. Al., 2002).

The HCM 2000, as cited by Umama, A., 2010, also uses a single PCE of 1.5 for level freeways, regardless of LOS. The currently suggested PCE value is based on the effect of HV dimensions and performance under steady-state traffic flow conditions.

2.1.2. Development of PCE evaluation practices

Shalini, K., and Kumar, B., 2014, have published a review of years of works of a number of scholars, who have been looking for an appropriate method of evaluating PCE for specific roadway, traffic and control conditions in different countries. The following PCE equations were developed by the respective scholars through studying different traffic characteristics as it is shown hereunder.

Table 2.1. A brief review of the PCE equations.

Publication Year	**Authors**	**Basic Formula**	***Variables (Factors Studied)***	***Remark***
1947	Greenshields, B.D et al	$PCE_i = \frac{H_i}{H_c}$	*Headways (time and/or space)*	H_i-average headway of vehicle type H_c- average headway of passenger car
1976	John and Glauz	$PCE = \frac{q_B - q_M(1-P_T)}{q_M X P_T}$	*Flow Rates and Density* (Percentage of grade, mixed vehicle flow, and truck volume to capacity ratio)	q_B-equivalent passenger car only flow rate for a given v/c ratio q_M- mixed flow rate P_T-truck proportion in the mixed traffic flow
1976	Werner and Moral	$PCE = \frac{\left(OT_i/VOL_i\right)\left[1/SP_M\right] - \left[1/SP_B\right]}{\left(OT_{LPC}/VOL_{LPC}\right)\left[1/SP_{PC}\right] - \left[1/SP_B\right]}$	*Delays* (relative capacity reducing effect of heavy vehicle)	***OT*** - the number of overtaking of vehicle ***VOL*** - the volume of vehicle ***SP*** - the mean speed *M* - mixed traffic stream *B* – base traffic fllow

				LPC – lower performance passenger cars PC - passenger cars
1976	Werner and Moral	$PCE = \frac{H_M/H_B - P_C}{P_T}$	*Headways*	H_M – is the average headway for a sample including all vehicle types, H_B – is the average headway for a sample of passenger cars only, P_C – is the proportion of cars P_T - is the proportion of trucks
1980	Crause et. at.	$PCE = \frac{d_{kt}}{d_{kp}}$	*Delays*(considered the difference between delay caused by heavy vehicle to standard passenger cars)	d_{kt}-average delay time caused by one truck d_{kp}-average delay time caused by one passenger car
1982	Huber M. J.	$PCE = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1$	*Flow rates and Density* (PCE-values are related to the ratio between the volumes of two streams at some common level of impedance)	q_B-equivalent passenger car only flow rate for a given v/c ratio q_M- mixed flow rate P_T-truck proportion in the mixed traffic flow
1982	Seguin, E. et.al	$PCE_{ij} = \frac{H_{ij}}{H_{pcj}}$	*Headways* (spatial headway)	H_{ij}- average headway for vehicle Type i for Conditions j, H_{pcj}- the average headway for passenger car for Conditions j
1982	Cunagin and Chang	$PCE = \frac{H_{ij}}{H_B}$	*Headways* (based on headway type, lane width, and traffic volume)	H_{ij}- the mean lagging headway of vehicle type i under conditions j H_B- the mean lagging headway of passenger cars
1983	Van Aerde and Yagar	$E_n = PCE_n = \frac{C_n}{C_1}$	*Speed* (PCE based on the relative rates of speed for each type of vehicle travelling in the main direction and for all vehicles combined travelling in the opposing direction).	C_n- speed reduction coefficient for vehicle type n C_1- speed reduction coefficient for passenger cars
1983	Cunagin and Messer	$PCE = \frac{D_{ij} - D_{base}}{D_{base}}$	*Delays* (using Walker spatial-headway and equivalent-delay methods)	D_{ij}- delay to passenger cars due to vehicle Type i under Conditions j, D_{base} - delay to standard passenger cars

				due to slower passenger cars.
1984	Sumner et al.	PCE is expressed in terms of additional vehicles-hours	*Vehicle-Hours*	PCE values between consecutive signalized intersections on urban arterial roads
1984	Keller and Seklas	$PCE = \frac{TT_i}{TT_o}$	*Travel time* (PCEs are functions of traffic volume, vehicle classification, and signal settings)	TT_i- total travel time of vehicle type i over the network in hours TT_o- total travel time of the base vehicle over the network in hours.
1986	Krammes and Crowley	$PCE = \frac{[(1-P_T).H_{TP}+p.H_{TT}]}{H_P}$	*Headways* (Lagging time headway)	H_{TP}- the lagging headway of trucks following passenger cars, H_{TT} - the lagging headway of trucks following trucks, H_P- the lagging headway of cars following either vehicle type.
1989	Fan, H. S.	Linear regression	$^v/_c$ *ratio*	Multiplies the observed flow by the V/C ratios
1998	Zhao, W.	$D-PCE_i = 1 + \frac{\Delta d_i}{d_o}$	*Delay*(delay-based passenger car equivalents method for heavy vehicles at signalized intersections)	$D-PCE_i$= delay-based PCE for vehicle type i, Δd_i= additional delay caused by a vehicle type i, d_o- average delay of passenger car queue
2000	Chandra and Sikdar	$PCE_i = \frac{V_c/V_i}{A_c/A_i}$	*Speed* (They have estimated the PCE values as a function of vehicle area and speed.)	V_c- & V_i-mean speeds of car and type i vehicle respectively, in the traffic stream; and A_c- & or A_i- = their respective projected rectangular areas (length * width) on the road.
2002	Al-Kaisyet al.	PCE >=X3 (X3 = 1.0) PCE <=X4 (X4 = 10.0)	Queue Discharge Flow (based on the assumption that the fluctuation in QDF capacity observations would be minimal if the traffic stream was uniform and consisted of passenger cars only)	Objective function: Minimize Z(C*) (Z = Coefficient of Variation = Standard Deviation/Mean) *Design variable:* PCE factor *Constraints:* C* >=X1 (X1 =1600 pcphpl at site 1, X1 = 1400 pcphpl at site 2) C* <=X2 (X2 =2800 pcphpl at site 1, X2 = 2600 pcphpl at site 2)

2003	Demarchi and Setti	$PCE = \frac{1}{\sum_{1}^{n} P_i}\left(\frac{q_B}{q_M} - 1\right) + 1$	*Flow rates and Density* (proposed the PCE's formula to eliminate the possible error for mixed heavy vehicles in the traffic stream, including interaction between multiple trucks types)	q_B-equivalent passenger car only flow rate for a given v/c ratio q_M- mixed flow rate P_i- truck proportion of type i in the mixed traffic flow
2005	Rahman and Nakamura	$PCE = \frac{1}{\nabla P}\left(\frac{q_B}{q_S} - \frac{q_B}{q_M}\right) + 1$	*Flow rates and Density* (PCE-values are related to speed and length of subject vehicles and vary with the proportion of trucks in the traffic stream.)	q_B-equivalent passenger car only flow rate for a given v/c ratio q_M- mixed flow rate q_S- additional subject flow rate ∇P- proportion of subject vehicles
2005	Rahman and Nakamura	$PCE_{max} = 1 + \frac{S_b - S_m}{S_b}$	*Speed* (PCE value for non-motorized vehicles was estimated)	PCE_{max}-PCE of non-motorized vehicles, S_b- Average speed of PC in the basic flow (km/hr), S_m- Average speed of PC in the mixed flow (km/hr)

Different scholars have used either one or combination of the above methods to evaluate PCE for urban or rural two-lane one way highways, two-lane two-way highways or multilane roads at midblock, signalized intersections and/or non-signalized intersections like roundabouts. But according to Shalini K., and Kumar B., 2014, headway ratio method is the most commonly used method for measuring PCE at signalized intersections. Many researchers have used headway as the basis of estimation. And hence, headway method is given emphasis in this study.

2.1.3. PCE Evaluation in developed countries

Since Greenshields, et. al., 1947, published their work on Traffic Performance at Urban Intersections, describing a possible way of analysing PCE using a headway method, there has been a surge in the interest of investigation of PCE. Specially, after the 1950 and letter the 1965 Highway Capacity Manual established the basis for the definition and scientific approach towards PCE, many scholars considered different variables and proposed a way to evaluate PCE for the respective roadway, traffic and control condition.

Lee, T., et. al., 2010, has studied the Passenger Car Equivalents (PCE) values of motorcycles in two traffic environments: at the beginning of a green period and in a saturation flow, of Lisbon, Portugal. They employed the flow rate method to estimate motorcycle PCE values, with the help of a recently developed agent-based simulation model, which is capable of representing the characteristic movement patterns of motorcyclists. This model indicated that the PCE values of motorcycles at the beginning of green periods are averagely 0.237 lower than those in multiple-lane saturation flows. In addition, the PCE values decrease by 0.143 with every 1.0 m increase of the lane width.

An analytical model was developed to estimate PCE values based on total travel time and vehicle type by Molina C. J., et. al., 1987. The objective of this investigation was to develop passenger car equivalents (PCE's) for trucks travelling straight through a level, signalized intersection. Using the developed model, PCE values were analysed for 2-axle, single unit; 3-axle, single-unit; 4-axle combination; and 5-axle combination trucks. But, the PCE values generated from this study were condensed into two values; one for light trucks and one for heavy trucks. In addition, the heavy vehicle adjustment factor equation was modified to analyse the effects of light and heavy trucks separately using the recommended PCE values developed in this report.

Kara, M. et. al., 2000, analysed the impacts of different light-duty trucks (LDTs) on the capacity of two signalized intersections in Austin, Texas, and regression analysis generated estimates of mean headways associated with various categories of LDTs, as well as passenger cars. Using the estimated headways Passenger Car Equivalents (PCEs) were calculated, and these suggest that the impacts of light-duty trucks should be given special consideration when analysing the capacity of signalized intersections.

Mario De Luca and Gianluca Dell'Acqua in 2013 used Two fixed RTMS (Remote Traffic Microwave Sensor) to record traffic data for two sections located at 3100 km on the SP30 and at 8900 km on the SP175 from 1 January to 31 December 2010. After analysing the collected data, results showed that the PCEs analysed vary significantly with vehicular flow, while they are scarcely affected by changes in speed. Although they have the same range recorded as in the Highway Capacity Manual 2010, they tend to be higher than those given in the manual. To consolidate these results, the research is proceeding with other experimental studies concerning different infrastructures on which tests are being carried out also in different traffic conditions.

A paper addressing the question of how to estimate Passenger Car Equivalents (PCEs) for heavy vehicles driving single-lane roundabouts was developed by Orazio G., et. al., 2017 in Palermo, Italy. The microscopic simulation package Aimsun - version 8.1 (TSS, 2011) was used for microscopic modelling of the single-lane roundabout. The differences between the values of PCEs estimated in this study and the HCM values for PCEs, which assumes a heavy vehicle to be equivalent to two passenger cars and sets as 2.0 the passenger car equivalents for heavy vehicles for roundabouts, a higher PCE effect would be expected depending on the quality of traffic conditions. When the traffic stream contains a high number of heavy vehicles; this effect should be accounted for when calculating capacity and level-of-services.

2.1.4. PCE Evaluation in Developing Countries at Signalized Intersection

According to Leong, L.V. A., 2004, on Saha, P., et. al., 2009, concluded that "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" and many more papers have used headway method as it is used in Saha, P. et. al., 2009. The estimated PCE for cars, auto-rickshaws, mini-buses and buses of Saha, P. et.al., 2009, and Bangladesh current practice are compared, and shows significant difference that should be addressed.

Dr. Yahya R. S., 2014, have also used time headway method to establish PCE values of heavy trucks, medium trucks and animal-driven carts at signalized intersections in Gaza, Palestine. A digital video camera was used to capture movements of vehicles and after undergoing statistical evaluation the researcher recommended the use of the UK PCE values (2.3) and (1.5) for heavy and medium trucks. This is because no significant difference was found between the locally established values and the UK values. But for animal driven carts the average value of this and a previously established research result is suggested to be used in Gaza City.

Obiri-Yeboah, A. A. 2014, took 11 signalized intersections which are fully saturated or have adequately saturated portions of the green interval of longer than 20 seconds with cycle lengths greater than 30sec. in Ghana Kumasi. He used camcorder with tripod to record real time traffic movements and headway method is used to study PCE values. The headway data was sorted out for three categories of vehicles; cars (C) (small cars, pickups, and taxis), medium vehicles (M) (small and medium buses) and trucks (T) (large buses, light, medium and heavy trucks and trailers). PCE values were investigated for the effect of roadside friction, there was significant difference. These values were also found to be different, larger than those adopted from Overseas Road Note 11.

Girum Tamene 2016, although it is not conducted for signalized intersection; have published his MSC thesis work which could be the first to try evaluate PCE in our country. His investigation was focused on PCE values of trucks and buses on a basic freeway segment on the Addis Abeba- Adama express way. He used the flow rates and density method and justified with its consideration in HCM 2010, to define LOS. He used video recorder to collect data and found out that as the proportion of trucks increase PCE decrease and become insignificant as it reaches 50%, again PCE also increase as the length of a grade increase and PCE is also found to be increasing with percentage of the grade. Finally concluded that the analyzed PCE were found to be better estimations for they consider the actual local condition.

Another research done in Pakistan, Karachi by Muhammad, A., 2013, conducted on 12 different urban arterial mid blocks of Karachi gave special attention to heterogeneous traffic environment. He presents the estimation of PCE factors from four different existing methods; Time Headway based Methods, Traffic Stream Speed based Method and Method based on Multiple Regression Analysis. After evaluation of PCE for 9 groups of vehicles including two passenger car groups, the author described an important notion in which speed method is more superior, because of the incorporation of dynamic and static characteristics of vehicle types; on the other hand, headway methods are just based on dynamic characteristics of the vehicles.

Nassiri, H., et. al., 2016, evaluated Passenger Car Equivalent at Signalized Intersections in Iran using delay as a parameter. Fourteen approaches, of four signalised intersection, were surveyed at five intersections for field data collection. Simulation model is used to cover a broad range of traffic conditions in this paper and the paper found out that, current research on PCE estimation does not support the HCM view and the constant PCE recommended in HCM overestimated the PCE for Iran's signalized intersections. They also discussed that, since PCE depends on factors influencing the traffic flow parameters, setting it at a constant value under different roadway and traffic conditions does not have to be correct.

The Ethiopian Road Authority, Geometric Design Manual describes traffic analysis as one of the primary inputs of design control and criterions of geometric design of a new or existing root. Especially when the volume of traffic is high, the road space occupied by different types of vehicle is an important element in designing for capacity, namely the highest traffic flow per hour that the road can carry. Large trucks, buses, and non-motorized vehicles, for example, have a strong influence. Traffic volume for basic design purpose is based on the number of two (or more)-axled motorized vehicles. Consideration of other traffic (motor cycles, motor cycle based taxis, non-motorized vehicles, pedestrians etc.) is taken in to account by modifying the basic standards. This is done by combining the number of such road users using the PCE concept as shown in table 2.

Table 2.2. PCE values for non-4-wheeled motorized vehicles (ERA, Geometric Design Manual, 2013)

Vehicle	**PCU value**
Pedestrian	0.15
Bicyclist	0.20
Motorcycle	0.25
Bicycle with trailer	0.35
Motor cycle taxi (Bajaj)	0.40
Motorcycle with trailer	0.45
Small animal-drawn carts	0.70
Bullock cart	2.00
All based on passenger car = 1.00	

Hence, lack of detail investigation of PCE shows more and more researches to be done to as much as possible explain PCE in terms of the local traffic, roadway and control conditions.

2.2. Factors affecting PCEs

Before listing of the most important factors that should be taken in to account for determining passenger car equivalents of vehicles; here are two basic principles brought by Kenneth et.at, to be seen as fundamental concepts that should be addressed through estimation of PCE values for any of the roadway types identified in capacity analysis procedures. The first principle links the concept of passenger car equivalency to the level of service (LOS) theory. The second principle emphasizes the consideration of all factors that contribute to the overall effect of trucks on traffic stream performance.

According to Al-Kaisyet, et. al., 2002, as it is mentioned on Shalini1, K., et. al., 2014, the effect of heavy vehicles on a traffic stream depends on prevailing traffic, geometric, and control conditions. In the freeways, it depends on the effect of grade, length of grade, and the percentage of heavy vehicles on PCEs. Earlier versions of the HCM considered other factors in estimating PCEs such as freeway facility type or level of service (a proxy measure for traffic level).

