JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF POST GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

Dynamic Passenger Car Unit Estimation for Urban Road Midblock and Signalized Intersection under Heterogenous Traffic Stream in Jimma, Ethiopia.

By: Merga Lemesa Kitata

A research thesis submitted to School of Post Graduate Studies, Jimma University, Jimma Institute of Technology; in Partial Fulfillment of the Requirements for the degree of master of science in Highway Engineering.

July, 2023

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Advisor: Tarekegn Kumala (PhD)

Co-Advisor: Basha Fayissa (MSc)

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DECLARATION

I, the author of this thesis, declare that this research work titled "**Dynamic Passenger Car Unit estimation for urban road midblock and signalized intersection under heterogenous traffic stream in Jimma, Ethiopia**" is my original work performed under the advisorships of Tarekegn Kumala (PhD) and Basha Fayissa (MSc) and it has not presented partially or whole for assessment and a degree in anywhere.

Author: Merga Lemesa Kitata. Signature: Date: 11/07/2023

APPROVAL

This is to approve that the thesis prepared by **Mr. Merga Lemesa Kitata** entitled "**Dynamic Passenger Car Unit estimation for urban road midblock and signalized intersection under heterogenous traffic stream in Jimma, Ethiopia**" and submitted in fulfillment of the requirements for the degree of master of science in Highway Engineering complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

APPROVED BY BOARD OF EXAMINERS

NAME	SIGNATURE	DATE
1. Tarekegn Kumala (PhD.) Main Advisor		18-07-2023
2. Basha Fayissa (MSc.) Co- Advisor		18/07/23
3. Alamirew Mulugeta (PhD.) External Examiner		14/07/2023 14/07/2023
4. Mohammed Hassen (MSc.) Internal Examiner	For	18/07/23
5. Oluma Gudina (MSc.) Chair Person		18/07/23

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Abstract

This study was conducted to estimate passenger car unit (PCU) of vehicles at urban road midblock section and signalized intersection under heterogeneous traffic system in Jimma city, Ethiopia. Traffic flow is heterogeneous in nature and its heterogeneity degree varies from nations to nations; usually more for developing nations. This heterogeneity in traffic causes the main challenges of traffic analysis and facility design unless it is converted into equivalent homogeneous traffic stream using proper passenger car unit determined at local setting. However, Ethiopian traffic engineers and transportation planners has used passenger car unit values adopted in highway capacity manual for transportation facility design, operational analysis and capacity estimation, which is not represents local roadway condition. Even though, many researchers estimated passenger car unit, they were exaggerated the values. The main objective of this study was to estimate passenger car unit of vehicle types at midblock road section and signalized intersection under heterogeneous traffic stream that represents a local roadway condition through incorporate optimization method in analysis. Data were collected from purposively selected two flat terrain midblock road section and pre-timed signalized intersection through video recording, measurement and observation method during a peak-hour. The passenger car units were estimated for vehicles; three-wheeler, standard car, four-wheel drive, bus and truck at mid-block section and pre-timed signalized intersection using three analysis methods. Firstly, analytical method; speed based and headway ratio were applied at midblock section and signalized intersection, respectively. Secondly, microscopic simulation analysis using Vissim software was carried out to validate analytical results. Thirdly, optimization was applied to optimize PCU between analytical and simulation method. Optimization method resulted passenger car unit for three-wheeler, four-wheel drive, bus and truck as 0.65, 1.39, 2.80, 3.60 at midblock while 0.64, 1.30, 2.56, 3.29 at signalized intersection in considering local roadway condition. These values are higher than the adopted values in highway capacity manual (HCM 2010), but lower than the recommended value in different literatures. Therefore, the researcher has recommended the future researchers, designers and planners to follow such analysis methods rather than totally using the adopted one since the PCU value for a vehicle type depends on different parameters of the existing roadway and traffic flow behaviors.

Keywords: Microscopic simulation, Mid-block section, Optimization, Passenger car unit, Signalized intersection

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Acronyms

4WD: Four Wheel Drive

EB: East Bound

ERA: Ethiopia Road Authority

GRG: Generalized Reduction Gradient

h_A: Adjusted headway

hc-c: headway of a car followed by a car

HCM: Highway Capacity Manual.

hc-x: headway of a car followed by a type x vehicle

hx-c: headway of a type x vehicle followed by a car

hx-x: headway of a type x vehicle followed by a type x vehicle.

NB: North Bound

NWB: North-West Bound

PCU: Passenger Car Unit

PHF: Peak Hour Factor

PTV: Planning Transport Verkehr

SB: South Bound

SEB: South-East Bound

SMS: Space Mean Speed

STA: Smart Traffic Analyzer

TMS: Time Mean Speed

TRB: Transportation Research Board

WB: West Bound

CHAPTER ONE

Introduction

1.1 Background

Traffic flow is heterogeneous in nature and its heterogeneity degree varies with context; it is usually more for developing nations. Passenger Car Unit (PCU) is commonly used approach to convert this heterogeneous traffic flow into its equivalent homogeneous. The term 'passenger car unit' was defined in Highway Capacity Manual (HCM 2010) and as "the number of passenger cars displaced in the traffic flow by other transport modes under the prevailing roadway and traffic conditions; it is used to convert heterogeneous traffic environment into homogenous stream in which it is assumed that only cars are travelling". Hence, the main importance of PCU values in traffic is to convert heterogenous traffic stream into equivalent homogenous traffic stream which is used for capacity analysis, facility design, traffic management, safety analysis, operational analysis, determination of saturation flow rate, Volume analysis, and developing traffic flow models (Bains et al. 2012).

The idea of conversion factor to count heavy vehicles effect on multi-lane highway level terrain was proposed in Highway Research Board (Highway capacity manual, 1950 edition). However, neither its name nor significance was explained in detail in this manual. Highway Research Board (*Highway Capacity Manual* 1965), conceptualized PCU and its importance in mixed traffic stream at the first time based on Walker's method, but it was demonstrated as constant number that not considering the sensitive variables. However, following the emerging of PCU concept in the Highway Research Board, considerable researchers have developed the estimation of PCU values by considering various sensitive variables of traffic conditions (Srikanth and Mehar 2017).

Ethiopian traffic engineers and planners uses PCU values from highway capacity manual for transportation facility design, safety analysis, operational analysis, the service flow rate analysis, volume analysis, and capacity analysis. However, the manual was developed empirically based on local condition of developed country and recommended international users to calibrate the values using local data. Therefore, it is unrealistic to apply it directly to Ethiopian context because of differ in driver behavior, nature of mixed traffic, non-lane discipline driving and poor enforcement of traffic rule.

Recently, national studies (Girum and Bikila 2016; Ararsa and Getu 2020; Hordofa Tullu and Tucay Quezon 2021) on PCU values estimation at different road segment, signalized intersection and roundabout road section using local level data justified the truth that using adopted PCU values from HCM did not represent the local traffic condition, overestimates the capacity of road facilities and causes traffic congestion. Therefore, this study was carried out to estimate the PCU value of vehicles at midblock and signalized intersection that represent the existing local condition and used for further traffic studies in Jimma city using data collected at local level following worldwide replicable methodology.

1.2 Statement of the Problem

In traffic analysis and facilities design, expressing traffic flow as number of vehicles passing a given section of roads per unit time per lane is inappropriate, because of their static and dynamic characteristics variation makes them their effect is not compared to each other's in heterogenous traffic flow. Therefore, the technique of measuring the effects of each vehicle and converting traffic stream with different types into an equivalent traffic stream composed of exclusively standard passenger cars with the same operational conditions and quality of service is required in traffic study (Raj et al. 2018).

Current standard manual, U.S HCM provides a single set of (static) PCU value, used as conversion factor of each vehicle into standard passenger car for entire range of traffic condition. However (Elefteriadou et al. 1997; Chandra and Sikdar 2000) studies concluded that the PCU value for a vehicle type depends on all parameters of the roadway and traffic that affect the behavior of vehicles in the traffic stream. Hence, usage of dynamic passenger car unit is recommended, unlike using static passenger car unit under entire roadway condition. The concept of dynamic PCU was introduced by (Chandra and Kumar 2003) which was based on relative speed and area of a vehicle type with respect to the standard car.

In Ethiopia many researchers shown that locally determined PCU of different vehicles is different from PCU values adopted in highway capacity manual. This is due to; traffic flow is highly heterogenous in which different vehicles having different static and dynamic nature are using the same facilities, traffic flow is not lane disciplined, poor driving behavior and quality of road facilities. (Firiiken and C. 2019) verified that the PCU value of vehicles determined in local level at roundabout is larger when compared with the value adopted in HCM and shown that adopted PCU value has overestimates the capacity up to 31.23%, hence the author recommended to use locally determined value. (Hordofa Tullu and Tucay Quezon 2021) justified that locally determined PCU value at urban road segment is higher than those provided in Highway Capacity Manual (HCM), hence local level PCU values are recommended to reflect the existing traffic condition in the locality. (Michael and Bikila 2019) shown that the value of PCU varies with respect to down and upgrades, lane width approach width and available green time at signalized intersection. (Ararsa and Getu 2020) studied the capacity of trunk road segment using locally determined PCU value and resulted that HCM has overestimate the capacity of road section. The study of (Girum and Bikila 2016) on PCU value truck and bus for freeway road at upgrade and downgrade road section concluded the local level PCU value of truck and bus is higher than the value recommended in highway capacity manual 2010. However, these all researcher overestimates the values of PCU as they did not optimize their results.

Generally, in Ethiopia for the decades and still nowadays, adopted static PCU value has used for traffic analysis and facility design, hence the results also have not represented existing traffic condition on field and leads traffic congestions. Currently, Jimma City is under rapid growth of transportation demands as increasing economic activities of the region leads rapid urbanization. Hence, proper and locally determined PCU values in traffic analysis and facility design should be available to smooth the transportation system of the city. Therefore, this study aimed to estimate dynamic PCU value of vehicles at mid-block road section and signalized intersection based on the local roadway conditions using analytical method; speed-based and headway ratio method. The results were verified by microscopic simulation model with the aid of PTV VISSIM software and finally optimization method was applied to optimize the result between analytic and simulation method. The result of this study can be used as database for future fellow researchers, planners and designers in transportation and the methodology used can be replicated globally.

1.3 Research questions

This study was carried out to answer the following questions.

1. What is the composition of traffic heterogeneity in jimma city?
2. What are the PCU values of vehicles at midblock road section and signalized intersection under heterogeneous traffic system according to local traffic conditions?
3. How to validate locally determined PCU values at midblock road section and signalized intersection?
4. How to obtain optimum PCU values ant midblock road section and signalized intersection?

1.4 Objectives

1.4.1 General Objective

The main objective of this study was the estimation of dynamic PCU of vehicles for urban road midblock section and signalized intersection under heterogenous traffic system using local data.

1.4.2 Specific Objectives

1. To analyze the composition of traffic heterogeneity at midblock road section and signalized intersection.
2. To estimate the PCU at midblock road section and signalized intersection using Analytical method.
3. To validate the PCU at midblock road section and signalized intersection using microscopic simulation analysis.
4. To optimize the PCU at midblock road section and signalized intersection using optimization method.

1.5 Scope of the Study

The author limited the scope of this study to the estimation of PCU of only motorized vehicles; three-wheeler, Standard car, four-wheel drive (4WD), Bus and Truck at two midblock road section; Bore and Ajip and two signalized intersections; Central Hotel and Fayid gas station, using analytical method (speed-based and headway ratio), microscopic simulation analysis and applying an optimization method.

1.6 Significance of the study

The result of this study is highly important in traffic studies that carry out in the Jimma and other city having similar traffic nature. It initiates policy makers, research institutions and different stake holders of the transportation sector to calibrate planning, analysis and design parameters to local condition. It also initiates further researcher to calibrating microscopic simulation software in local data and incorporating the optimization method in PCU estimation. Finally having the result of this study at local level means, possible to properly carried out capacity analysis, facility design, operational analysis, determination of saturation flow rate and LOS study that can represents the existing condition.

1.7 Limitation of the study

Smart traffic analyzer (STA) is the professional project software for urban & road traffic management, Counting and categorizing vehicles in different classes, calculating average traffic volume, calculating the average speed of vehicles, incident detection based on artificial vision (video processing) and save the image and reports in different forms, including tables, charts and excel files (Urban Road Traffic 2021). The camera should be mounted at a height that the camera image, covers a rectangle with length at least 16 meters of the road surface and the angle of view should be almost perpendicular to the road surface, but you can also set the camera with an angle to the camera's mast (between 0° and 45°). However, the building located proximity to studied sites did not allow these requirements and limited to collect and analysis the traffic using STA software. Therefore, the author of this study extracted required data from video manually on media player.

CHAPTER TWO

Literature Review

This portion includes analyzed summary of both published and unpublished relevant literature regarding general concept of PCU, most common method of PCU estimation used in literature, dynamic nature of PCU and literatures gap.

2.1 General

The heterogeneity of traffic stream in developing country, Ethiopia, where all vehicles having different static and dynamic nature uses the same traffic facility is the main challenge of traffic analysis and facility design.

According to ERA 2013 manual, motorized vehicles categorized into thirteen groups, they all uses the same traffic facilities. This condition has become a critical challenge in traffic studies to design, performance analyses of traffic facilities, manage and control of traffic. Hence to quantify homogeneous traffic and vehicles effects in mixed traffic accurately, appropriate PCU value of vehicle types which can represents the existing local conditions are required.

2.2 Passenger Car Unit estimation methods

A review of relevant studies available in literature shows that there are many PCU values estimation methods for different vehicle categories under a wide range of traffic conditions over the world. The selection of these methods is mainly depended on the suitability of an approach, requirement and scope of the study and nature of the traffic condition. Therefore, the selection of right approach is very crucial, since the PCU values of vehicle categories are vary with the approach adopted to derive it (Sharma and Biswas 2021). Here given in below briefly.