Shalinil. K., et. al., 2014, also specified additional factors that are sought to influence PCE's by Anand, K., et al., 1999; as dimensions, power, speed, acceleration and braking characteristics of the vehicle, road characteristics such as geometric characteristics including gradients, curves, access controls, type of road: rural or urban, and presence and type of intersection.

2.3. Methods of Estimating PCEs

Several approaches to estimate PCE values have been used by different scholars. The most commonly applied approaches are discussed as follows.

2.3.1 Highway Capacity Manual (HCM) Method

In HCM 2000, according to Metkari, M. K., et. al., 2012, for two-lane highways, PCEs were calculated from speed distributions of cars and trucks for given volume and grade. For multilane highways, PCEs were based on the relative delay (HCM 2000).

Speed method is a way to estimate PCEs based on the relative rates of speed for each type of vehicle traveling in the main direction and for all vehicles combined traveling in the opposing direction. Shalinil, K., et. al, 2014, described the work of Van Aerde, et. al., 1983, as they found that PCE decreases for higher speed percentiles. The speed analysis using the linear regression model structure is:

Percentile Speed = Free speed +C_1[number of passenger cars] + C_2[number of trucks] +C_3[number of RVs] +C_4[number of Other Vehicles] +C_5[number of Opposing Vehicles] …….(2.1)

Where, C_1 to C_5= are speed reduction coefficients for each vehicle type

Hence, using the speed reduction coefficient, the PCE for a vehicle type n is calculated as;

$$PCE_n = \frac{C_n}{C_1} \quad \text{.. (2.2)}$$

Where, C_n − speed reduction coefficient for vehicle type n and

C_1 − Speed reduction coefficients for passenger car

In addition; Chandra and Sikdar 2000, have also proposed a different PCE evaluation techniques for mixed traffic conditions using vehicle area and speed, and Rahman and Nakamura, 2005, come up with new PCE values for non-motorized vehicles at midblock section along urban arterial based on the speed difference of mixed flow and basic flow of passenger cars (Shalini, K., et. al., 2014).

The second method considers delay to vehicles due to opposing traffic as described by Craus, J., et. al., 1980, in Shalini, K., et. al., 2014, and the same author assumed delay method for two-lane high volumes (faster vehicles are always impeded by slower vehicles, and thus queues form) are made. The equation they used is;

$$PCE_{ij} = \frac{D_{ij} - D_{base}}{D_{base}} \quad \text{... (2.3)}$$

Where PCE_{ij} −*PCE of vehicle type i under condition j*

D_{ij} − *delay to passenger cars due to vehicle type i under condition j*

D_{base} − *delay to standard passenger cars due to slower passenger cars*

HCM instead of computing PCE explicitly, generally it considers previously studied values. HCM uses PCE factors to adjust flow rate due to the effects of heavy vehicles in the traffic stream and does not take into account the differences in operational characteristics of buses and trucks.

According to Benekohal and Zhao 2006, from Shalini, K., et. al., 2014, Heavy Vehicle Factor (f_{HV}) is used to reduce the ideal saturation flow rate at intersections using the HCM The Heavy Vehicle Factor (f_{HV}) is computed from the following equation:

$$f_{HV} = \frac{1}{1+P_H(PCE-1)} \qquad (2.4)$$

Where PCE - is the Passenger Car Equivalent for heavy vehicles and:

P_H - is the percentage of heavy vehicles

2.3.2. Flow Rates and Density Method

Here are different models suggested by respective scholars for estimating PCE values using flow rates and density. Special traffic and geometric considerations of each methods are also described along with:

According to John and Glauz 1976, PCE is computed based on percentage of grade, mixed vehicle flow, and truck volume to capacity ratio (Shalini, K., et. al., 2014). Hence, they used this equation:

$$PCE = \frac{q_B - q_M(1-P_T)}{q_M X P_T} \qquad (2.5)$$

$where: q_B -$ Passenger Car only flow rate for a given $\frac{v}{c}$ ratio

$q_M -$ Mixed flow rate

$P_T -$ Truck proportion in the mixed traffic flow

In 2003, Demarchi and Setti, calculated an aggregate PCE formulated for density of various types of trucks and this model eliminate the possible error for mixed heavy vehicles in the traffic stream, including interaction between multiple trucks types. The proposed equation was:

$$PCE = \frac{1}{\sum_i^n P_i}\left(\frac{q_B}{q_M} - 1\right) + 1 \quad \text{.................................... (2.6)}$$

$Where\ q_B -$ is the base flow rate (passenger cars only)

$P_i -$ is the proportion of trucks of type *i* out of all trucks *n* in the mixed traffic flow

$q_M -$mixed flow rate

Shalini, K., et. al., 2014, has also disclosed the work of Huber, M. J., 1982, that suggested a model for estimating PCE values for vehicles multilane conditions under free flowing. PCE-values are related to the ratio between the volumes of two streams at some common level of impedance. He has given equation to calculate PCE value

$$PCE = \frac{1}{P_T}\left(\frac{q_B}{q_M} - 1\right) + 1 \quad \text{.................................... (2.7)}$$

$Where\ \ q_B -$ Equivalent Passenger Car only flow rate for a given $\frac{v}{c}$ ratio

$q_M -$ mixed flow rate

$P_T -$ truck proportion in the mixed traffic flow

2.3.3. Headways method

Ahmed, U., 2010, defined time headway approach as "actual measurements of the relative position maintained by drivers in the traffic stream under prevailing conditions to arrive at PCE values." He also said that headway is the time between successive vehicles in the traffic stream. The basic equation is

$$PCE = \frac{h_t}{h_c} \quad \text{.. (2.8)}$$

Where, $h_t -$ average headway (in seconds) maintained by trucks following PC;

$h_c -$ saturation flow headway of PC following PC

The most important issues that are addressed by this equation were:

- the effect of larger truck size and lower truck acceleration characteristics
- truck drivers are expected to keep longer headways than PC following PC, thus PCE values are expected to be greater than 1

Generally, Ahmed, U., 2010, described the two factors which affect PCE magnitude as: Heavy Vehicle (HV) length and HV operating capabilities. Trucks, take up more space than PC; therefore, headways for PC following trucks will be longer than those for PC following PC- which means the numerator of equation (2.8) will be larger than the denominator, increasing with truck length. In addition, inferior truck operating capabilities (lower acceleration rates and lower travel speeds) compared to PC, require truck drivers to maintain longer headways from leading vehicles than PC drivers maintain, contributing to a large numerator in equation (2.8).

Krammes and Crowley 1986, recommended the following equation as their works final formulation for use in highway capacity analysis; because it accounts for the effect of leading vehicle type on the driver's perception of equivalent densities.

$$PCE = \frac{[(1-p)(\bar{h}_{px}+\bar{h}_{xp}-\bar{h}_{pp})+p\bar{h}_{xx}]}{\bar{h}_{pp}} \qquad (2.9)$$

Where: $\bar{h}_{px}$ *−mean lagging time headway for mixed flow passenger car following vehicle x*

$\bar{h}_{xp}$ *−mean lagging time headway for mixed flow vehicle x following passenger car*

$\bar{h}_{pp}$ *− mean lagging time headway for mixed flow passenger car following PC*

$\bar{h}_{xx}$ *− mean lagging time headway for mixed flow vehicle x following vehicle x*

X – Vehicle x, *P – Passenger Car*, *and p – proportion of truck*

According to Krammes and Crowley 1986, this more sophisticated headway-based approach has three advantages:

1. It accounts for the effect of leading trucks on the inter-vehicular spacing's maintained by a vehicle of interest.

2. The percentage of trucks in the traffic stream, which has an important effect on PCE values, is included as a variable in the model.
3. The estimation procedure allows PCE values to be estimated for specific speeds and flow rates, enabling the effect of these variables to be considered explicitly.

Cuddon, A.P. and Ogden, K.W. 1992, in Mohammed, A. 2013, presented a sufficient and necessary condition to be fulfilled for applicability of headway ratio method for PCE determination. This condition is shown from the following equation (2.10), which implies that *'effect of a certain type of vehicle is independent of the type of vehicle preceding it and following it'*.

$$\bar{h}_{p-p} + \bar{h}_{x-x} = \bar{h}_{p-x} + \bar{h}_{x-p} \quad \text{(2.10)}$$

Where, $\bar{h}_{p-p}$ – average headway of a PC followed by a PC,

$\bar{h}_{x-x}$ – average headway of a car followed by a car,

$\bar{h}_{p-x}$ –average headway of X-vehicle followed by PC

$\bar{h}_{x-p}$ – average headway of PC followed by X-vehicle

Furthermore, Saha P., et. al. 2009, stated that for the given data set, where equation (2.10) does not hold, the following corrective factor need to be applied, which is shown in equation 2.11:

$$C = \frac{abcd(w-x-y+z)}{abc+abd+acd+bcd} \quad \text{(2.11)}$$

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; and

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

Hence, the adjusted mean headways for a car following a car will be eq. (2.12):

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

$$\bar{h}_{A(x-x)} = U - \frac{C}{Number\ of\ headway\ of\ X-vehicle\ following\ X-vehicle}$$

Where: $\bar{h}_{A(x-x)}$ −adjusted mean headway for X-vehicle following X-vehicle

U − Uncorrected mean headway, C − correction factor

$$PCE_{X-vehicle} = \frac{\bar{h}_{A(x-x)}}{\bar{h}_{A(p-p)}} \quad (2.12)$$

The literature indicated three factors that primarily influence the size of the PCE for a truck at a signalized intersection. Firstly, the PCE value will increase as the length of vehicle increases since the vehicle is physically occupying more roadway space which would otherwise be available to passenger cars. Secondly, the acceleration characteristics of a truck will also influence the size of the PCE. As the acceleration rate increases, the PCE value will decrease since the truck will delay the passenger cars less, and of course, the converse will result in a higher PCE value. The final factor that was found to affect the PCE is the behavior of motorists. The available information seems to indicate that drivers "shy away" from large trucks. This results in drivers following further back from the truck which increases the delay on the passenger car drivers which, in turn, results in a higher PCE value (Cesar, J. et. al., 1987).

From the different methods discussed above and many more, the time headway method is found to be the most commonly used and occasionally found to produce better estimate of PCE than saturation flow rate based on regression analysis method (Saha, P., et. al., 2009). In addition, utilizing such a dynamic characteristic of traffic stream (i.e. headway) which is able to explain driver behavior, roadway surroundings, traffic volume and speed characteristics through a single parameter, Krammes and Crowley, analyzed a mixed traffic stream and developed an equation considering headway differences between trucks and other vehicles.

3. MATERIALS AND METHODS

3.1. Background

In determining the capacity of a signalized intersection, it is assumed that all vehicles in the traffic stream are identical and depart at a constant saturation flow headway (HCM, 2010). However, this is not true as there are many types of vehicles in the traffic stream whose different performance capabilities cause their headways to be vastly different from one another. To correct for this discrepancy, the saturation flow rate is expressed in terms of straight-through passenger car equivalents. In other words, each vehicle type is converted into the equivalent number of passenger cars it displaces.

The objective of this study is investigation on PCE for all vehicles available at signalized intersections, taking a case study of four signalized intersections at Hawassa City, Ethiopia. To achieve this, time headway ratio method is used and the effect of different vehicle on traffic system is studied in terms of passenger cars. A video recording of all traffic activity at the selected signalized intersection is explored for the lagging time headways of each pair of vehicles. The time headway data is then sorted, analyzed and interpreted in the latter sections of the study.

3.2. Study Area Descriptions

Hawassa is a city in Ethiopia, on the shores of Lake Hawasa in the Great Rift Valley. It is located 285 km south of Addis Ababa via Bishoftu, 130 km east of Sodo, and 75 km north of Dilla. The town serves as the capital of the Southern Nations, Nationalities, and Peoples' Region, and is a special zone of this region. It lies on the Trans-African Highway 4 Cairo-Cape Town, and has a latitude and longitude range of 7.106^{0}S to 7.006^{0}N and 38.457^{0}W to 38.524^{0}E and an average elevation of 1708 meters above sea level. Since the city is political, economic, industrial, educational and recreational hub, it is mandatory to have a well-designed and efficient traffic management spatially at intersections. More than eight signalized intersections are available in Hawassa city. Among this, four are chosen since they satisfy the intersection selection criterion considered in section 3.2.

The first signalized intersection is very close to Hawassa main bus station near "Yeshi" hotel. It is located at latitude 7.048^0 N, longitudinal 38.489^0E and at an altitude of 1692.0 m. It is four-legged intersection in which two (North -West to South-East) of them are on the asphalt road that takes traffic from the bus station to the outskirts of Hawassa, and the other two (South to North) are cobble stone roads.

The second intersection is "Tirufat" intersection, which is located latitude 7.041^0 N, longitudinal 38.479^0E and at an altitude of 1713.0 m. It is found, 200m from the old Hawassa Stadium, on the way from Hawassa bus station to Hawassa Referral Hospital on the road "Woldeamanuel-Dubale" at a place called "Tirufat". It is also four legged, where all are asphalt paved roads taking traffic from "Atote to Piazza" along "Woldeamanuel-Dubale" road and from bus station to Referral Hospital.

The third intersection is at the heart of downtown Hawassa, just before Dashen bank. It comprises four legs of which three are with larger traffic, since all three connect major business and recreational locations. This intersection is located at Latitude 7.051^0 N, Longitudinal 38.474^0E and at an altitude of 1689.0 m.

The fourth sample intersection is located at "Arab sefer", on the way from down town Piazza to "Hiwet Birihan" Church and from main bus station to old market "Gebeya". It comprises four legs as described above. This intersection is located Latitude 7.055^0 N, Longitudinal 38.476^0E and at an altitude of 1693.0 m.

The selected four intersections are demonstrated on fig. 3.1 that shows their relative position on map of the city.

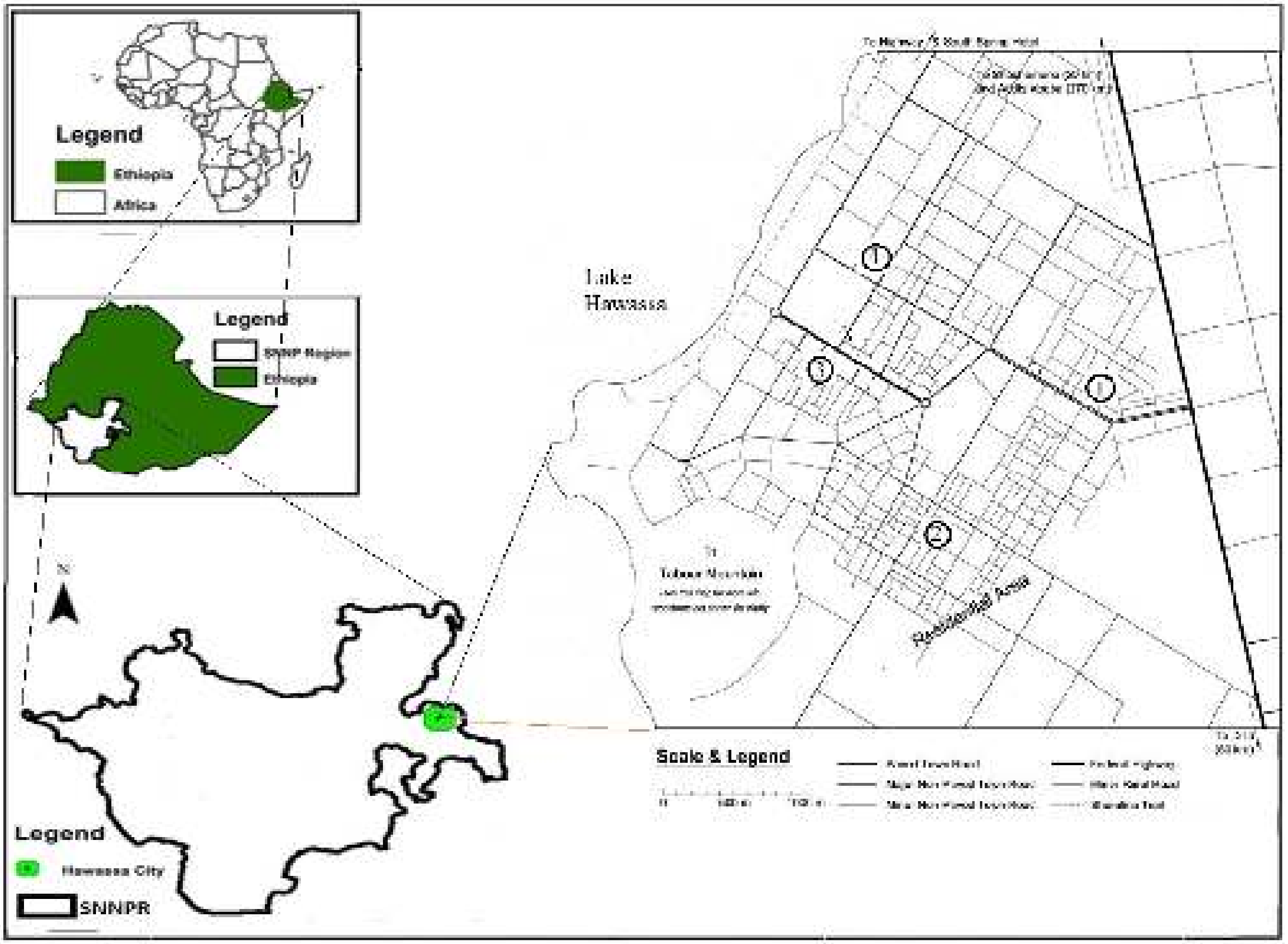


Fig. 3.1. Relative position of Selected Signalized intersections

3.3. Method of Data Collection

Data was collected from through lanes at four signalized intersections described above. The sites were selected based on consideration of several factors such as achievement of saturation queues during peak conditions, uninterrupted flow of the traffic during the green interval (main traffic approach), adequate spacing between intersections to avoid offset measurement of the same platoon of vehicles and to have good mix of different vehicle types. The selected intersections are:

1. Menehariya or “Yeshi” hotel intersection located near Hawassa bus station
2. “Tirufat” intersection located on Woldeamanuel-Dubale street

3. Piazza Dashen bank intersection located downtown piazza
4. “Arab sefer” intersection located near the main market area

Data was collected by using a digital video recorder which can record the actual time headway between successive straight-ahead vehicles. Since it is difficult for observer to record the actual time headway of different vehicles manually passing through the stop line, video recording was chosen. Thus, by using a video recorder, events in the observed lane such as beginning of green interval, the crossing of the rear of each passing vehicle over the stop line as well as the vehicle type, the end of saturation flow and the beginning of amber and red interval times were noted. This method was judged to be fast and accurate because, the observer had only one task to perform in the field.