2.2.1 Headway Method

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

(Romig et al. 1949) introduced headway method and determined PCU values based on basic headway for homogenous traffic condition using PCU value of a vehicle type is the ration of average headway of that vehicle type to average headway of passenger car. However, it was limited to homogeneous traffic condition.

Many studies were done to modify and make capable method of finding PCU of any vehicle category present in the traffic stream. (Asaithambi et al. 2017) modified and developed the condition to be satisfied to use headway method for PCU determination:

$h_{c-c} + h_{x-x} = h_{c-x} + h_{x-c}$ …………………………………………….................. (2.1)

Where: h_{c-c} is Average headway of a car followed by a car, h_{c-x} is Average headway of a car followed by a type x vehicle, h_{x-c} is Average headway of a type x vehicle followed by a car and h_{x-x} is Average headway of a type x vehicle followed by a type x vehicle.

Hence; PCU of a vehicle is calculating by:

$PCU_{x-x} = \frac{h\,A(x-x)}{h\,A(c-c)}$………………………………………………………………... (2.2)

Where: PCU_{x-x} is PCU of vehicle x, $h_{A(x-x)}$ is Adjusted Mean headway of a type x vehicle followed by a type x vehicle, $h_{A(c-c)}$ is Adjusted Mean headway of a car followed by a car

(Shalini and Kumar 2014) stated that headway ratio method is the most common used method among many existing methods for measuring PCUs at signalized intersections. However, (Yeung et al. 2015) stated the limitation of this methods that difficult in accurate field measurement of headway is difficult without using advanced tool and technique, difficult of sample collection for less proportion vehicles and difficult of data collection when lane discipline is not followed

2.2.2 Speed-based method

Chandra proposed this method to find PCU values of vehicles and he found that PCU is directly proportional to speed ratio and inversely proportional to the projected area ratio with respect to the standard vehicle as following equation

$PCU_i = (\frac{Vc/Vi}{Ac/Ai})$…………………… ……………………………………………… (2.3)

Where: V_i and V_c mean speeds of vehicle type 'i' and car respectively and A_i and A_c projected rectangular areas of vehicle type 'i' and car; on the road.

This method is better for estimating the PCU values of different vehicle under heterogeneous traffic for both interrupted and uninterrupted traffic condition (Chandra et al. 1997). And (Sharma and Biswas 2021) discussed that 'Speed Based Method' is the most popular approach to determine PCU when the traffic stream has a high degree of heterogeneity.

(Biswas et al. 2017; Biswas et al. 2020) justify that this method is simple, suitable for mixed traffic stream composed of any number of vehicle categories and has the ability to capture dynamic nature of PCU. However, projected rectangular areas of vehicles on road would be more logical and accurate (Raj et al. 2018).

2.2.3 Homogeneous Coefficient method

The speed, as well as the length of a vehicle considered to formulate the Homogeneous Coefficient (HCi) as follow:

$$PCU_i = \left(\frac{Li/Vi}{Lc/VC}\right) \qquad (2.4)$$

Where; Li is length of vehicle 'i' (meter), Vi is average speed of vehicle 'i' (Km/h), Lc is length of passenger car (meter) and Vc is average speed of passenger car (Km/h)

This method is proposed by Permanent International Association of Road Congress (PIARC) to determine 'Homogeneous Coefficient' which is PCU of a vehicle category present in a mixed traffic stream (Sharma and Biswas 2021). According to this study, even though the collection of parameters used in this method is easy, taking the average of speed and length of vehicles does not show its dynamic nature of vehicles and not enough to assess its interaction with other vehicles in mixed traffic.

2.2.4 Multiple Linear Regression Method

The number of vehicles type constituting the queue is counted, then regressed with base saturation flow which could occur during the period of analysis (Mohan and Chandra 2017). The form of regression model is given by

$Q_b\, t = n_{car} + \sum_{i=1}^{k} n_i * PCU_i$ ………………………………………………………….. (2.5)

Where; Q_b is the base saturation flow in PCE per unit time, t is the duration of counting, n_{car} and n_i are the respective number of cars and vehicle type i crossing the stop line during the time period t. Even this method is well suited for traffic streams composed of multiple vehicles, improper PCU value as regression coefficient can be negative value and it criticized based on the argument that speed is not always linear function of volume (Minh and Sano 2003).

2.2.5 Saturation flow ratio method

Knowing heavy vehicle adjustment factor (f_{HV}) multiplied with base saturation flow to calculate the saturation flow of mixed traffic recommended in HCM and proportion of heavy vehicles (P_{HV}) in the traffic stream is used to determine PCU value of heavy vehicle (Mohan and Chandra 2017), as equation (2.6).

$$f_{HV} = \frac{1}{1 + P_{HV}(PCU - 1)} \quad \text{……………………………………………………………… (2.6)}$$

However, the accuracy of this method is depending on high accuracy of saturation flow rate, which is difficult to calculate in heterogenous traffic stream.

2.2.6 Queue clearance rate method

(Mohan and Chandra 2016) developed Queue Clearance Rate (QCR) method for PCU estimation at unsignalized intersections operating under heterogeneous traffic conditions and later used it for signalized intersection for its advantage of not require the value of saturation flow. This method is based on the assumption that "the time taken by a queue of vehicle to clear a conflict area is the function of its composition and time spends in conflict area reflects its impacts on the capacity of the movement" (Mohan and Chandra 2017).

2.2.7 Simulation Technique

Simulation from microscopic through macroscopic is a computer-aided approach and becoming popular traffic modeling tool for analyzing various traffic operations and vehicular interactions in the last few decades (Arasan and Arkatkar 2010; Mehar et al. 2014). The model developed by computer simulation is replicating the behaviors of vehicles observed in the field and predict the traffic parameter used for estimating PCU values of vehicle categories.

Among available microscopic simulation program, " Germany developed Planning Transport Verkehr (PTV) Vissim is the leading microscopic simulation program for modeling multimodal transport operations and belongs to the Vision Traffic Suite software, Vissim is now being used worldwide by the public sector, consulting firms and universities"(PTV Group 2018). Simulation technique is effective method for any traffic condition since traffic and geometric condition can be controlled, but difficult to validate the model as it required real world data covering wide traffic and geometric condition (Yeung et al. 2015).

2.3 Static Versus Dynamic nature of PCU values

Many researchers conceptualized PCU as a static value which implies that the effect of a vehicle type on a traffic stream is the same across different location and traffic condition. However, a significant volume of studies, specifically in the last two decades, showed how it is dynamic in nature and varies with the change in traffic condition, road geometric, driver behaviors and other circumstances(Sharma and Biswas 2021). Similarly, the numbers of researchers justify the variation of PCU values with respect to traffic composition (Alecsandru et al. 2012; Bains et al. 2012; Praveen and Arasan 2013; Biswas et al. 2020), traffic volume (Bains et al. 2012; De Luca and Dell'Acqua 2014; Rao and Yadav 2018), LOS (Cunha and Setti 2011), road geometry which is road width (Chandra and Kumar 2003; Arasan and Arkatkar 2010; Shalkamy et al. 2015), gradients (Chandra and Kumar 2001; Rakha et al. 2007; Bains et al. 2012) and horizontal curvature (Shalkamy et al. 2015), Pavement unevenness (Chandra 2004), Weather condition (Alhassan and Ben-edigbe 2012; Subotić et al. 2016) and over time and location. Therefore, dynamic PCU values are widely applicable nowadays as many recent literatures concluded that each vehicles type has specific PCU value for specific traffic and roadway condition.

2.4 Works related with Passenger Car Unit determination

2.4.1 Recent studies across the globe

(Bomzon et al. 2021) determined the PCU values for mixed traffic conditions along 11 km stretch of the hilly road section in east Sikkim using speed-based methods. The researcher determined the PCU value for six vehicle groups namely two-Wheeler (TW), Standard Car (CS), Big Car (CB), Light Commercial Vehicles (LCV), Heavy Commercial Vehicles (HCV) and Bus(B). According to this study, two-wheeler has minimum PCU value and Big Car and Light Commercial Vehicles have almost the same PCU value. However, the author suggested that traffic conditions has less influence in PCU values specially when speed-area based method is used.

According to (Dhamaniya and Chandra 2016) the PCU values are not static, but vary with traffic volume and traffic composition. The researcher developed conceptual approach for estimating dynamic PCU on Urban Arterial Roads by Using Simultaneous Equations for five types of vehicles. The author developed general and quite equation to be used to derive the PCU values for different categories of vehicles using data from three major road segment section major metropolitan cities in India. However, these equations are only applicable to traffic situations like studied area.

(Bains et al. 2012) developed traffic flow model on Indian Expressways by evaluating Passenger Car Unit (PCU) of different vehicle categories at different volume levels in a level terrain using the micro-simulation model, VISSIM, evaluate capacity of expressways and to study the effect of vehicle composition on PCU values. The author found that, PCU decreases with increase in volume-capacity ratio irrespective of vehicle category and with increases own proportion in the stream. Finally, the author justified that the magnitude of PCU values of heavy vehicles such as buses, trucks, and light commercial vehicles in heterogeneous traffic in Indian expressways is higher than the static PCU value given by Highway capacity manual of 2000.

(Obiri-Yeboah 2014) determined the PCU for three vehicle categories namely cars, medium vehicles and trucks at signalized intersections within the Kumasi Metropolis in Ghana. The author used headway ratio method to develop PCU values which accurately represent the prevailing traffic mix, flow condition and effects of roadside friction using data collected from eleven pre-timed signalized intersections. According to this study, locally determined PCU values are larger than those adopted from other manual, hence the author concluded that PCU at local level is better and accurately represent the impact of local conditions.

2.4.2 Recent Local Studies

(Hordofa Tullu and Tucay Quezon 2021) determined the dynamic PCU values of urban road segment using speed-based method in Addis Ababa, Ethiopia for four vehicle types based on the variation of traffic volume and carriageway width. The author founded that the PCU values has increases as volume and carriageway width increases and PCU determined with local condition is higher than those provided in Highway Capacity Manual.

(Ararsa and Getu 2020) also conducted the study on capacity and passenger car unit estimation for heterogeneous traffic stream of trunk roads section outward to four directions from Addis Ababa, Ethiopia. The study determined the capacity of trunk road segment section, PCU value of 4WD, bus, truck and three-wheeler using Chandra's and Homogenization coefficient methods and analyze the variation of PCU values with respect to different interval of traffic volume. The result of the study was validated by microscopic simulation and concluded that the PCU values of all vehicles except three-wheeler was decreases as the volume of road sections increases. The author also founded that the capacity of road section based on local PCU value is lower than the value adopted in HCM 2010; hence, it is better to use locally determined dynamic PCU values instead of fixed value for different types of vehicles.

(Michael and Bikila 2019) developed local through traffic passenger car equivalents for small bus, large bus, truck and truck trailer on three 4-legged and one 3-legged signalized intersections in Addis Ababa, Ethiopia using headway ration method. The researcher found out the PCU values of vehicles type with respect to inner, middle and outer lane, and concluded that small bus and large bus has larger PCU in middle lane, truck has larger PCU value in inner lane whereas, track trailer has larger PCU value in outer lane. Finally, the authors recommended that local PCU value should get attention in capacity analysis and design of traffic infrastructures than adopted PCU value from HCM 2010.

(Girum and Bikila 2016) determined the passenger car equivalent for basic freeway segment on Addis Ababa – Adama expressway by considering trucks proportion, grade percentages, and length of grades using Equal Flow Density method. This study came up with the results that when the proportion of trucks and buses is from 10% up to 50%, the Passenger Car Equivalent increases as the proportion of trucks and buses decreases. The major variation observed in lower trucks and buses proportion non-linearly because the interaction between trucks and buses with passenger cars increases. Moreover, for trucks and buses proportions from 10 % up to 50 %, the value of PCE varies in between 1.4 up to 7.8 for upgrade up to 5 % which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0. For trucks and buses proportions of 10 %, the value of PCE varies with the length of grade in between 5.6 up to 7.8 for 5 % upgrade which is higher than the HCM 2010 recommended value that varies between 1.5 up to 3.0. Finally, the authors concluded that local Passenger Car Equivalents shows a better assumption than Passenger Car Equivalents on HCM 2010.

2.5 Summary of literature review and research gap

Many literatures are available regarding PCU values estimation across the world. Most of them has done in developed countries where there is less traffic heterogeneity and lane discipline is followed, unlike in Ethiopia. These literatures used different methodologies and local data to estimate PCU values. However, determined PCU values represent only traffic condition, roadway condition, driving behavior and location where it determined and similar with it. Therefore, this study fills the gap of 'proper PCU values' of different types of vehicles using analytical method (speed-based and headway method), validated with microscopic simulation analysis and optimized through optimization method.

Most literatures estimate the PCU values using analytical method specially speed-based and headway ratio method for segment and signalized intersection, respectively. Whereas, in recent decade few researchers used microscopic simulation analysis to determine PCU values. Analytical method is simple, quick, and required less data, but it cannot cover all dynamic nature of traffic stream with analytical equation and difficult to extract microscopic parameters of the traffic stream. While, microscopic simulation needs large data and enabled to simulate all traffic nature on field and possible to extract microscopic parameters for further analysis. But the overall simulation software parameters should be calibrated to local traffic condition, hence it required huge traffic data. The author of this study used both analytical method and microscopic simulation method, and applied new concept of optimization technique to optimize the values of PCU that can properly represents local roadway condition.

CHAPTER THREE

Research Methods and Materials

3.1 Study period and Area

This study was carried out in Jimma city, for six months from January, 2023 to June, 2023 G.C. Detail information about study area is here in below.

Jimma city locates in Oromia national regional state of Ethiopia. It locates at about 352 kilometers from Addis Ababa, the capital city of the country, in the southwest direction of the country. It locates at an elevation of 1718 to 2000 meters above mean sea level, has an average maximum temperature that ranges from 20 to 30 °C and an annual rainfall that ranges from 800 to 2500 mm. The city has a population of 120,960, according to the Ethiopia central statistical agency (CSA) census report of 2007. According to the recent information stated in (Sorsa et al. 2020), the population of Jimma town is 207,573.