Since there were no preexisting traffic flow data; determination of peak-hour flows on the selected intersection’s what so ever was impossible, hence Rush-hour periods on dry weather, week days (Tuesday through Friday) are considered. It is important to make sure that the traffic flow at signalized intersections being studied are saturated flow. A fully saturated cycle is one in which the queue has not fully discharged by the beginning of the red interval (Yahya, Dr. R. S., 2014).

The geometric data of specific lanes at signalized intersections such as lane width, and approach grade were measured and recorded on table 4.2.

3.4. Method of Data Analysis

Form the different methods of evaluating PCEs mentioned in literature chapter, the time headway ratio method which was for the first time proposed by Greenshield, et. al., 1947, and further developed by many more scholars were used (Umama, A. 2010).

Time headway based method is preferred over others as it is utilizing such a dynamic characteristic of traffic stream (i.e. headway) which is able to explain driver behavior, roadway surroundings, traffic volume, traffic density and speed characteristics through a single parameter (Shalini, K., et. al, 2014). In addition, according to Shalini, K., et. al, 2014, this is the most commonly used method for measuring PCE at signalized intersections. Many researchers have used headway as the basis of PCE estimation. Measurements will be conducted on a roadway that are almost horizontal/ flat terrain, where PCE values will be evaluated by using the basic traffic parameter (time), and under a signalized intersection.

3.5. Headway Measurement

The time headway in equation (2.12) was lagging time headway which was measured for each combination of pairs of vehicle types that were found in the traffic stream. Since inter-vehicular spacing's are affected by the types of the vehicles that delimit the spacing, and headways method PCEs are based on the driver's perception of equivalent proximity and freedom to maneuver and because the types of both the vehicle of interest and the leading vehicle may influence this equivalence, the headways in equation (2.12) were expressed in terms of the mean lagging time headways.

During preliminary survey, it was observed that the queues at the selected intersections were denser and had longer lengths at morning rush-hour peak from 7:45 am to 9:45 am and at noon 11:30am to 1:30pm of week days. A digital video camera was placed at a convenient point to capture every second of traffic movement at the intersection approaches. The camera was placed at a point such that the recording will be done without interfering with the traffic flow. The video recording was done for two hours on the study approach at each of the intersections. All traffic events were recorded during the observation. The camera was arranged and ready about 15 minutes before the start of each study period. The recording was done from Tuesdays to Friday for typical maximum week day traffic under clear weather conditions. The video recording was then analyzed manually on a computer by trained observer. Classified counts were obtained for the vehicles discharging from the stop line throughout the green interval. All vehicles that stood behind this stop line were considered in the analysis; they were counted as their rear end crosses the stop line.

The extracted data is then tabulated in a way one can easily find any descriptive information; and these include, headways of each vehicle group in every cycle, headways of similar vehicle group, headways of similar vehicle groups preceded by a different vehicle group and it is given in Annex B.

The next step was inserting the extracted headway data values for every group of vehicles in the following relationship formula to determine Passenger Car Equivalents.

$$\boldsymbol{PCE_{X-vehicle}} = \frac{\bar{\boldsymbol{h}}_{\boldsymbol{A(x-x)}}}{\bar{\boldsymbol{h}}_{\boldsymbol{A(p-p)}}} \text{ (from equation 2.12)}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

$\bar{h}_{A(x-x)}$ −adjusted mean headway for X-vehicle following X-vehicle

$$\bar{h}_{A(x-x)} = U - \frac{C}{Number\ of\ headway\ of\ X-vehicle\ following\ X-vehicle}$$

$U -$ Uncorrected mean headway,

$C -$ correction factor (equation 2.11)

In addition, equation 2.10, was also used to make sure that the *'effect of a certain type of vehicle is independent of the type of vehicle preceding it and following it'*.

$$\bar{h}_{p-p} + \bar{h}_{x-x} = \bar{h}_{p-x} + \bar{h}_{x-p}$$

3.6. Data Analysis

This sections discuses on techniques and methodologies for the data analysis. These arrangements included computation of regression equation from the time headway data of each observation and these data were used to predict the PCE values for different vehicle groups.

Each data set for the respective cycle, were evaluated for the following possible erroneous misrepresentation;

- If there were left or right turning vehicle hindering the through vehicle not to travel at normal speed, and those cycle that possess such vehicle are rejected
- If a recording includes vehicles who were not in a queue and the recordings for those vehicles were rejected

After checking each cycle for the above errors, the total observed vehicles were summarized in the table 3.1.

Table 3.1. The number of cycle and total vehicles observed

Vehicle Type	Total number of Observed Cycle that include the Vehicle	Total Number of Vehicles Observed
Motor Cycle (I)	174	241
Auto Rick-show/ Bajaj (II)	163	540
Passenger Car (III)	120	193
Pick-up/SUV (IV)	65	295
Minibus (V)	118	318
Small Bus (VI)	5	5
Large Bus (VII)	15	15
Small Truck (VIII)	20	23
M/Large Truck (IX)	18	19
Truck Trailer (X)	2	2
Total	184	1,651

3.7. Descriptive and Inferential Statistical investigations

In statistics, an outlier is an observation point that is distant from other observations, sample mean. An outlier can cause serious problems in statistical analyses. Outliers can have many anomalous causes. Therefore, in this part of the analysis, outliers are separated from the observed data using box and whisker plot (Fig.3.2).

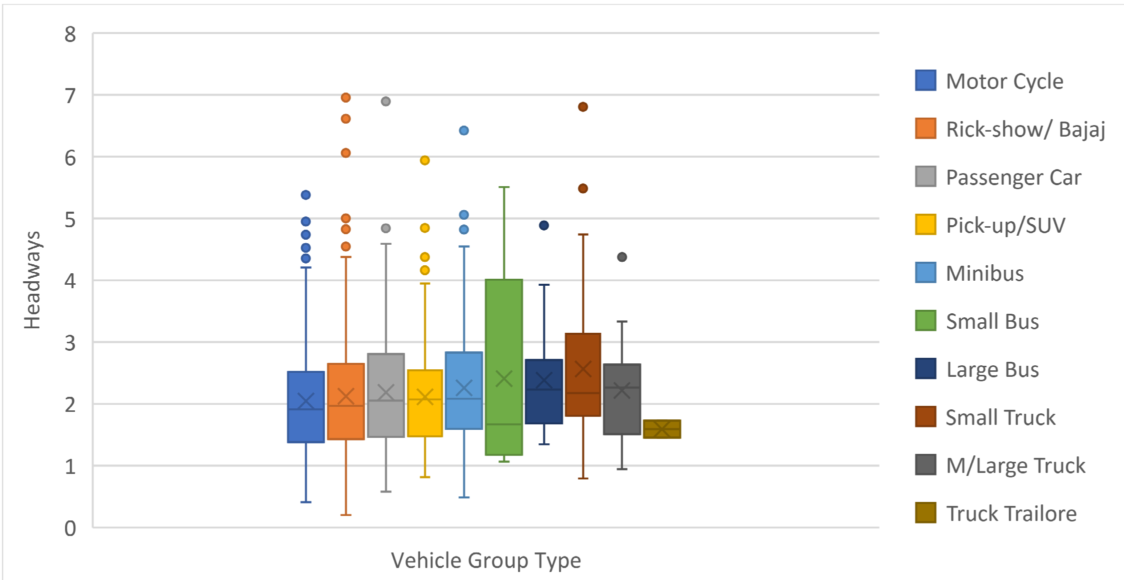


Fig. 3.2. Box and Whisker plot of Headways of different vehicle groups

Table 3.2. Differential statistics of all observation

		I	II	III	IV	V	VI	VII	VIII	IX	X
N		185	458	183	271	277	4	15	22	20	2
Mean		1.63443	1.83380	2.08472	2.34966	2.40429	3.26550	4.42440	4.48073	4.43190	3.18100
Std. Error of Mean		0.03669	0.028019	0.05669	0.04422	0.046501	0.639924	0.35645	0.391114	0.371168	0.27700
Median		1.62200	1.79300	2.04100	2.35560	2.38200	2.94600	4.18200	4.22500	4.52400	3.18100
Std. Deviation		0.49906	0.599635	0.76694	0.72799	0.773926	1.279848	1.38053	1.834489	1.659915	0.39174
Variance		0.249	0.360	0.588	0.530	0.599	1.638	1.906	3.365	2.755	0.153
Range		2.133	2.811	3.392	2.996	3.386	2.902	5.162	7.894	6.874	0.554
Minimum		0.406	0.198	0.577	0.972	0.582	2.134	2.690	1.580	1.878	2.904
Maximum		2.539	3.009	3.969	3.968	3.968	5.036	7.852	9.474	8.752	3.458
	25	1.25900	1.36600	1.43000	1.74120	1.76760	2.24100	3.33000	3.44350	2.90400	2.90400
Percentiles	50	1.62200	1.79300	2.04100	2.35560	2.38200	2.94600	4.18200	4.22500	4.52400	3.18100
	75	2.04900	2.32700	2.75300	2.86800	3.00960	4.60950	5.29200	5.52650	5.27350	

From table 3.1, the total vehicles observed was found to be 1,651. But there are only two truck trailers, nineteen medium and large truck, twenty-three small truck, fifteen large bus and five Small Bus which are very small in number relative to other groups. In addition, table 4.1 demonstrates the dimensional and power to curb weight ratio difference between the five vehicle groups (VI to X) listed and the other groups establishes similar maneuverability which leads to formation a single group called Heavy Vehicles. Similar, analogy is well-thought-out to form pick-up trucks and minibus in a group called light duty vehicles.

Table 3.3. Regrouping of the initial 10 groups to 5

New Group No.	Typical vehicle group members	Vehicle group Name
I	Motorcycles of different made ex. Bajaj, TVS, Liffan, Yamaha, Suzuki, etc.	Motorcycle (m)
II	Bajaj, TVS, Piaggio Auto Rickshaws, etc	Bajaj (b)
III	Toyota executive, Corolla, Vitz, Yaris, and other made but similar (in Dimension and Hp/CW) vehicles etc.	Passenger Car (p)
IV	Pick-up trucks of all kind and made, SUV, Minibus with capacity up to 16 people etc.	Light Duty Vehicles (LDV)
V	Small and Large bus; small, medium and heavy trucks etc.	Heavy Vehicle (HV)

To make sure that the regrouping does not have any statistical significant problem; hence, IBM SPSS 20 statistical software was used, each new group was checked for any statistically significant difference.

Light Duty Vehicle

Light Duty Vehicle is composed of group IV and group V, from result and discussion section, the calculated mean headway of LDV is 2.377.

Table 3.4. One-Sample Statistics for vehicle group IV

Group	N	Mean	Std. Deviation	Std. Error Mean
IV	271	2.34966	0.727987	0.044222

Table 3.5. One-Sample Test for vehicle group IV

Group	Test Value = 2.377					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
IV	-0.618	270	0.537	-0.027338	-0.11440	0.05973

For degree of freedom of 270, level of significance $\alpha = 0.05$ one sample two tailed t-test result is **-0.618** (table 3.5) and the corresponding critical value was found to be **1.969**. Which means

- The Critical Value (CV) is greater than the calculated t- value
- The significance value (Sig. (2-tailed) = 0.537) is greater than 0.05 and
- The 95% confidence interval shows a lower and upper bound values of different sign which means it include the hypothesized null value zero difference

Therefore, we can conclude that there is no statistically significant difference between group IV and group LDV.

Table 3.6. One-Sample Statistics for vehicle group V

Group	N	Mean	Std. Deviation	Std. Error Mean
V	277	2.40429	0.773926	0.046501

Table 3.7. One-Sample Test for vehicle group V

Group	Test Value = 2.377					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
V	0.587	276	0.558	0.027293	-0.06425	0.11883

Similarly, for degree of freedom of 276, level of significance $\alpha = 0.05$ one sample two tailed t-test result is **+0.587** (table 3.7) and the corresponding critical value was found to be **1.969**. Which means

- The Critical Value (CV) is greater than the calculated t- value
- The significance value (Sig. (2-tailed) =0.558) is greater than 0.05 and
- The 95% confidence interval shows a lower and upper bound values of different sign which means it include the hypothesized null value zero difference

Therefore, we can conclude that there is no statistically significant difference between the groups.

Hence, the regrouping of Vehicle group IV and V in to LDV statistically does not have any problem.

<u>Heavy Vehicle group</u>

The Heavy Vehicles group is composed of group VI, VII, VIII, IX and group X, from Chapter 5 the calculated mean headway of HV is 4.333.

Table 3.8. One-Sample Statistics for Vehicle group VI, VII, VIII, IX and group X

Group	N	Mean	Std. Deviation	Std. Error Mean
VI	4	3.26550	1.279848	0.639924
VII	15	4.42440	1.380525	0.356450
VIII	22	4.48073	1.834489	0.391114
IX	20	4.43190	1.659915	0.371168
X	2	3.18100	0.391737	0.277000

Table 3.9. One-Sample Test for vehicle group VI, VII, VIII, IX and X

Group	Test Value = 4.333							
	t (1)	df (2)	Sig. (2-tailed) (3)	Mean Difference (4)	95% Confidence Interval of the Difference		α **(7)**	Critical Value CV (8)
					Lower (5)	Upper (6)		
VI	-1.668	3	0.194	-1.067500	-3.10402	0.96902	0.05	3.182
VII	0.256	14	0.801	.091400	-0.67311	0.85591	0.05	2.145
VIII	0.378	21	0.709	0.147727	-0.66564	0.96109	0.05	2.080
IX	0.266	19	0.793	0.098900	-0.67796	0.87576	0.05	2.093
X	-4.159	1	0.150	-1.152000	-4.67162	2.36762	0.05	12.706

For degree of freedom column (2), level of significance column (3) p-value is $\alpha = 0.05$, and one sample two tailed t-test result listed on column (1) in which the corresponding critical value are also recorded in column (8) of the same table indicating that in all of the vehicle groups:

- The Critical Value (CV) is greater than the calculated t- value
- The significance value (Sig. (2-tailed)) is greater than 0.05 and
- The 95% confidence interval shows a lower and upper bound values of different sign which means it include the hypothesized null value zero difference

Therefore, we can conclude that there is no statistically significant difference between group VI, VII, VIII, IX and X group HV.

Hence, the regrouping of Vehicle group VI, VII, VIII, IX and X in to HV statistically does not have any problem, possible.

Once establishing the basis for the final analysis results, regression model is prepared which can explain the collected data and then, the analysis results are determined in chapter four.

3.8. Model Preparation

For each observation; the total travel time, which is the time for a vehicle's rear to cross over the roadway stop line from its position in queue, regression equation was prepared (Cesar J. et. al. (1987)). The model regression equation has the following general form;

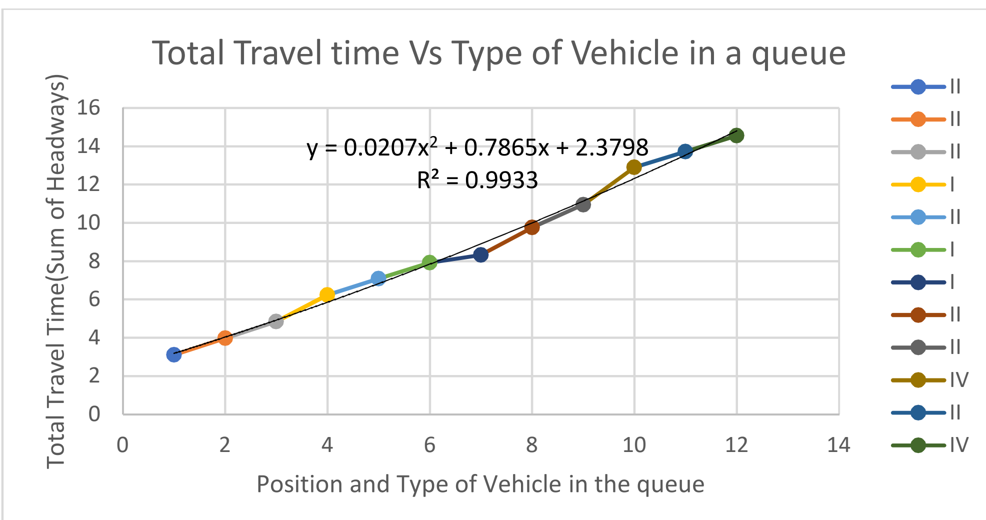
$$\boldsymbol{TTT = A_1V^2 + A_2V + A_3} \quad \text{......................................} \quad (3.1)$$

Where: TTT - total travel time of a vehicle in a queue

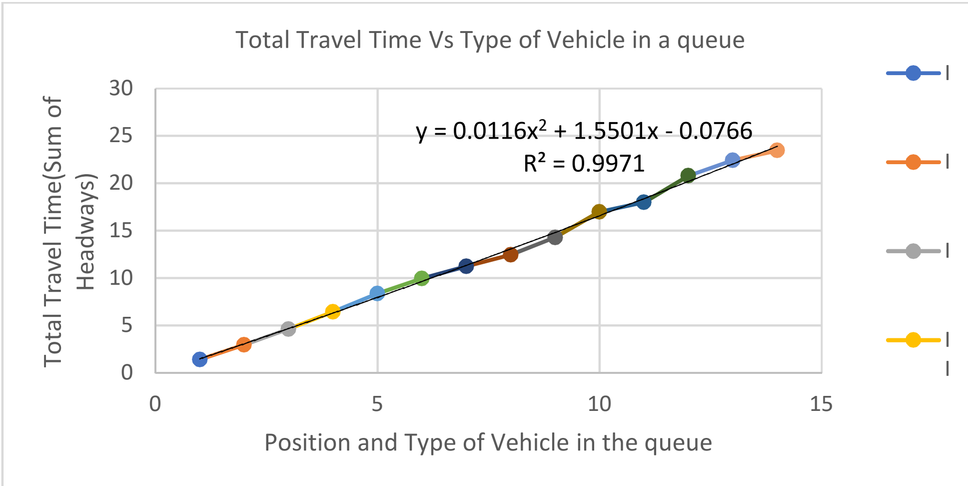
V – location of vehicle in a queue

$A_1,\ A_2\ and\ A_3$ – are regression coefficients.

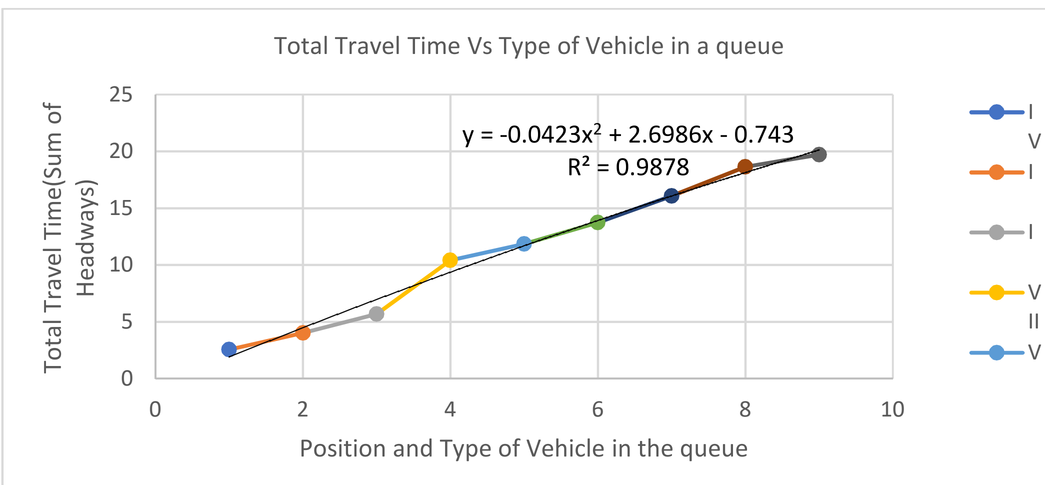
Figure 3.3. demonstrates the extent of fit of the model for a typical observation, it is found that all model fits the observed data to a significant level because their R^2 test is very close to 1 ($R^2 \approx 0.99$).



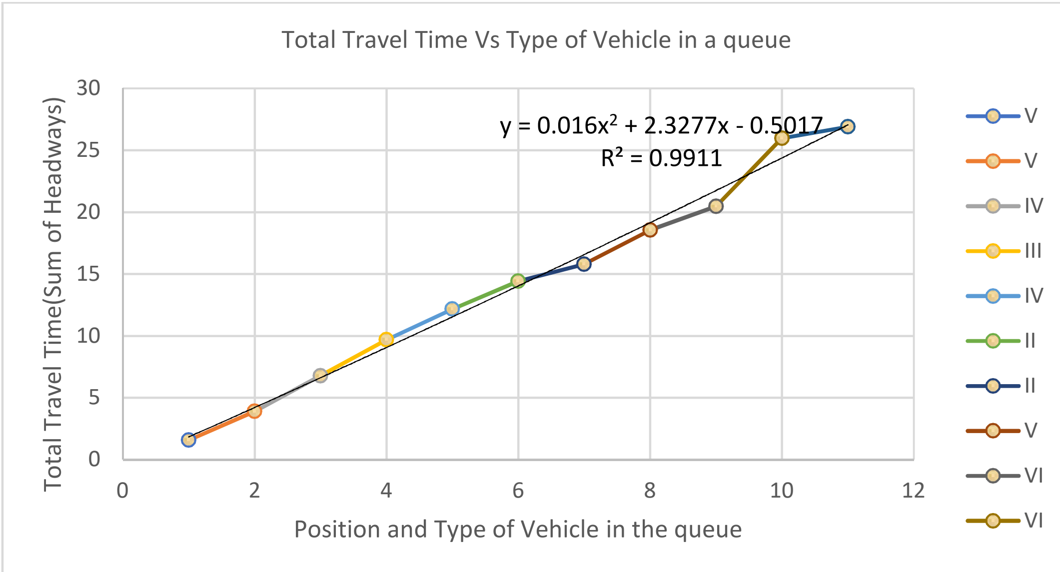
(a) Yeshi hotel intersection



(b) Tirufat Supermarket intersection



(c) Dashen bank intersection



(d) Arab sefer intersection

Fig. 3.3 A typical total travel time Vs Vehicle position regression model

4. RESULTS AND DISCUSSIONS

4.1 Over View

This section of the study presents the final steps towards evaluating the Passenger Car Equivalents of different vehicle groups, based on the collected data. The Ethiopian Road Authority (ERA), Geometric Design Manual (2013), classifies vehicles in more than thirteen groups (Annex A). This classification is based on a measure of the damaging effect of vehicle axles i.e. Equivalent Standard Axels (ESA). Class one and class two are classified as passenger car and from class three up to class thirteen are classified as heavy vehicles as illustrated in annex A. In addition to the above grouping, this study has included motorcycles and rick-shaw (Bajaj) and regrouped passenger cars, LDV (light duty vehicles), and HV (heavy vehicles).

The regrouping is considered because, first these vehicles (motorcycles, rick-shaw (Bajaj)) are abundantly available in the city and are growing fast in number contributing significant portion of the total traffic; second, the ERA classification is predominantly based on a measure of the damaging effect of vehicle axles that is Equivalent Standard axels (ESA) in which case the damaging effect, according to this parameter, of the newly included group of vehicles is insignificant, but recurrence of lighter vehicles has a significant damaging effect on pavements. The third reason is lack of data to further classify heavy vehicles, accordingly and light duty vehicles; though initially grouped as passenger car, are observed to behave differently. Fourth reason, according to table 3.1, proximity of power to curb weight ratio and vehicular dimensions grouped under light duty vehicles and heavy vehicle have complimented the regrouping. Statistical mean of headways of these group members do not have statistically significant difference.

Finally, from practical point of view while designing signalized intersection practitioners don’t often tend to consider each vehicle count independently rather in groups.

4.2 Roadway and traffic condition

The first objective of this research was to evaluate or to set the actual roadway and traffic conditions currently available in the considered intersections.

Roadway condition includes geometric elements of the intersection; number of lane, lane width, class of the road, type of signal protection, horizontal and vertical alignment conditions are well described in Table 4.2.

According to ERA geometric design manual 2013, the administrative classifications of these roads were addressed accordingly, the type of control here is signal controlled. From the horizontal and vertical design elements; grade, lane size and number were measured.

Traffic condition of the intersections include traffic type and acceleration performance properties were addressed to demonstrate the kind of traffic, acceleration behavior and its impact on headways between vehicles that exist at the intersections of choice. Table 4.1 discloses the recorded data that includes dimension and power to curb weight ratio of sample vehicles.

Instinctively, as a vehicle's length increases, it requires more time to cross an intersection, and confines subsequent vehicles not to perform up to capacity. Research by Kockelman (1998), indicates that length contributes negatively to highway flows. Table 4.1. demonstrates that passenger cars length, width and height in comparison with other vehicles. For example, passenger cars are smaller than small bus units by 61% in length, 13% in width and 77% in height; and occupying larger space of the highway that adds one more reason to the headway.

Another important factor is vehicle performance, acceleration characteristics are likely to be highly correlated with horsepower-to-curb weight ratios (Kara M. Kockelman and Raheel A. Shabih, 2000). For instance, these ratios for passenger car to small bus and small truck are 53% and 34% respectively, which means passenger cars outperform small trucks and busses as far as horse power to curb weight is taken in to account.

It is clear that vehicles have operators; drivers, whose behaviors may vary depending on weather they are following passenger car or another car. It is hypothesized that the presence of a larger vehicle in front of a passenger car causes the passenger-car driver to be more cautious because of the large size of the preceding vehicle and the resulting diminished sight distances. This may cause the headways of passenger cars to be larger;

and, if so, this increase must be considered in the overall capacity reduction due to vehicle size which is ultimately brought in to being with the concept of headway.

Table 4.1. Vehicle dimensions and brake horse power to curb weight ratio

Vehicles	**Symbol**	**Length**	**Width**	**Height**	**Power (BHP)**	**Curb Weight (Kg)**	**(Power/Curb Weight)**
Motor cycle	I	2.03	0.78	1.44	12	132	0.091
Rick-show/ Bajaj	II	2.80	1.12	1.89	8.17	295	0.028
Passenger Car	III	4.35	1.798	1.465	104	1395	0.075
Pick-up	IV	5.34	1.855	1.82	177	1960	0.090
Minibus	V	4.70	1.695	1.98	100.5	1850	0.054
Small Bus	VI	6.99	2.035	2.6	135	3405	0.040
Large Bus	VII	10.12	2.34	2.9	140	10200	0.014
Small Truck	VIII	6.02	1.77	2.16	130	5200	0.025
M/Large Truck	IX	8.50	2.55	3.5	371	12800	0.029
Truck Trailer	X	11.00	2.5	3.7	400	25000	0.016

Sources: http://lovson.com/lovson/motorcycles-and-scooter.html
http://www.automobile-catalog.com
https://en.wikipedia.org/wiki/Alfa_Romeo_Giulietta_(940)
https://www.automobiledimension.com/car-comparison.php

Table 4.2. Roadway and Traffic condition of the intersections with date and time of data collected

Data Collection Station	Coordinates		Grade of the Intersection approach	Approach speed (Spot Speed)	Lane		Data collection date	Data collection time	
	Easting	Northing			Number (both direction)	Width (m)		Start	End
Yeshi Hotel Meneharia	38.489^0	7.048^0	1.5%	32KM/hr	3	3.6	09/01/18	7:45am	9:45am
							09/01/18	11:30am	1:30pm
Tirufat Supermarket	38.479^0	7.041^0	1.5%	35KM/hr	2	3.5	10/01/18	7:45am	9:45am
							10/01/18	11:30am	1:30pm
Dashen Bank area	38.474^0	7.051^0	3.5%	28KM/hr	3	3.2	11/01/18	7:45am	9:45am
							11/01/18	11:30am	1:30pm
Arab Sefer	38.476^0	7.055^0	3.8%	38Km/hr	2	3.5	12/01/18	7:45am	9:45am
							12/01/18	11:30am	1:30pm

4.3. Passenger Car Equivalent

Before proceeding to evaluate PCE using headways ratio, according to Cuddon and Ogden, it is important to confirm that the sufficient and necessary condition to be fulfilled for applicability of headway ratio method for PCE determination. This requirement is confirmed using equation 2.10, which implies that *'effect of a certain type of vehicle is independent of the type of vehicle preceding it and following it'*. If the data fails to satisfy equation 2.10, Saha et al (2009), provided a correction factor in equation 2.11.

Hence, the passenger car equivalent of each group of vehicles will be computed using equation 2.12.

The statistics is summarized for each group of vehicles in the following section.

4.3.1. For Motorcycle (m)

To make sure that PCE of motorcycle is free from the effect of motorcycles preceding and following passenger car, we need to compute the following equation, and if it fails we shall find the correction factor "C".

$$\bar{h}_{p-p} + \bar{h}_{M-M} = \bar{h}_{p-M} + \bar{h}_{M-p}$$

Where: $\bar{h}_{p-p}$ average headway of a PC followed by a PC;

$\bar{h}_{m-m}$ average headway of a motorcycle followed by a motorcycle,

$\bar{h}_{p-m}$ average headway of motorcycle vehicle followed by PC and

$\bar{h}_{m-p}$ average headway of PC followed by motorcycle.

Hence, a frequency table and related descriptive statistics data analysis result from IBM SPSS Statistics Version 20 are displayed hereunder.