Jimma City faces increasing transportation demand due to rapid economic development and urbanization. The main contribution factors are agricultural products makes the investors mobilizing to the area, proximity to Bonga regional capital city, construction of Gilgel-Gibe (i – v) mega project, development of Koisha Park around 150km from Jimma, and extraction of coal mining around 80km from jimma are some pillar contributors to rapid urbanization of the city. It is the main corridor in southwest direction of the country as the major road from Addis Ababa toward Bonga; southwest regional capital town, Mizanteppi, Beddelle, Matu and Gambella; Gambella regional capital town passes through the city.

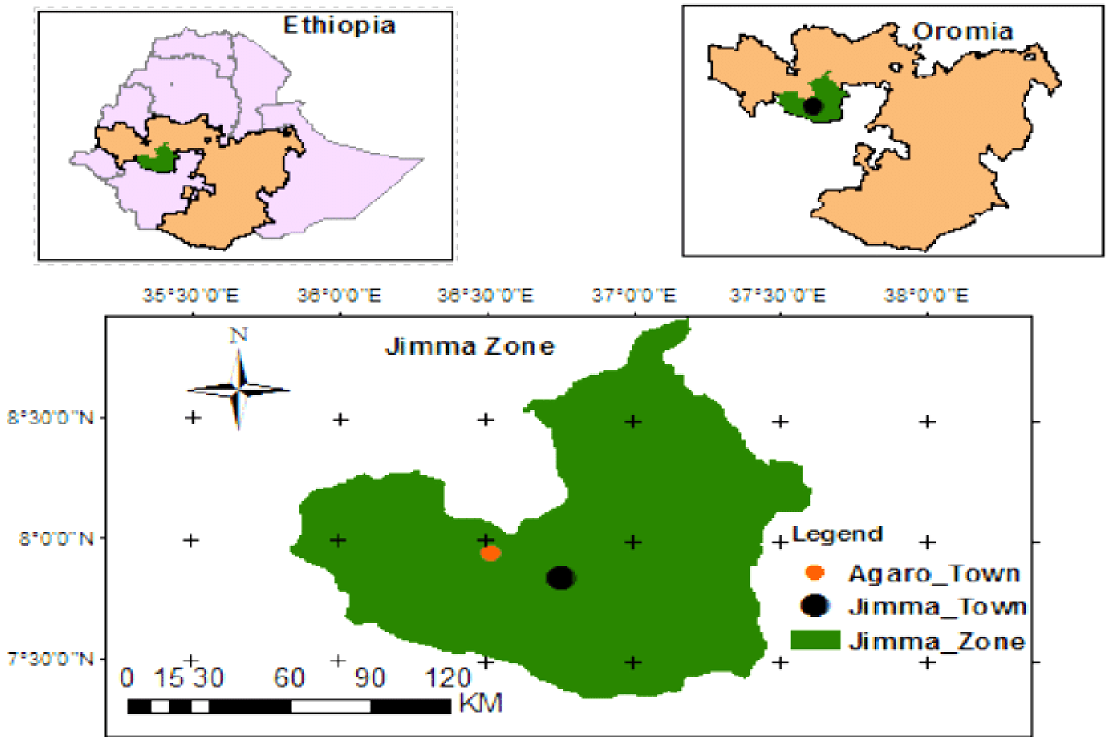


Figure 3.1: Study area map. (Source: Municipal administration of Jimma Zone)

3.2 Study design

The research approach applied to this study was quantitative in nature and figure 3.2 shows the flow of the activities to achieve the goal of the study which was the estimation of passenger car unit with incorporating a local roadway condition.

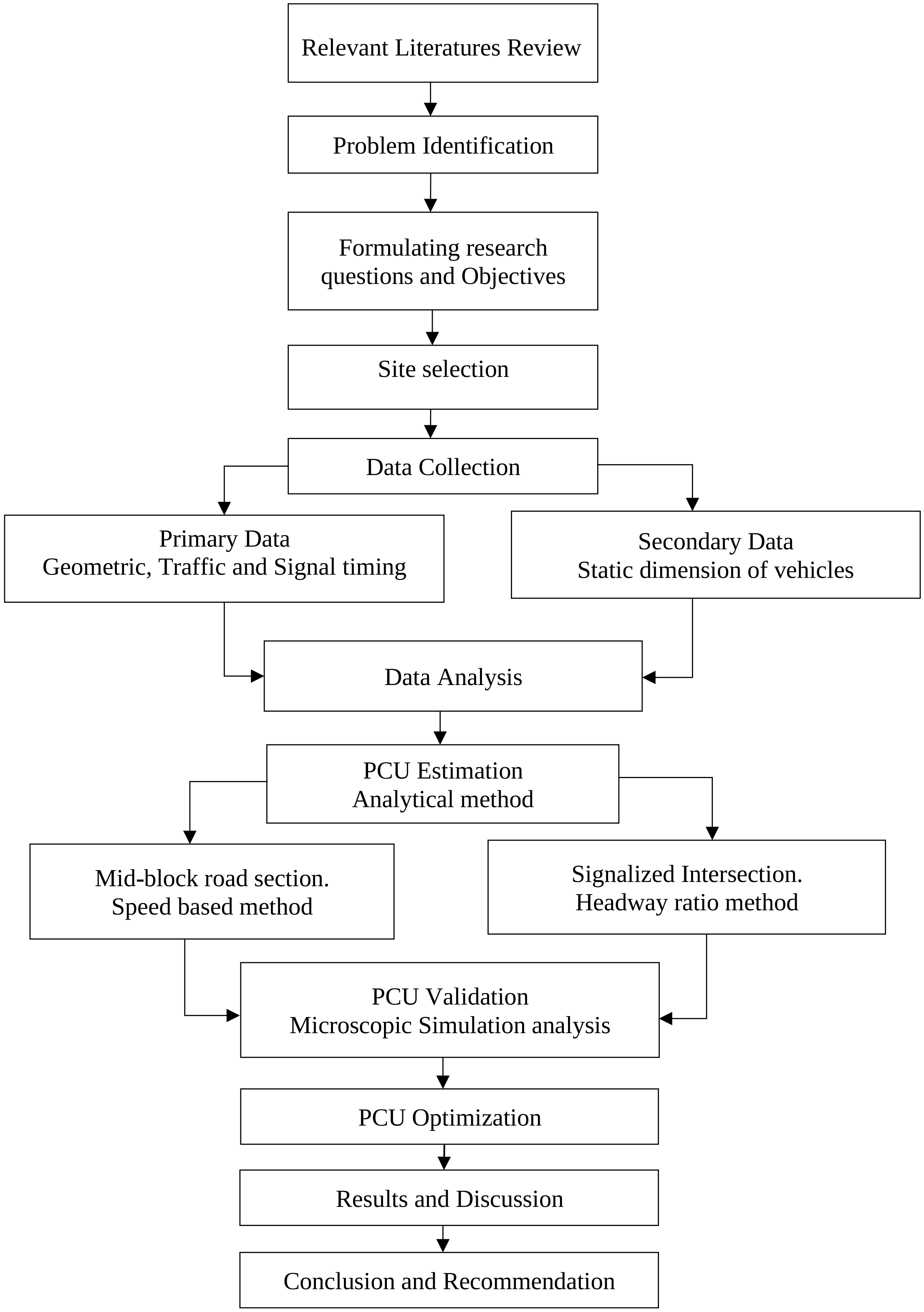


Figure 3.2: Research flow chart

3.3 Population

Jimma urban roadway system and different types of automobile vehicles used the roadway during traffic data collection were considered as study population.

3.4 Identification of data collection sites

The author selected study sites based on purposive sampling technique in which certain important criteria considered. Accordingly, the sites selected are nearly free from surface deterioration, good mix of traffic stream, flat gradient, no long-time parking allowed in the proximity and minimum pedestrian effect. The researcher selected representative sites in the procedure of; total signalized intersections and possible mid-block road segments were identified, the signalized intersections and mid-block road sections that fulfill predefined criteria were identified. Finally, two representative pre-timed signalized intersection with four approaches and two mid-block road section having similar characteristics with 500-meter length were selected as data collection sites.

3.4.1 Mid-block road section

The (HCM 2010) defines six main types of roadway system elements; these are points, segments, facilities, corridors, areas, and systems. "A segment is the length of roadway between two points". According to this manual, urban streets are designed to accommodate longer trips. The author of this study selected two urban street segments; Ajip and Bore road as representative sample site for midblock road section. Ajip midblock road section is the results of two merging routes, it is the corridor of Addis Ababa exiting and entering. Whereas, Bore midblock road section is one of the major road in Jimma city, in which different types of vehicle passes through it to Bonga Southwest regional capital city, Mizanteppi and different mega project sites. Therefore, these two samples were rich in traffic heterogeneity.

3.4.2 Signalized Intersection

The author of the study considered two representative signalized intersection; Central Hotel and Fayid gas station for data collection at signalized intersection. These intersections are the major intersection in city, where two major road East- West and North- South roads are crosses each other. The distance between them is 232-meter from end to end. Each intersection has four approaching legs and regulated by independent pre-timed traffic control. Central Hotel signalized intersection has bypass in northwest approach which used as right turning lane.

(HCM 2010b) described two analysis methodology; evaluating entire facility together and evaluating individual intersection in isolation form. Signalized intersection analyzed as isolation form if either the nearest upstream signalized intersection is sufficiently distant from the subject intersection or the subject signalized intersection is not coordinated with the upstream signal.

Even though, both signalized intersections are not sufficiently far enough, they are not coordinated with each other's. Hence, the signalized intersection operates in isolation from nearby intersections. The influence of an upstream signalized intersection on the subject intersection is addressed by the uniformity of arrivals on a cyclic basis. Subjected signalized intersection is effectively isolated from influence of upstream signalized intersections. Flow at subjected signalized intersection is effectively random over the cycle and without a discernible platoon pattern evident in the cyclic profile of arrivals. Therefore, the signalized intersection was analyzed as an isolation form.

(a) Central Hotel and Fayid gas station signalized intersection

(b) Ajip midblock road section

Figure 3.3: Study area from google map

3.5 Study variables

The variables in this study classified into two main groups which is dependent variables and independent variables.

Dependent variables are:

- ✓ Passenger car unit (PCU) values

Whereas, independent variables are:

- ✓ Vehicle types
- ✓ Vehicles static dimension (Length and Width)
- ✓ Traffic volume
- ✓ Traffic speed
- ✓ Time Headway
- ✓ Road geometry (Lane, length, width and gradient)
- ✓ Signal timing

3.6 Sampling size

(Wray 2013) discussed that the sample size of traffic volume is mainly depends on purpose of study and varies from fraction of hour to 24 hours, a day to 365 days a year. Four hours traffic volume from four day a week which is three hours from week day and 1 hour from weekend were used in this study. The total traffic volume of 4324 vehicles and 7282 vehicles were collected at both midblock and signalized intersection, respectively during peak hour of 6:00 to 7:00 am local time.

Similarly, it discusses that the sample size of traffic speed with a rule of thumb, at least 100 speeds collected during traffic data collection. This will generally provide mean or 85th percentile speeds within ± 1 kph with 95% confidence. Since the exact population during study is not known, traditional sample size determination using 95% confidence interval (Z-value = 1.96, standard deviation σ = 0.5 and margin of error e = 0.05), the sample size N is 385 vehicles for speed using equation (3.1)

$$N = \left(\frac{Z*\sigma}{e}\right)^2 \quad (3.1)$$

Accordingly, the author collected total 4324 vehicles and 7282 vehicles at midblock and signalized intersection which is more enough than defined sample size.

3.7 Research Materials

The following common instrument and software were used for data collection and data analysis in this study.

3.7.1 Instrument

Measuring tape, portable digital camera with tripod were used for data collection

3.7.2 Software

PTV VISSIM 2022, Statistical tool (excel), Microsoft Office, EdrawMax 10.5.0 and Google Earth were used in this study for data analysis and documentation

3.8 Data Collection method

Research data required to achieve the objective of this study were collected from primary source and secondary source. Primary data collected through video recording, observation and direct measurement on site. These data included geometric data (lane width, number of lanes, gradient, length), traffic data (volume, speed), headway data and signal timing. Whereas secondary data mainly vehicle's static dimension and classes collected from related literature and standard specification.

3.8.1 Geometric and signal timing

Road geometric data (length, width of lane, number of lane and gradient) for each section and signal timing for signalized intersection were collected through measurement using measuring tape, recording geographic coordinates and observation on the site.

The length of urban streets should longer enough to incorporate the variation of traffic data along the streets. The author of this study fixed the total length of midblock section to 500-meter end to end and collected average traffic data at equal trap length of 50-meter. The researcher determined the gradient of midblock road as the ratio of end-to-end point's elevation difference to distance between them.

According to (HCM 2010b), approaching gradient at signalized intersection measured from stop line to a point not less than 30.48m (100ft) upstream along line parallel to the direction of travel. Accordingly, the author of this study determined approaching grade at 50-meter from stop line along each approach. It is the ratio of elevation difference from geographic coordinate to 50-meter distance between the point. An uphill condition has a positive grade, and a downhill condition has a negative grade. According to this manual, the road having gradient less than 2% is considered as flat terrain.

The length of analysis for signalized intersection is depends on expected queue to occurs during the study period and the influence length should extended at least 76-meter (250ft) back from stop line on each intersection leg (HCM 2010b). Accordingly, the author of this study analyzed signalized intersection at 100-meter from stop line along each intersection leg.