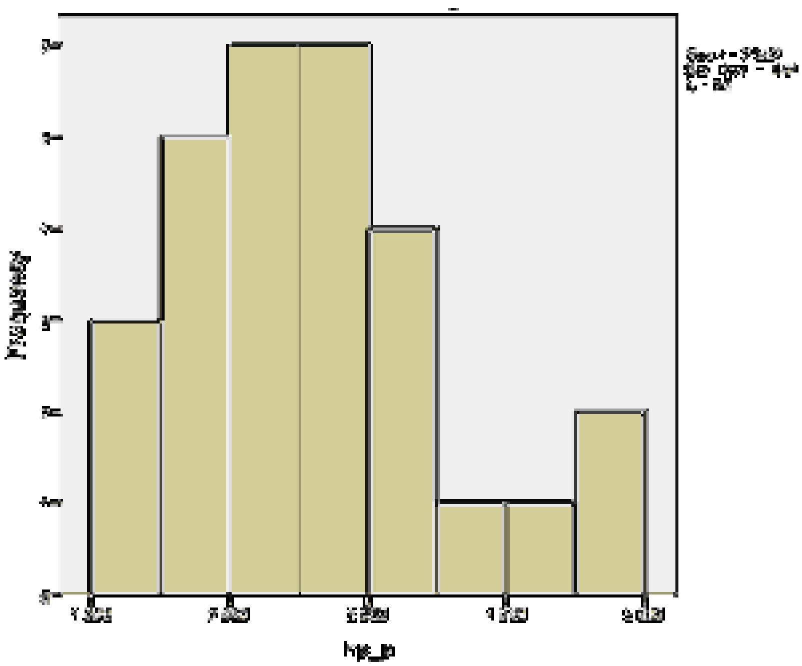


Fig. 4.1. Headway frequency graph of PC following PC

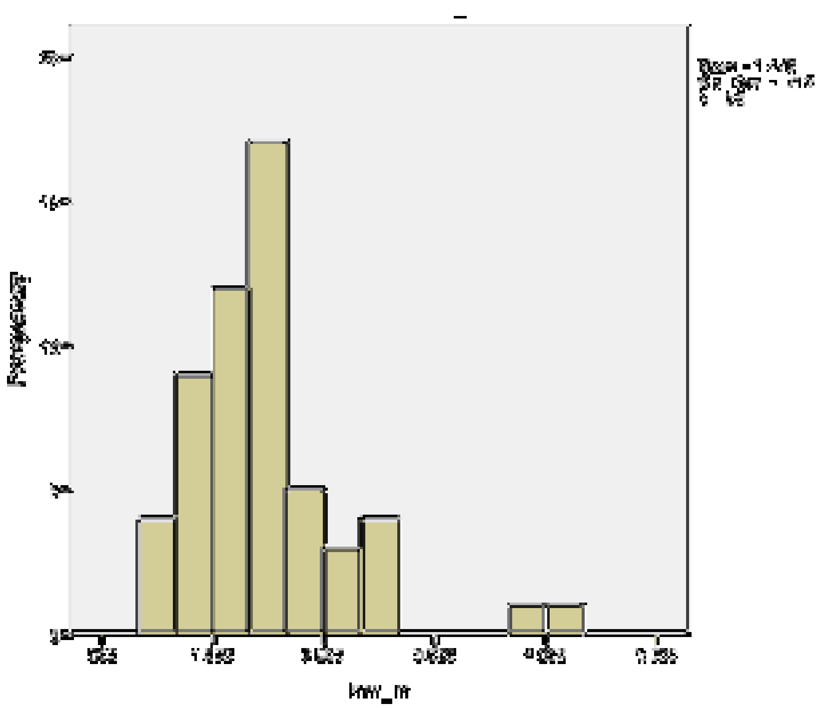


Fig. 4.2. Headway frequency graph of Motorcycle following Motorcycle

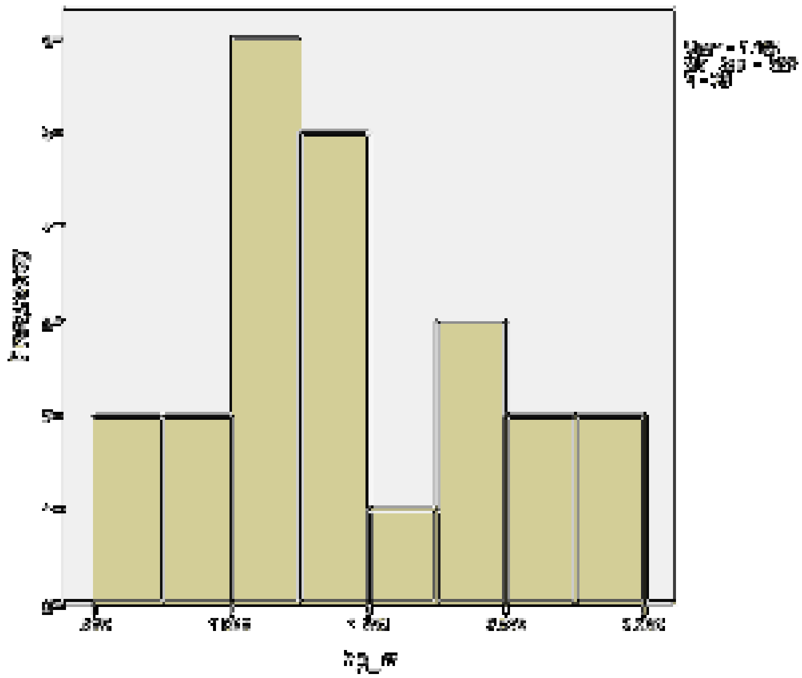


Fig. 4.3. Headway frequency graph of PC following Motorcycle

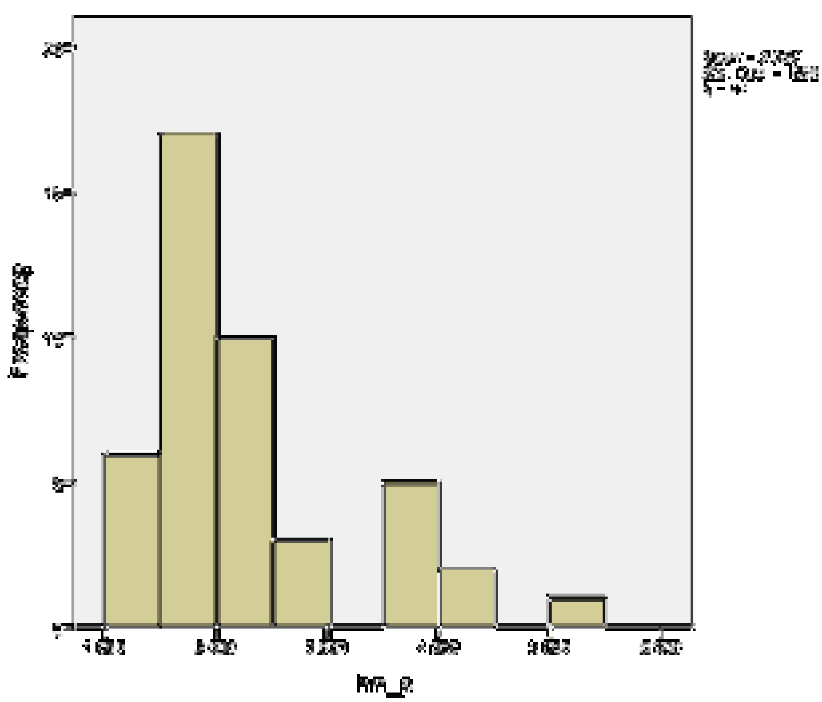


Fig. 4.4. Headway frequency graph of Motorcycle following PC.

Table 4.3. Descriptive Statistical study of Motorcycle-Passenger Car Study

Headway	N	Range	Minimum	Maximum	Mean		Variance	Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
hp_p	28	3.792	1.051	4.843	2.562	0.187923	0.989	0.994396
hm_m	56	3.798	0.406	4.204	1.408	0.095193	0.507	0.712358
hp_m	23	1.855	0.577	2.432	1.402	0.110927	0.283	0.531989
hm_p	44	4.246	1.131	5.377	2.267	0.145642	0.933	0.966079

Therefore, from $\bar{h}_{p-p} + \bar{h}_{M-M} = \bar{h}_{p-M} + \bar{h}_{M-p}$

$\bar{h}_{p-p} = 2.562$, $\bar{h}_{M-M} = 1.408$, $\bar{h}_{p-M} = 1.402$, $\bar{h}_{M-p} = 2.277$

And substituting the values in the equation

2.562+ 1.408 = 1.402 +2.277

$3.970 \neq 3.679$, hence the correction coefficient "C" must be calculated so that we can procced with the headways method.

From equation (2.11), $C = \frac{abcd(w-x-y+z)}{abc+abd+acd+bcd}$

Where in this case

a = Number of headways for PC following PC; **which is 28**

b = Number of headways for PC following type motorcycle; **which is 23**

c = Number of headways for type motorcycle following PC; **which is 44**

d = Number of headways for motorcycle following motorcycle; **which is 56**

w = Mean headways for PC following PC; which is 2.562

x = Mean headways for PC following motorcycle; which is 1.402

y = Mean headways for motorcycle following PC; which is 2.277

z = Mean headways for motorcycle following motorcycle; which is 1.408

$$C = \frac{28 * 23 * 44 * 56(2.562 - 1.402 - 2.277 + 1.408)}{28 * 23 * 44 + 28 * 23 * 56 + 28 * 29 * 56 + 23 * 29 * 56}$$

$$C = 3.748$$

Hence, the adjusted mean headways for a PC following a PC will be eq. (2.12):

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

U − Uncorrected mean headway (2.764),

C − correction factor (3.748)

$$\bar{h}_{A(p-p)} = 2.562 - \frac{3.748}{28}$$

$$\bar{h}_{A(p-p)} = 2.764 - \frac{3.748}{28}$$

$$\boldsymbol{\bar{h}_{A(p-p)} = 2.428}$$

And the adjusted mean headways for a motorcycle following a motorcycle will also be eq. (2.12):

$$\bar{h}_{A(m-m)} = U - \frac{C}{Number\ of\ headway\ of\ motorcycle\ following\ motorcycle}$$

Where: $\bar{h}_{A(m-m)}$ −adjusted mean headway for motorcycle following motorcycle

U − Uncorrected mean headway($U = 1.408$),

C − correction factor ($C = 3.748$)

$Number\ of\ headway\ of\ motorcycle\ following\ motorcycle\ is$ 56

$$\bar{h}_{A(m-m)} = 1.408 - \frac{3.748}{56}$$

$$\boldsymbol{\bar{h}_{A(m-m)} = 1.341}$$

Therefor, $PCE_{Motorcycle} = \frac{\bar{h}_{A(m-m)}}{\bar{h}_{A(p-p)}}$

$$PCE_{Motorcycle} = \frac{1.341}{2.428}$$

$$\boldsymbol{PCE_{Motorcycle} = 0.552}$$

Hence, the PCE of motorcycle is **0.552**.

4.3.2. For Rickshaw/Bajaj (b)

To make sure that PCE of Bajaj is free from the effect of Bajaj preceding and following passenger car, we need to compute the following equation, and if it fails we shall find the correction factor "C".

$$\bar{h}_{p-p} + \bar{h}_{b-b} = \bar{h}_{p-b} + \bar{h}_{b-p}$$

Where: $\bar{h}_{p-p}$ average headway of a PC followed by a PC;

$\bar{h}_{b-b}$ average headway of a Bajaj followed by a Bajaj,

$\bar{h}_{p-b}$ average headway of Bajaj followed by PC and

$\bar{h}_{b-p}$ average headway of PC followed by Bajaj.

Hence, a frequency table and related descriptive statistics data analysis result from IBM SPSS Statistics Version 20 are displayed hereunder.

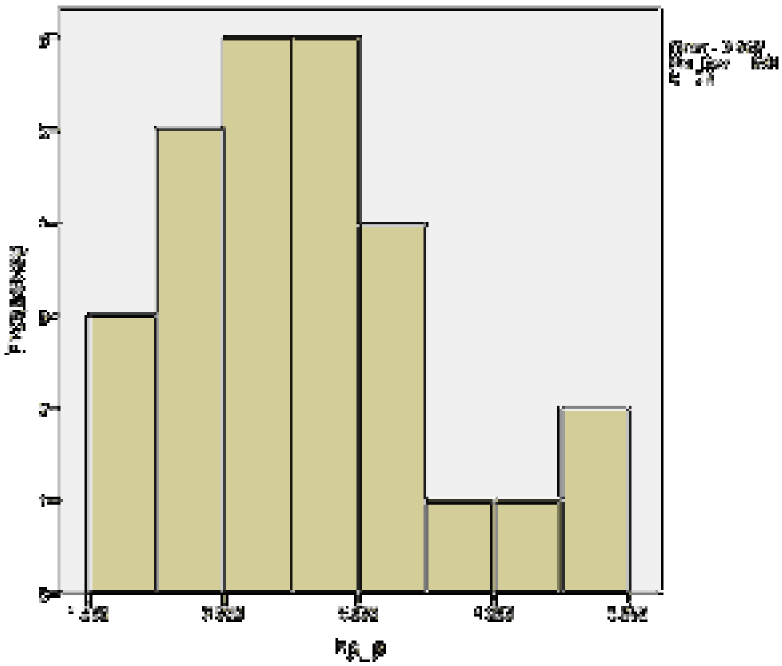


Fig.4.5. Headway frequency graph of PC following PC.

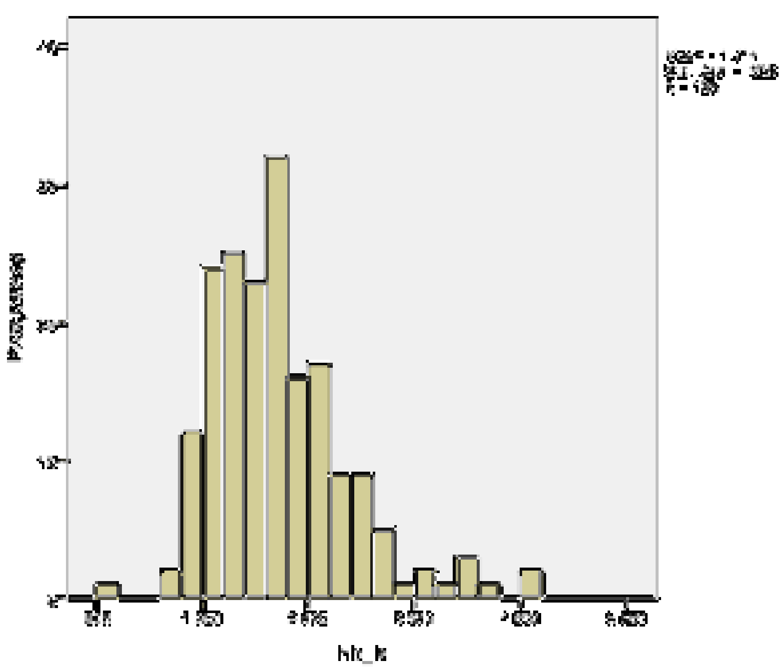


Fig.4.6. Headway frequency graph of Bajaj following Bajaj.

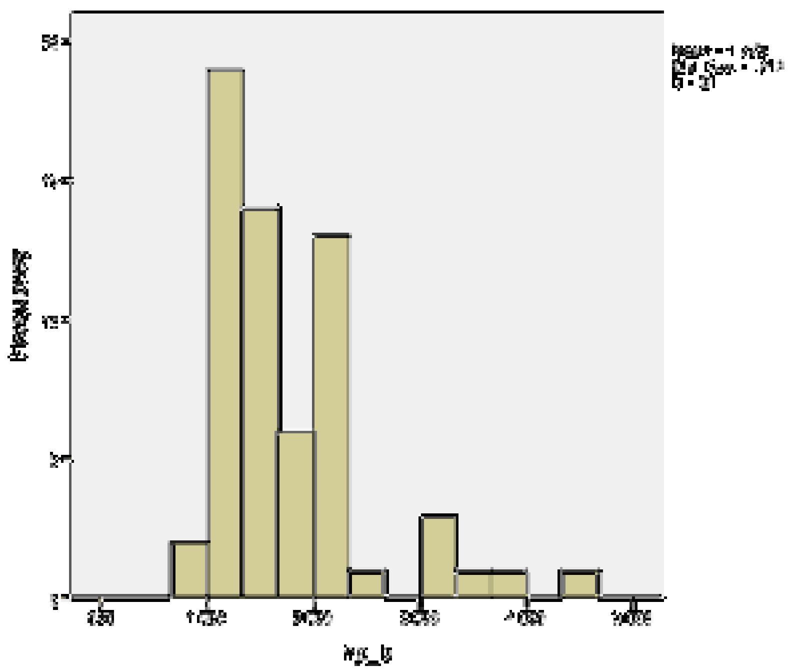


Fig. 4.7. Headway frequency graph of PC following Bajaj.

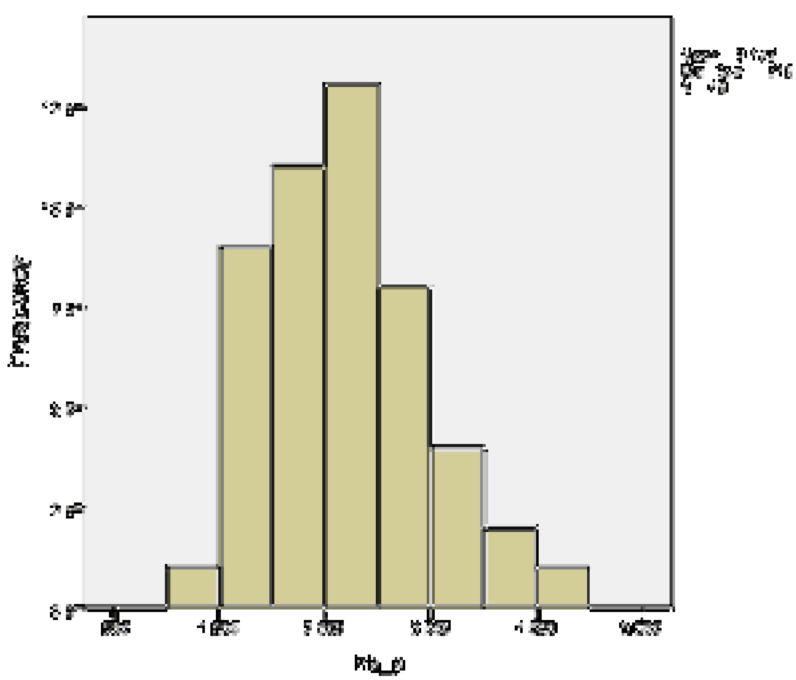


Fig. 4.8. Headway frequency graph of Bajaj following PC.

Table 4.4. Descriptive Statistical study of Autorickshaw/Bajaj-Passenger Car Study

	N	Range	Minimum	Maximum	Mean		Variance	Std. Deviation
Headway	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
hp_p	28	3.792	1.051	4.843	2.562	0.187923	0.989	0.994396
hb_b	185	3.857	.198	4.055	1.714	0.046946	0.408	0.638538
hp_b	61	3.777	.811	4.588	1.773	0.095011	0.551	0.742058
hb_p	49	3.308	.853	4.161	2.177	0.102308	0.513	0.716158

There, from $\bar{h}_{p-p} + \bar{h}_{B-B} = \bar{h}_{p-B} + \bar{h}_{B-p}$

$\bar{h}_{p-p} = 2.562$, $\bar{h}_{B-B} = 1.714$, $\bar{h}_{p-B} = 1.773$, $\bar{h}_{B-p} = 2.177$

And substituting the values in the equation

2.562 + 1.714 = 1.773 +2.177

4.276 ≠ 3.95, hence the correction coefficient "C" must be calculated so that we can procced with the headways method.

From equation (2.11), $C = \frac{abcd(w-x-y+z)}{abc+abd+acd+bcd}$

Where in this case

a = Number of headways for PC following PC; **which is 28**

b = Number of headways for PC following Bajaj; **which is 61**

c = Number of headways for Bajaj following PC; **which is 49**

d = Number of headways for Bajaj following Bajaj; **which is 185**

w = Mean headways for PC following PC; which is 2.562

x = Mean headways for PC following Bajaj; which is 1.773

y = Mean headways for Bajaj following PC; which is 2.177

z = Mean headways for motorcycle following motorcycle; which is 1.714

$$C = \frac{28 * 61 * 49 * 185(2.562 - 1.773 - 2.177 + 1.714)}{28 * 61 * 49 + 28 * 61 * 185 + 28 * 49 * 185 + 61 * 49 * 185}$$

$$C = 4.184$$

Hence, the adjusted mean headways for a PC following a PC will be; from eq. (2.12):

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

$Number\ of\ headway\ of\ PC\ following\ PC$ (28)

$U -$ Uncorrected mean headway (2.562),

$C -$ correction factor (4.184)

$$\bar{h}_{A(p-p)} = 2.562 - \frac{4.184}{28}$$

$$\boldsymbol{\bar{h}_{A(p-p)} = 2.413}$$

And the adjusted mean headways for a Bajaj following a Bajaj will also be eq. (2.12):

$$\bar{h}_{A(b-b)} = U - \frac{C}{Number\ of\ headway\ of\ Bajaj\ following\ Bajaj}$$

Where: $\bar{h}_{A(m-m)}$ −adjusted mean headway for Bajaj following Bajaj

$U -$ Uncorrected mean headway($U = 1.714$),

$C -$ correction factor ($C = 4.184$)

$Number\ of\ headway\ of\ Bajaj\ following\ Bajaj\ is$ 185

$$\bar{h}_{A(b-b)} = 1.714 - \frac{4.184}{185}$$

$$\bar{\boldsymbol{h}}_{A(\boldsymbol{b}-\boldsymbol{b})} = \mathbf{1.691}$$

Therefor, $PCE_{Bajaj} = \frac{\bar{h}_{A(b-b)}}{\bar{h}_{A(p-p)}}$

$$PCE_{Bajaj} = \frac{1.691}{2.413}$$

$$\boldsymbol{PCE_{Bajaj}} = \mathbf{0.701}$$

Hence, the PCE of Bajaj is **0.701**.

4.3.3. For Light Duty Vehicle (ldv)

To make sure that PCE of LDV is free from the effect of LDV preceding and following passenger car, we need to compute the following equation, and if it fails we shall find the correction factor "C".

$$\bar{h}_{p-p} + \bar{h}_{ldv-ldv} = \bar{h}_{p-ldv} + \bar{h}_{ldv-p}$$

Where: $\bar{h}_{p-p}$ average headway of a PC followed by a PC;

$\bar{h}_{ldv-ldv}$ average headway of a LDV followed by a LDV,

$\bar{h}_{p-ldv}$ average headway of LDV followed by PC and

$\bar{h}_{ldv-p}$ average headway of PC followed by LDV.

Hence, a frequency table and related descriptive statistics data analysis result from IBM SPSS Statistics Version 20 are displayed hereunder.

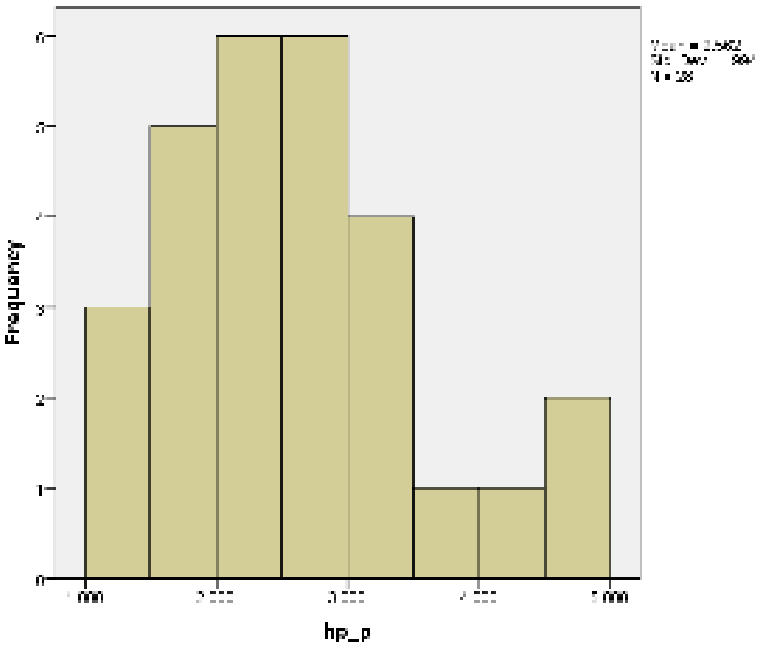


Fig. 4.9. Headway frequency graph of PC following PC.

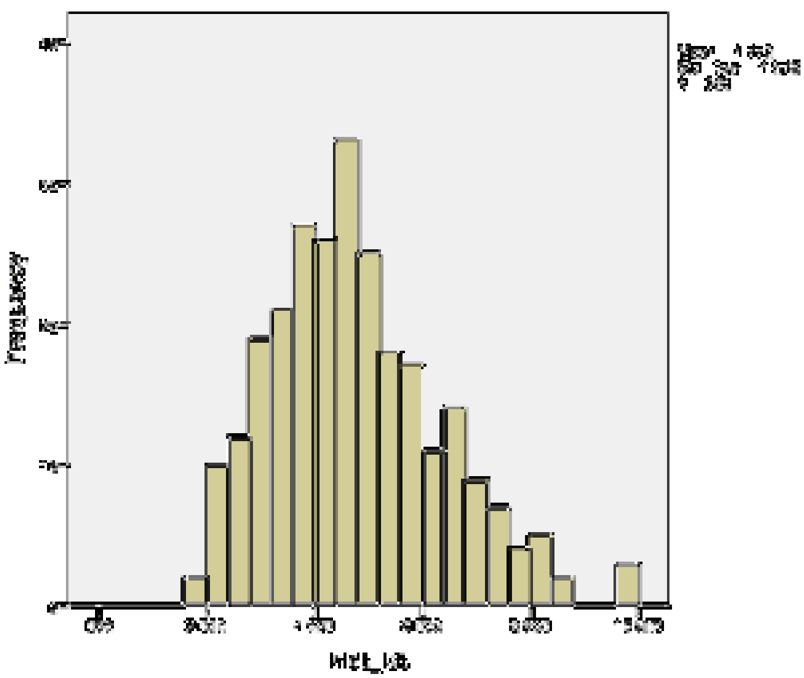


Fig. 4.10. Headway frequency graph of LDV following LDV.

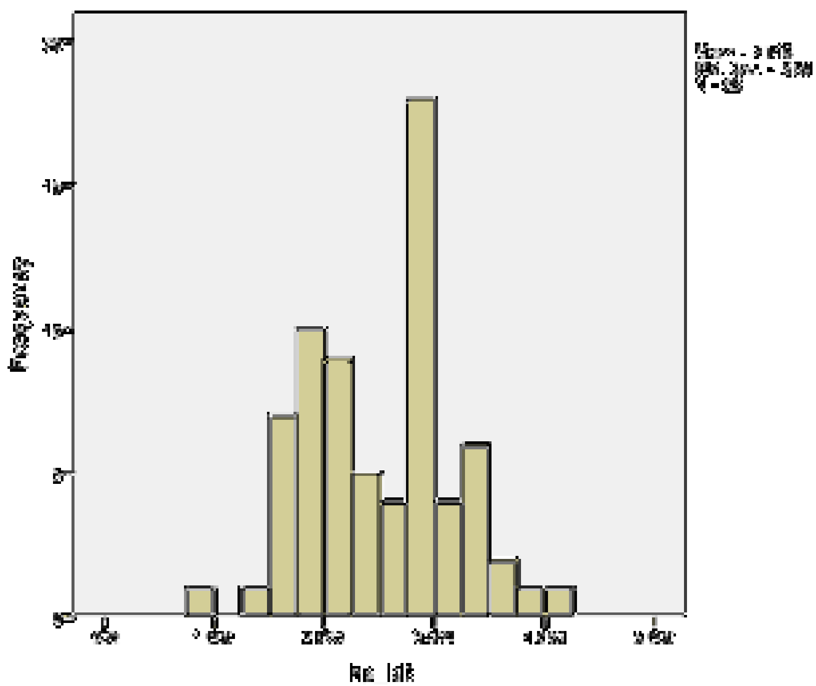


Fig. 4.11. Headway frequency graph of PC following LDV

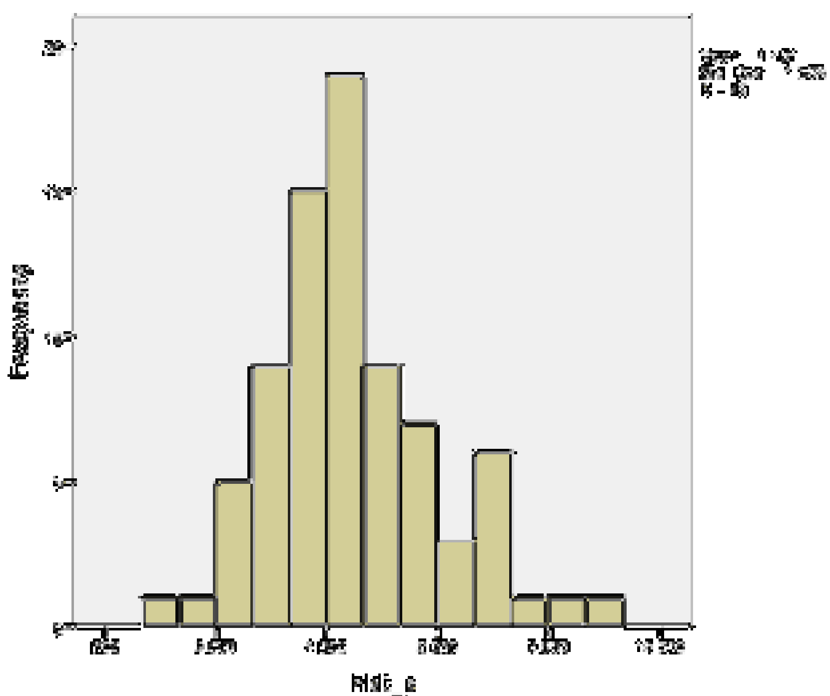


Fig. 4.12. Headway frequency graph of LDV following PC

Table 4.5. Descriptive Statistical study of Light Duty Vehicle-Passenger Car Study

Headway	N	Range	Minimum	Maximum	Mean		Variance	Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
hp_p	28	3.792	1.051	4.843	2.562	0.187923	0.989	0.994396
hldv_ldv	265	7.938	1.878	9.816	4.773	0.096839	2.485	1.576426
hp_ldv	69	3.136	0.918	4.054	2.519	0.079367	0.435	0.659273
hldv_p	78	7.822	0.970	8.792	4.461	0.170749	2.274	1.508015

There, from $\bar{h}_{p-p} + \bar{h}_{ldv-ldv} = \bar{h}_{p-ldv} + \bar{h}_{ldv-p}$

$\bar{h}_{p-p} = 2.562$, $\bar{h}_{ldv-ldv} = 4.773$, $\bar{h}_{p-ldv} = 2.519$, $\bar{h}_{ldv-p} = 4.461$

And substituting the values in the equation

2.562 + 4.773 = 2.519 + 4.461

7.335 ≠ 6.980, hence the correction coefficient "C" must be calculated so that we can procced with the headways method.

From equation (2.11), $C = \frac{abcd(w-x-y+z)}{abc+abd+acd+bcd}$

Where in this case

a = Number of headways for PC following PC; **which is 28**

b = Number of headways for PC following LDV; **which is 69**

c = Number of headways for LDV following PC; **which is 78**

d = Number of headways for LDV following LDV; **which is 265**

w = Mean headways for PC following PC; which is 2.562

x = Mean headways for PC following LDV; which is 2.519

y = Mean headways for LDV following PC; which is 4.461

z = Mean headways for LDV following LDV; which is 4.773

$$C = \frac{28 * 69 * 78 * 265(2.562 - 2.519 - 4.461 + 4.773)}{28 * 69 * 78 + 28 * 69 * 265 + 28 * 78 * 265 + 69 * 78 * 265}$$

C =5.314

Hence, the adjusted mean headways for a PC following a PC will be; from eq. (12):

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

$Number\ of\ headway\ of\ PC\ following\ PC$ (28)

$U -$ Uncorrected mean headway (2.562),

$C -$ correction factor (5.314)

$$\bar{h}_{A(p-p)} = 2.562 - \frac{5.314}{28}$$

$$\boldsymbol{\bar{h}_{A(p-p)} = 2.372}$$

And the adjusted mean headways for LDV following LDV will also be eq. (2.12):

$$\bar{h}_{A(ldv-ldv)} = U - \frac{C}{Number\ of\ headway\ of\ LDV\ following\ LDV}$$

Where: $\bar{h}_{A(ldv-ldv)}$ −adjusted mean headway for LDV following LDV

$U -$ Uncorrected mean headway($U = 4.773$),

$C -$ correction factor ($C = 5.314$)

$Number\ of\ headway\ of\ LDT\ following\ LDT\ is$ 265

$$\bar{h}_{A(ldv-ldv)} = 4.773 - \frac{5.314}{265}$$

$$\boldsymbol{\bar{h}_{A(ldv-ldv)} = 4.753}$$

Therefor, $PCE_{LDV} = \frac{\bar{h}_{A(ldv-ldv)}}{\bar{h}_{A(p-p)}}$

$$PCE_{LDV} = \frac{4.753}{2.372}$$

$$\boldsymbol{PCE_{LDV} = 2.004}$$

Hence, the PCE of Light Duty Vehicles is **2.004**.

4.3.4. For Heavy Vehicle (HV)

To make sure that PCE of HV is free from the effect of HV preceding and following passenger car, we need to compute the following equation, and if it fails we shall find the correction factor “C”.

$$\bar{h}_{p-p} + \bar{h}_{HV-HV} = \bar{h}_{p-HV} + \bar{h}_{HV-p}$$

Where: $\bar{h}_{p-p}$ average headway of a PC followed by a PC;

$\bar{h}_{HV-HV}$ average headway of a HV followed by a HV,

$\bar{h}_{p-HV}$ average headway of HV followed by PC and

$\bar{h}_{HV-p}$ average headway of PC followed by HV.

Hence, a frequency table and related descriptive statistics data analysis result from IBM SPSS Statistics Version 20 are displayed hereunder.