Table 3.1: Geometric and signal timing data

(a) Mid-block segment geometric data

S/N	Segment ID	Trap length	Longitudinal grade (%)	Number of lanes	Through lane	Average width of lane (m)	Width of Median
1	Ajip	50m	1.31 (+, -) < 2	4	2	3.65	Undivided
2	Bore	50m	1.60 (+, -) < 2	4	2	3.50	Undivided

(b) Signalized intersection data

S/N	Name of Intersection	Approach direction	Approach Grade (%)	No of approach lane	No of through lane	Average width of lane	Green Time (sec)	Yellow Time (sec)	Red Time (sec)
1	Central Hotel	EB	0 < 2	2	2	3.5	35	3	111
		WB	0 < 2	2	2	3.5	40	3	106
		NWB	-1.5 < 2	2	2	3.5	25	3	121
		SEB	1.2 < 2	2	2	3.5	25	3	121
2	Fayid gas station	EB	0 < 2	2	2	3.65	30	3	101
		WB	0 < 2	2	1	3.25	30	3	101
		NB	-0.8 < 2	2	2	3.5	25	3	106
		SB	1 < 2	2	2	3.5	25	3	106

EB: east bound, WB: west bound, NB: north bound, SB: south bound, NWB: northwest bound, SEB: south east bound

3.8.2 Traffic data

Vehicle classes, traffic volume, traffic speed, projected area of the vehicles and time headway are the basic traffic data required for PCU values estimation at mid-block road section and signalized intersection using Chandra's and Headway ratio method, respectively. These traffic data were collected for four days of the week; Monday, Wednesday, Thursday and Saturday during peak hour from 6 am to 7 am local time under dry weather condition. This peak hour is not only when the maximum flow occurs in a day, but also when good traffic heterogeneity is present in a day.

To ensure traffic data accuracy and incorporate speed variation and volume variation, total length of midblock section was divided into 10 equal trap length of 50m. Hence average speed along each trap length was used for data analysis. Portable digital camera was setup at proper position to records the movement of vehicular traffic in both direction and identify vehicular categories, determine traffic volume, traffic speed and composition of traffic stream over the entire length of midblock.

Recorded video has played on video play media and manual data extraction was carried out in which travel time of each vehicle was calculated from the time difference between entry of pre-defined trap length and end of trap length. Then, using travel time and predefined distance, the speed of each vehicle was determined. Hence, the speed of vehicle and physical dimension of the vehicles were used in the determination of passenger car unit at selected mid-block road sections.

The researcher carried out traffic analysis in both travel direction together to recognize the interaction between vehicles in both directions. (HCM 2010b) discussed on analysis of automobile performance, that an analysis of only one travel direction does not adequately recognize the interactions between vehicles at the boundary intersections and their influence on segment operation.

Table 3.2: Traffic data at mid-block road section.

Segment ID: Bore Road. Trap length = 50m						
Vehicle classes	Max. Flow (Veh./15min)	PHF	Flow (Veh./Hr)	Avg. travel time (Sec.)	Avg. speed (m/sec)	Traffic Composition (%)
P. Car	39	0.78	201	10.4	4.82	10.6
4WD	50	0.89	226	10.3	4.86	11.90
Bus	9	0.83	43	9.6	5.21	2.3
Truck	23	0.86	107	10.6	4.73	5.7
3Wheeler	312	0.95	1317	11.0	4.56	69.50
Segment ID: Ajip Road. Trap length = 50m						
P. Car	83	0.88	379	11.4	4.40	16
4WD	68	0.85	320	11.2	4.46	13
Bus	15	0.55	109	10.1	4.93	4
Truck	29	0.83	140	11.0	4.55	6
3Wheeler	346	0.93	1481	11.7	4.26	61

In the case of signalized intersections, vehicular movement; traffic flow, discharge speed and roadway interactions were collected at influence length of 100m extend back from stop line. Traffic flow, vehicle discharge speed and time headway during effective green phase were extracted from recorded video along each approaches separately. Detail traffic data within 15-minute time interval, percentage of through traffic, turning right and turning left are attached at appendix-A.

Table 3.3: Traffic data at signalized intersection.

Intersection ID: Central Hotel Signalized intersection						
Approach Name	Vehicle classes	Max. Flow (Veh,/15min)	PHF	Flow (Veh./hr)	Composition. (%)	Discharge speed (m/s)
Ajip	3Wheeler	188	0.89	690	63	4.37
	Car	30	0.85	141	13	4.29
	4WD	33	0.81	163	15	4.50
	Bus	8	0.66	49	4	4.24
	Truck	10	0.73	55	5	5.84
Merkato	3Wheeler	171	0.98	695	67	3.57
	Car	31	0.98	127	12	3.92
	4WD	30	0.89	135	13	4.03
	Bus	5	0.55	36	4	4.10
	Truck	8	0.72	45	4	4.43
Awetu	3Wheeler	142	0.96	594	69	3.84
	Car	16	0.84	76	9	4.07
	4WD	22	0.89	99	12	4.57
	Bus	6	0.54	44	5	3.84
	Truck	7	0.61	46	5	4.39
Bore	3Wheeler	124	0.98	508	67	3.58
	Car	18	0.83	86	11	4.18
	4WD	18	0.88	82	11	4.07
	Bus	4	0.56	28	4	3.96
	Truck	11	0.75	59	8	4.39
Intersection ID: Fayid Signalized intersection						
Ajip	3Wheeler	171	0.88	629	64	3.98
	Car	23	0.88	104	11	4.04
	4WD	26	0.83	126	13	4.31
	Bus	10	0.65	62	6	4.11
	Truck	12	0.73	66	9	5.41
Merkato	3Wheeler	151	0.99	611	66	3.25
	Car	27	0.96	112	12	3.64
	4WD	25	0.88	114	12	3.86
	Bus	6	0.58	41	4	3.97
	Truck	9	0.75	48	5	4.11
Central Hotel	3Wheeler	143	0.92	624	71	3.50
	Car	13	0.81	64	7	3.78
	4WD	19	0.87	88	10	4.38
	Bus	7	0.57	49	6	3.72
	Truck	8	0.66	49	6	4.07
Bore	3Wheeler	114	0.95	479	65	3.26
	Car	16	0.80	80	11	3.88
	4WD	17	0.87	78	11	3.90
	Bus	6	0.67	36	5	3.83
	Truck	12	0.77	62	8	4.07

3.8.3 Headway data

Vehicle classes, traffic volume and time headway of the traffic discharge during green time interval are the basic data required to estimate PCU of vehicles at signalized intersection using headway ration method.

Headway data collection was done as per (HCM 2010) requirement, which is “saturated headway at signalized intersection is measured when at least eight vehicles in queue”. In Jimma city, the lane discipline is not followed, the vehicles are discharge close together during green time interval at signalized intersection. This makes headway method difficult to extract time headway between the existing vehicles just crossing stop line. To overcome this difficulty, the researcher aggregated total width of approaching lane to equivalent occupancy of three-wheeler and unique headway extracted from playing recorded video on playback media with great caution to ensure data quality. Extracted headway for vehicles, Car followed by car (hc-c), car followed by subjective vehicle (hc-x) and subjective vehicle followed by car (hx-c) are summarized as table 3.4 for central hotel intersection whereas, Fayid intersection is attached in appendix B.