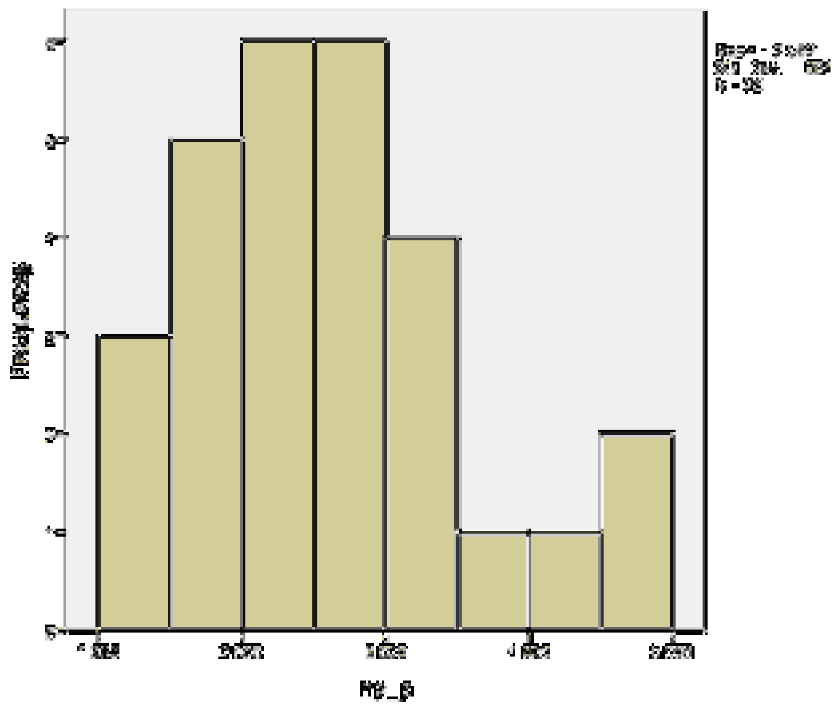


Fig. 4.13. Headway frequency graph of PC following PC.

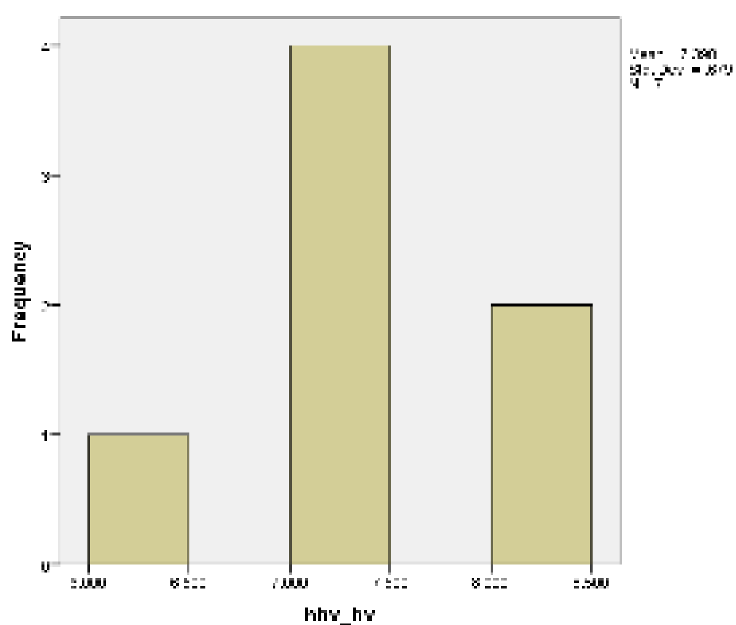


Fig. 4.14. Headway frequency graph of HV following HV.

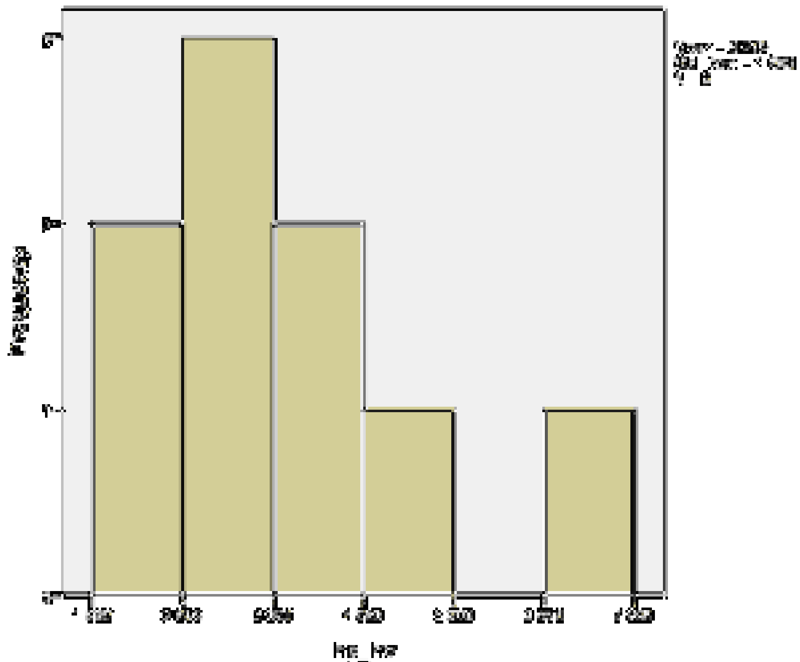


Fig. 4.15. Headway frequency graph of PC following HV.

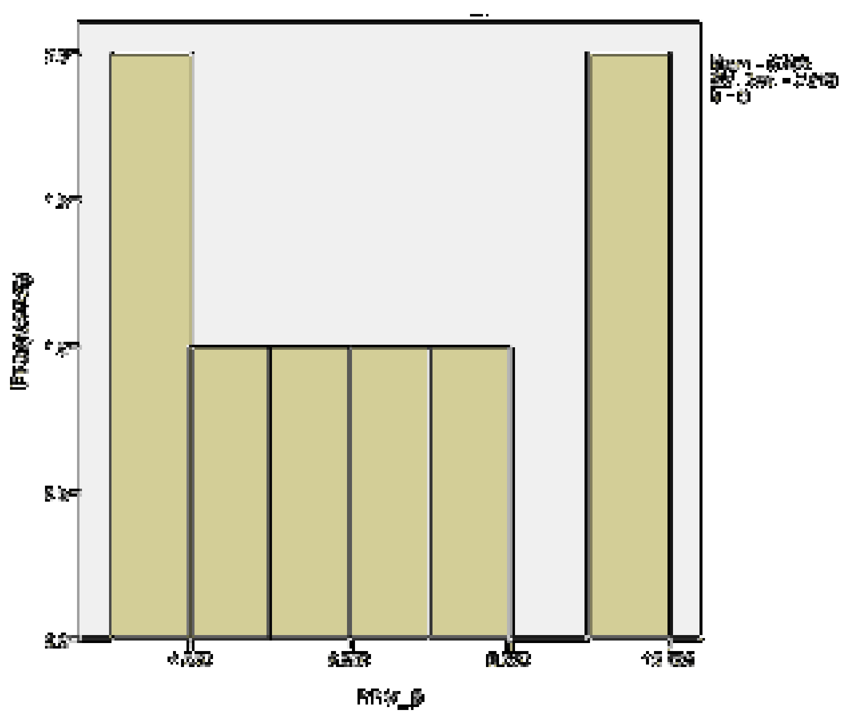


Fig. 4.16. Headway frequency graph of HV following PC.

Table 4.6. Descriptive Statistics of Heavy Vehicles - Passenger Car Study

Headway	N	Range	Minimum	Maximum	Mean		Variance	Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
hp_p	28	3.792	1.051	4.843	2.562	0.187923	0.989	0.994396
hhv_hv	7	1.963	6.295	8.258	7.398	0.256753	0.461	0.679305
hp_hv	9	5.227	1.665	6.892	3.272	0.544447	2.668	1.633341
hhv_p	8	6.612	3.203	9.815	6.355	0.891966	6.365	2.522861

There, from $\bar{h}_{p-p} + \bar{h}_{HV-HV} = \bar{h}_{p-HV} + \bar{h}_{HV-p}$

$\bar{h}_{p-p} = 2.562$, $\bar{h}_{HV-HV} = 7.398$, $\bar{h}_{p-HV} = 3.272$, $\bar{h}_{HV-p} = 6.355$

And substituting the values in the equation

2.562 + 7.398 = 3.272 + 6.355

9.960 ≠ 9.627, hence the correction coefficient “C” must be calculated so that we can procced with the headways method.

From equation (2.11), $C = \frac{abcd(w-x-y+z)}{abc+abd+acd+bcd}$

Where in this case

a = Number of headways for PC following PC; **which is 28**

b = Number of headways for PC following HV; **which is 09**

c = Number of headways for HV following PC; **which is 08**

d = Number of headways for HV following HV; **which is 07**

w = Mean headways for PC following PC; which is 2.562

x = Mean headways for PC following HV; which is 3.272

y = Mean headways for HV following PC; which is 6.355

z = Mean headways for HV following HV; which is 7.396

$$C = \frac{28 * 9 * 8 * 7(2.562 - 7.398 - 3.727 + 6.355)}{28 * 9 * 7 + 28 * 9 * 7 + 28 * 8 * 7 + 9 * 8 * 7}$$

$\boldsymbol{C}$ =**-5.564**

Hence, the adjusted mean headways for a PC following a PC will be; from eq. (2.12):

$$\bar{h}_{A(p-p)} = U - \frac{C}{Number\ of\ headway\ of\ PC\ following\ PC}$$

Where: $\bar{h}_{A(p-p)}$ −adusted mean headway for PC following PC

$Number\ of\ headway\ of\ PC\ following\ PC$ (28)

$U -$ Uncorrected mean headway (2.562),

$C -$ correction factor (-5.564)

$$\bar{h}_{A(p-p)} = 2.562 - \frac{-5.564}{28}$$

$$\boldsymbol{\bar{h}_{A(p-p)} = 2.761}$$

And the adjusted mean headways for HV following HV will also be eq. (2.12):

$$\bar{h}_{A(HV-HV)} = U - \frac{C}{Number\ of\ headway\ of\ HV\ following\ HV}$$

Where: $\bar{h}_{A(HV-HV)}$ −adjusted mean headway for HV following HV

$U -$ Uncorrected mean headway($U = 7.396$),

$C -$ correction factor ($C = -5.564$)

$Number\ of\ headway\ of\ HV\ following\ HV\ is$ 07

$$\bar{h}_{A(HV-HV)} = 7.396 - \frac{-5.564}{7}$$

$$\bar{\boldsymbol{h}}_{\boldsymbol{A(HV-HV)}} = \mathbf{8.191}$$

Therefor, $PCE_{HV} = \frac{\bar{h}_{A(HV-HV)}}{\bar{h}_{A(p-p)}}$

$$PCE_{HV} = \frac{8.191}{2.761}$$

$$\boldsymbol{PCE_{HV} = 2.967}$$

Hence, the PCE of Heavy Trucks is **2.967**.

Therefore, the PCE values of different vehicle groups is summarized in the following Table.

Table 4.7. Calculated PCE Values

Serial No.	Vehicle group typical Members	Vehicle group	PCE
I	Motorcycles of different made ex. Bajaj, TVS, Laffan, etc.	Motorcycle	0.552
II	Bajaj, TVS, Piaggio Auto Rickshaws,	Bajaj	0.701
III	Toyota executive, Corolla, Vitz, Yaris, and other made but similar vehicles etc.	Passenger Car	1.00
IV	Pick-up trucks of all kind and made, SUV, Minibus with capacity up to 15 people etc.	Light Duty Vehicles s	2.004
V	Small and Large bus; small, medium and heavy trucks etc.	Heavy Vehicle	2.967

4.4. Assessment of PCE values

The Ethiopian Road Authority Geometric Design Manual (2013), considers similar PCE value of vehicles for intersections (signalized/non-signalized and roundabouts), midblock segments, freeway sections, rural and/or urban road sections. On the other hand, the provided PCE values are often directly adopted from overseas or not properly adapted to actual roadway, traffic and control conditions of the nation. Hence, this dissertation investigated PCE values at a specific section of a roadway, i.e. signalized intersection, within the countries roadway, traffic and control condition. For this reason, comparison of PCE's in this section considers different roadway element from various literatures and manuals, to show how far the considered PCE's deviate from what they should have been.

The comparison should take the following themes in to account:

- PCE values from developed as well as developing countries, which were calculated at different roadway sections using different methods are brought in to comparison in table 4.8. because, different practitioners used to take PCE values from different findings and manuals from abroad which literally can be seen as wrong approach for they did not match Ethiopia's conditions.
- It is obvious that a traffic system is only as good as its weakest spots, which are intersections. That is why this paper focus on PCE of vehicles at the weakest position so that they can be used elsewhere with a significant enough margin of safety, in the absence of actual PCE values that is conducted for the specific roadway segment type.

Table 4.8 demonstrates a typical comparison of passenger car equivalents from different literatures, manuals and practices. Obviously, all shows that as vehicles size increase it will have a negative effect on traffic. On the other hand, depending on the assumed method; and hence considered variable, traffic mix, roadway condition, drivers behavior alter the PCE value. It is observed that, the calculated PCE is significantly different from previous findings, including ERA Geometric Design Manual (2013) as well as HCM (2010).

Table 4.8. Comparison of PCE from different countries

S. No	Mode	A. Muhamed (2013) Pakistan	R. Yahya et. el (2014) Palestine	G. Tamene (2016) Ethiopia	C. J. Molina et. al. (1987) USA	A.A. Obiri et. al. (2014) Ghana	C.A. Adams et. at. (2014) Ghana	P. Saha et. al. (2009) Bangladesh
1	Motorcycle	0.603	-	-	-	-	0.340*	-
2	Bajaj	1.076	-	-	-	-	0.710*	0.860
3	Passenger Car	1.000	1.000	-	1.000	1.000	1.000	1.000
4	Light Duty Vehicle	1.150*	1.435	-	1.700	1.650	1.600*	1.460
5	Heavy Vehicle	1.461	2.233	2.500**	3.700	3.050	-	2.160

*Weighted Average, not exact value **Level Terrain

S. No	Mode	MoC (2001) Bangladesh	HCM (2010) USA	Overseas Road Note 11	Indian Road Congress	ERA (2013) Ethiopia	Calculated PCE (2018) Ethiopia
1	Motorcycle	0.750	-	-	0.500	0.25	0.552
2	Bajaj	0.750	-	-	0.700	0.4	0.701
3	Passenger Car	1.000	1.000	1.000	1.000	1.000	1.000
4	Light Duty Vehicle	3.000	-	1.100	-	-	2.004
5	Heavy Vehicle	3.000	2.000	2.250	2.000	-	2.967

Table 4.8. can be assessed from two perspectives, the first one is comparison of PCE values between developed and developing countries. One can also evaluate the calculated PCE's against different study research findings and manuals described.

From developed countries, we have a study report conducted in USA by C. J. Molina et. al. (1987), Oversees Road Note 11 from UK and the 2010 HCM again from USA. As table 4.8. proves, the PCE values from these manuals and studies are by far different in each case from the calculated PCE's of this report. This is primarily because of the difference in roadway facility provisions, traffic conditions (homogeneous traffic and recently manufactured vehicles are driven) and well-designed control condition. On the other hand, when the calculated PCE is compared to studies and manuals of developing countries; for motorcycle and autorickshaw the proximity of PCE's is greater than for light duty and heavy vehicle, which can be attributed to the similarity of roadway, traffic and control conditions as well as driver's behavior.

When the calculated PCE's are compared with manuals and practices; the Bangladeshi's MoC (2001) PCE's better resembles the calculated PCE's. Similarly, the IRC PCE's also have better proximity to this study results for they have more or less similar roadway, traffic and control conditions. Scientific research results, on the other hand, confirmed this fact.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study has discussed in estimation of PCE factors for vehicles at signalized intersection in heterogeneous traffic environment of Hawassa city, Ethiopia.

- The PCE factor for five vehicle groups were derived using the headway ratio method. The traffic mix derived from this study shows that there are as much motorcycles in the traffic stream as there are cars; likewise, auto rickshaws and light duty vehicles are counted almost equal but the category of heavy vehicles took the least place in quantity.
- The PCE of Motorcycle, Auto rickshaw, Light Duty Vehicle and Heavy Vehicle are found to be 0.510, 0.701, 2.004 and 2.967 respectively. The PCE factor value of Motorcycle used by the national standard book, ERA Geometric Design Manual (2013) is less than half of the calculated finding of the study; similarly, for Auto rickshaw the ERA provision is slightly larger than half of the calculated value of this study. There is no clear provision regarding the other two groups on the manual. The absence of PCE for LDV and HV groups and deviation of PCE factors for the remaining vehicle groups from this study result indicates a significant quantity of calculations involving PCE, such as saturation flow rate and thus influences the design of signalized intersections, have been misleading.
- The foregoing discussion implies that since PCE depends on factors influencing the traffic flow parameters, setting it at a constant value under different roadway, traffic and control conditions does not have to be taken correct.
- Finally, it is suggested that the values obtained in this study can be used as a guideline in the design and analysis of signalized intersections in Hawassa City as well as in Ethiopia. This is because the calculated PCE obtained in this study are determined under local roadway, traffic and control conditions; which are the ultimate determining factors of PCE values.

5.2. Recommendations

The results of this investigation have indicated that;

- The PCE values calculated are different from HCM (2010) or ERA (2013), urging a series further study on all PCE factors
- Further research into the development of PCEs at signalized intersections is suggested but the data collection is recommended to use techniques that take in to account
  - ✓ automatic vehicle weight collection ability for a significantly long period of time
  - ✓ the effect of turning maneuver of through vehicles
  - ✓ a further classification of vehicles and to collect sufficient quantity of a specific vehicle
  - ✓ other methods of calculating PCE that might explain the roadway, traffic and control condition and compare it with headway method
- Finally, the departure of the results of this study from other findings and practice shows that there needs to be a clear separation for PCE values of future study in different roadway segments (i.e. signalized and/or non-signalized intersection, roundabout, mid-block, freeway etc), level of urbanization of the segment (like Urban, sub-urban, rural) size and number of lanes.

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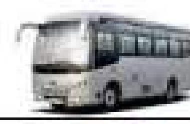
Annex A.

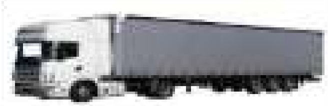
Table A.1. Classification of Vehicle According to ERA 2013 Manual

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		Passenger Car
3	Small Bus	2	≤ 27 seats		Trucks and Buses
4	Bus/coach	2	> 27 seats		Trucks and Buses
5	Small truck	2	≤ 3.5 tonnes		Trucks and Buses

(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

(ERA 2013:p.2-3)

Annex B. Raw Data

The raw data, headways of different group of vehicles is reported in this part of the paper.

Fig. B1. Frequency of Vehicle Headway Before Regrouping

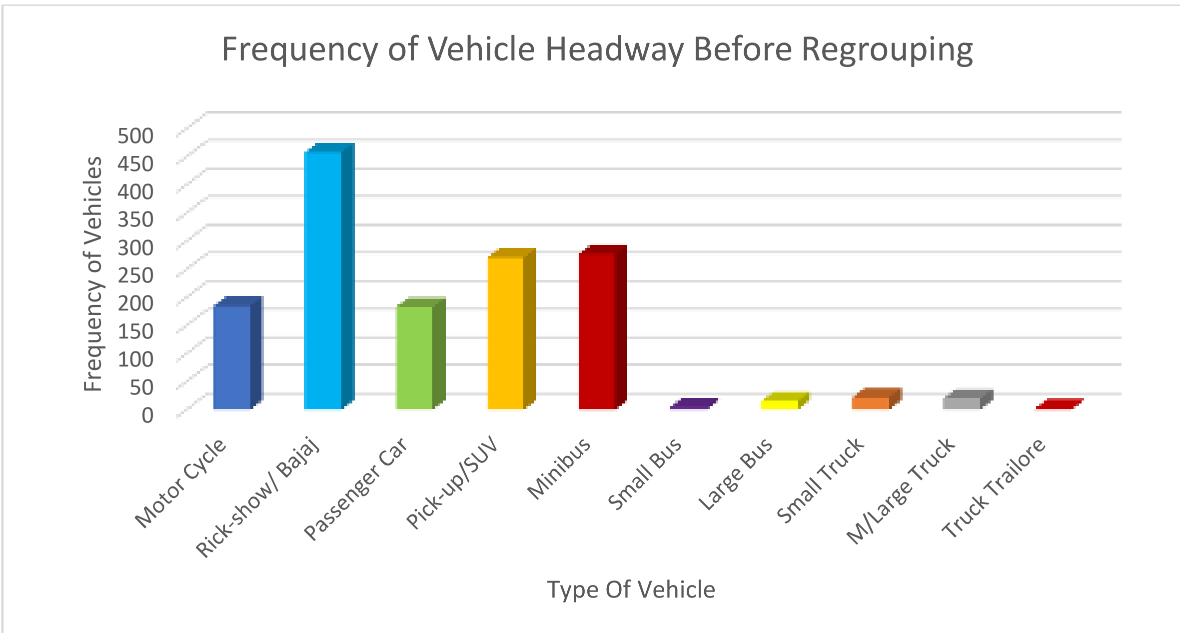


Fig. B2. Frequency of Vehicle Headway After Regrouping

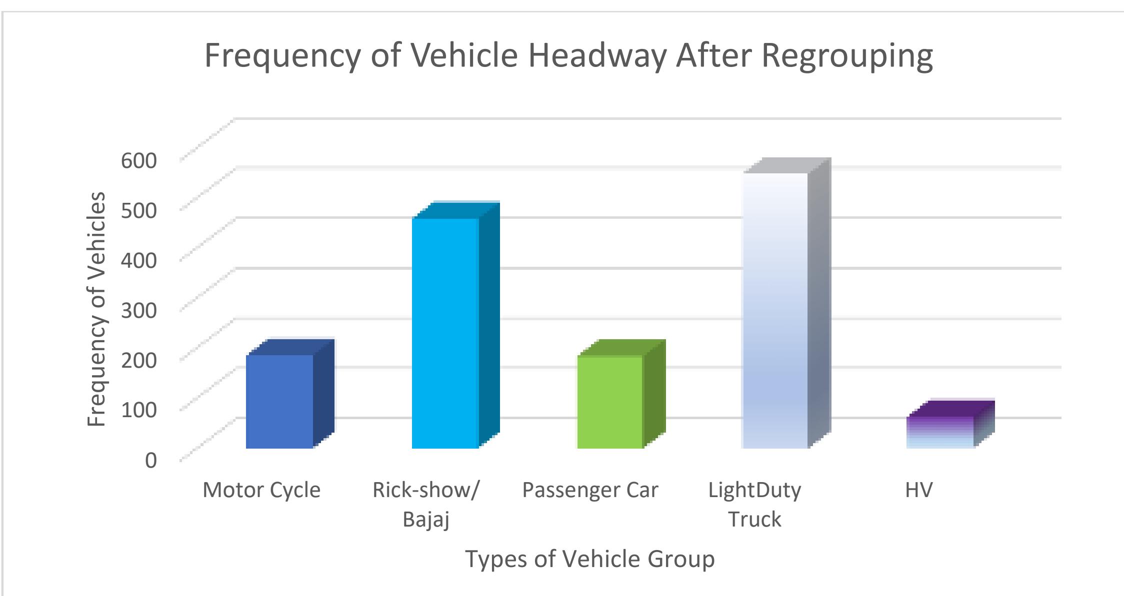


Table B1. Table of Grouped Vehicle Data

Motorcycles	Auto Rickshaw	Passenger Car	Light Duty Vehicles	Heavy Vehicle
0.406	0.198	0.577	0.972	2.134
0.598	0.662	0.726	0.9924	2.562
0.601	0.683	0.811	0.9996	3.330
0.641	0.702	0.875	1.050	5.036
0.683	0.703	0.897	1.050	2.690
0.684	0.726	0.918	1.0752	2.860
0.704	0.726	0.94	1.0764	3.286
0.79	0.726	1.002	1.0764	3.330
0.811	0.747	1.003	1.1016	3.458
0.832	0.79	1.004	1.1016	3.500
0.832	0.81	1.025	1.1268	3.798
0.833	0.811	1.047	1.128	4.182
0.854	0.811	1.051	1.1532	4.736
0.897	0.833	1.067	1.1604	4.822
0.918	0.833	1.091	1.1784	5.292
0.919	0.833	1.11	1.2036	5.292
0.961	0.853	1.11	1.2288	5.464
0.982	0.854	1.124	1.2552	5.804
0.982	0.855	1.152	1.2804	7.852
0.982	0.875	1.153	1.2804	1.58
0.982	0.875	1.174	1.3056	1.922
1.003	0.875	1.196	1.3068	2.518
1.003	0.897	1.217	1.3332	2.988
1.02	0.897	1.217	1.3572	3.016
1.024	0.918	1.238	1.3572	3.586
1.025	0.919	1.238	1.3836	3.714
1.025	0.939	1.238	1.4088	3.744
1.046	0.96	1.259	1.4088	3.758
1.067	0.961	1.259	1.4088	3.842
1.067	0.961	1.259	1.4604	4.098
1.067	0.961	1.26	1.4604	4.352
1.11	0.982	1.281	1.4604	4.352
1.11	1.003	1.281	1.4604	4.618
1.131	1.003	1.302	1.4856	4.694
1.131	1.003	1.302	1.4856	4.694

1.132	1.003	1.302	1.4856	5.292
1.152	1.003	1.303	1.4856	6.230
1.153	1.003	1.309	1.4868	6.274
1.153	1.024	1.34	1.5108	6.36
1.174	1.025	1.345	1.5108	7.470
1.174	1.025	1.367	1.5108	9.474
1.195	1.025	1.367	1.5372	1.878
1.195	1.046	1.368	1.5624	2.348
1.196	1.047	1.388	1.5624	2.348
1.237	1.068	1.409	1.5636	2.434
1.259	1.088	1.43	1.5876	2.944
1.259	1.089	1.451	1.6128	3.244
1.281	1.089	1.468	1.614	3.926
1.281	1.089	1.472	1.614	4.096
1.303	1.089	1.473	1.614	4.226
1.304	1.089	1.537	1.614	4.482
1.323	1.089	1.537	1.6392	4.566
1.323	1.089	1.559	1.6392	4.736
1.324	1.11	1.571	1.6404	5.064
1.344	1.11	1.579	1.6644	5.078
1.344	1.11	1.579	1.6644	5.08
1.345	1.11	1.579	1.6656	5.338
1.366	1.111	1.6	1.6908	5.676
1.366	1.131	1.601	1.6908	5.762
1.367	1.131	1.623	1.716	6.66
1.387	1.131	1.643	1.716	8.752
1.409	1.131	1.665	1.716	2.904
1.429	1.152	1.665	1.7172	3.458
1.43	1.152	1.686	1.7412	
1.43	1.153	1.686	1.7412	
1.431	1.153	1.687	1.7412	
1.451	1.153	1.692	1.7412	
1.451	1.153	1.707	1.7412	
1.451	1.16	1.729	1.7412	
1.451	1.174	1.729	1.7412	
1.452	1.174	1.729	1.7412	
1.472	1.174	1.75	1.7424	
1.473	1.174	1.75	1.7676	

1.473	1.174	1.771	1.7676
1.494	1.174	1.772	1.7928
1.494	1.195	1.814	1.7928
1.535	1.195	1.857	1.7928
1.537	1.195	1.878	1.818
1.558	1.195	1.878	1.8444
1.558	1.206	1.879	1.8696
1.558	1.216	1.921	1.8696
1.558	1.217	1.921	1.8696
1.559	1.217	1.923	1.8708
1.579	1.217	1.942	1.8948
1.579	1.238	1.963	1.896
1.579	1.238	1.964	1.896
1.6	1.238	1.964	1.896
1.601	1.238	1.985	1.9212
1.601	1.238	1.986	1.9212
1.601	1.238	2	1.9332
1.622	1.28	2.006	1.9464
1.622	1.28	2.041	1.9476
1.622	1.281	2.042	1.9476
1.642	1.286	2.042	1.9716
1.643	1.286	2.049	1.9728
1.644	1.302	2.05	1.998
1.644	1.302	2.07	1.998
1.644	1.302	2.071	2.0232
1.664	1.302	2.092	2.0232
1.664	1.302	2.134	2.0232
1.665	1.302	2.134	2.0736
1.665	1.303	2.155	2.0748
1.686	1.311	2.156	2.0748
1.708	1.323	2.173	2.076
1.75	1.323	2.177	2.100
1.751	1.323	2.177	2.100
1.771	1.323	2.177	2.1012
1.772	1.324	2.198	2.1012
1.793	1.345	2.198	2.1264
1.793	1.345	2.198	2.1264
1.814	1.345	2.219	2.1768

1.814	1.361	2.219	2.1768
1.835	1.365	2.221	2.1768
1.835	1.366	2.241	2.1768
1.835	1.366	2.241	2.1768
1.876	1.367	2.263	2.1852
1.878	1.367	2.276	2.1972
1.878	1.368	2.284	2.202
1.899	1.387	2.284	2.2032
1.899	1.387	2.305	2.2284
1.9	1.387	2.305	2.2284
1.92	1.387	2.305	2.2476
1.921	1.387	2.348	2.2536
1.921	1.388	2.348	2.2536
1.921	1.408	2.39	2.2536
1.942	1.408	2.432	2.2548
1.942	1.409	2.433	2.2788
1.943	1.409	2.475	2.2788
1.963	1.409	2.497	2.3052
1.963	1.409	2.518	2.3064
1.964	1.409	2.562	2.3304
1.964	1.409	2.613	2.3304
1.985	1.409	2.668	2.3304
2.008	1.409	2.689	2.3556
2.027	1.43	2.71	2.3556
2.028	1.43	2.731	2.3556
2.049	1.43	2.738	2.3556
2.049	1.43	2.753	2.3616
2.049	1.43	2.774	2.382
2.049	1.43	2.776	2.382
2.049	1.43	2.795	2.4072
2.07	1.431	2.796	2.4072
2.071	1.431	2.8	2.4096
2.091	1.451	2.817	2.4324
2.113	1.451	2.817	2.4576
2.113	1.451	2.839	2.484
2.113	1.451	2.881	2.484
2.114	1.451	2.881	2.484
2.134	1.451	2.881	2.484

2.134	1.451	2.881	2.484
2.134	1.451	2.903	2.4852
2.135	1.451	2.923	2.4852
2.155	1.452	2.944	2.5092
2.177	1.472	2.946	2.5092
2.198	1.473	2.966	2.5092
2.198	1.473	2.966	2.5092
2.198	1.473	2.966	2.5344
2.219	1.473	2.988	2.5356
2.219	1.473	3.009	2.5356
2.219	1.473	3.071	2.5368
2.24	1.473	3.094	2.544
2.241	1.494	3.115	2.5608
2.241	1.494	3.117	2.5608
2.241	1.494	3.137	2.5608
2.263	1.515	3.139	2.562
2.283	1.516	3.222	2.586
2.283	1.517	3.265	2.586
2.284	1.537	3.265	2.5872
2.284	1.558	3.286	2.5872
2.326	1.577	3.327	2.6112
2.347	1.579	3.33	2.6136
2.349	1.579	3.35	2.6376
2.369	1.579	3.35	2.6388
2.39	1.579	3.371	2.6628
2.391	1.579	3.371	2.664
2.392	1.601	3.414	2.664
2.412	1.601	3.435	2.664
2.433	1.601	3.563	2.664
2.454	1.601	3.585	2.664
2.455	1.601	3.634	2.6892
2.455	1.601	3.691	2.6904
2.518	1.601	3.948	2.7156
2.519	1.601	3.969	2.7156
2.519	1.622		2.7156
2.539	1.622		2.7396
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1.643	2.7924
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1.665	2.8176
1.665	2.8188
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1.686	2.844
1.686	2.868
1.687	2.868
1.707	2.868
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1.707	2.868
1.708	2.8692
1.728	2.8824
1.728	2.8932
1.729	2.8932
1.729	2.8968
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1.729	2.9448
1.729	2.9712
1.75	2.9724
1.75	2.9964
1.75	3.0216
1.75	3.0468
1.75	3.0468
1.75	3.0468
1.751	3.048
1.771	3.048
1.771	3.0732
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1.771	3.0732

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1.814	3.1248
1.814	3.1752
1.814	3.1752
1.815	3.2016
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1.857	3.2784
1.857	3.3036
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1.857	3.354
1.862	3.4056
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1.942	3.8916
1.944	3.8916
1.963	3.8928
1.964	3.9432
1.964	3.9684
1.97	3.9684
1.985	0.582
1.985	0.8196
1.985	0.9732
1.985	0.9924
2	0.9984
2.006	0.9984
2.007	0.9996
2.027	1.05
2.027	1.1016
2.028	1.1016
2.029	1.1016
2.034	1.1268
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2.091	1.3068
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2.091	1.3572
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2.092	1.3632
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2.177	1.5108
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2.177	1.5372
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2.327	1.818
2.347	1.818
2.347	1.8696
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2.369	1.9212
2.369	1.9332
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2.39	1.9476
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