Table 3.4: Traffic headway at signalized intersection.

Intersection ID: Central Hotel.							
Leg	Vehicle category	Headway category	No of Cycle	Flow (Veh. /hr.)	Flow used	Flow Rejected	Headway (Unadjusted)
Ajip	Car	Average $h_{C\text{-}C}$	25	141	98	59	3.5
	4WD	Average $h_{4W\text{-}4W}$	25	163	114	70	4.5
		Average $h_{C\text{-}4W}$	25	68	54	14	9.2
		Average $h_{4W\text{-}C}$	25	47	40	7	4.5
	Bus	Average $h_{B\text{-}B}$	25	49	20	19	11.6
		Average $h_{C\text{-}B}$	25	21	16	5	6.9
		Average $h_{B\text{-}C}$	25	32	24	8	8.1
	Truck	Average $h_{T\text{-}T}$	25	55	38	17	13.2
		Average $h_{C\text{-}T}$	25	48	30	18	6.6
		Average $h_{T\text{-}C}$	25	42	32	10	10.0
	3Wheeler	Average $h_{3W\text{-}3W}$	25	690	516	174	2.2
		Average $h_{C\text{-}3W}$	25	109	80	29	2.5
		Average $h_{3W\text{-}C}$	25	98	80	18	1.9
Merkato	Car	Average $h_{C\text{-}C}$	25	127	100	65	5.0
	4WD	Average $h_{4W\text{-}4W}$	25	135	90	51	6.2
		Average $h_{C\text{-}4W}$	25	101	87	14	5.9
		Average $h_{4W\text{-}C}$	25	67	54	13	4.9
	Bus	Average $h_{B\text{-}B}$	25	36	18	17	16.0
		Average $h_{C\text{-}B}$	25	22	14	8	8.7
		Average $h_{B\text{-}C}$	25	18	12	6	8.2
	Truck	Average $h_{T\text{-}T}$	25	45	30	15	17.8
		Average $h_{C\text{-}T}$	25	36	24	12	6.3
		Average $h_{T\text{-}C}$	25	28	18	10	7.0
	3Wheeler	Average $h_{3W\text{-}3W}$	25	695	604	200	2.3
		Average $h_{C\text{-}3W}$	25	87	70	17	3.3
		Average $h_{3W\text{-}C}$	25	68	56	12	3.5

Leg	Vehicle category	Headway category	No of Cycle	Flow (Veh./hr.)	Flow used	Flow Rejected	Headway (Unadjusted)
Awetu	Car	Average h $_{C-C}$	25	76	68	8	2.9
	4WD	Average h $_{4W-4W}$	25	99	84	15	3.6
		Average h $_{C-4W}$	25	56	50	6	8.0
		Average h $_{4W-C}$	25	48	37	11	7.0
	Bus	Average h $_{B-B}$	25	44	36	8	9.5
		Average h $_{C-B}$	25	32	20	12	8.0
		Average h $_{B-C}$	25	28	20	8	10.0
	Truck	Average h $_{T-T}$	25	46	33	13	10.3
		Average h $_{C-T}$	25	31	25	6	3.2
		Average h $_{T-C}$	25	34	24	10	2.2
	3Wheeler	Average h $_{3W-3W}$	25	594	502	92	1.8
		Average h $_{C-3W}$	25	54	44	10	2.5
		Average h $_{3W-C}$	25	64	50	14	3.0
Bore	Car	Average h $_{C-C}$	25	86	80	6	3.3
	4WD	Average h $_{4W-4W}$	25	82	72	10	4.4
		Average h $_{C-4W}$	25	72	60	12	3.2
		Average h $_{4W-C}$	25	74	58	16	2.5
	Bus	Average h $_{B-B}$	25	28	21	7	10.0
		Average h $_{C-B}$	25	17	12	5	9.0
		Average h $_{B-C}$	25	16	13	3	7.0
	Truck	Average h $_{T-T}$	25	59	50	9	12.0
		Average h $_{C-T}$	25	46	38	8	9.0
		Average h $_{T-C}$	25	41	30	11	11.0
	3Wheeler	Average h $_{3W-3W}$	25	508	460	48	2.1
		Average h $_{C-3W}$	25	73	61	12	3.5
		Average h $_{3W-C}$	25	67	54	13	4.0

3.8.4 Vehicle's data

As per (Ethiopian Roads Authority 2013) motorized vehicles are classified into thirteen classes as table 3.5 and the researcher focused on finding the PCU values of vehicle which is aggregated to simpler classification for study purpose mainly three-wheeler (TVES /Bajaj), car (Passenger cars and taxis), 4Wheel drive (Pick-up, minibus, Land Rovers, Land Cruisers), bus (Small bus, Bus/coach) and truck (2-axled, to 6-axled truck). Static dimensions of vehicles used to determine projected area of corresponding vehicle was taken from standard manufacturing specification and related literatures.

Table 3.5:Vehicular classification (Source: ERA 2013, flexible pavement design P 2.3)

Class	Type	Axles	Description
1	Car	2	Passenger cars and taxis
2	Pick-up/4-wheel drive	2	Pick-up, minibus, Land Rovers, Land Cruisers
3	Small bus	2	≤ 27 seats
4	Bus/coach	2	> 27 seats
5	Small truck	2	≤ 3.5 tonnes
6	Medium truck	2 or 3	3.5 – 7.5 tonnes
7	Large 2-axled truck	2	> 7.5 tonnes
8	3-axled truck	3	>7.5 tonnes
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	*: (Not needed for definition)

The author of this study collected average static dimensions of vehicle classes (length and width), used in rectangular area determination and microscopic simulation analysis, from relevant literatures and standard specification of each vehicle as summarized in table 3.6.

A = L*W …………………………………………………………………………..(3.2)

Where; A: projected rectangular area of vehicle category in meter square, L and W are average length and width of vehicle category in meter respectively.

Table 3.6: Average physical dimension of vehicles

Vehicle types		3Wheeler	Car	4WD	Bus	Truck
(Ararsa and Getu 2020)	L (m)	2.60	3.7	4.70	9.05	9.84
	W (m)	1.20	1.6	1.80	2.35	2.37
(Raj et al. 2019)	L (m)	3.20	3.72	-	10.10	-
	W (m)	1.40	1.44	-	2.43	-
(Srikanth and Mehar 2017)	L (m)	3.20	3.72	-	9.05	7.50
	W (m)	1.30	1.44	-	2.35	2.42
Specification	L (m)	2.64	4.31	4.91	9.51	10.74
	W (m)	1.30	1.71	1.84	2.40	2.52
Average dimension for this Study	L (m)	2.91	3.86	4.81	9.43	9.36
	W (m)	1.30	1.55	1.82	2.38	2.44
Rectangular Area	A(m^2)	3.78	5.98	8.75	22.46	22.81

3.9 Data Analysis method

Among different analytical methods used for PCU estimation in literatures, speed-based method and headway ratio method are the most common method at mid-block road section and signalized intersection, respectively. Microscopic simulation method is also popular traffic modeling tool for analyzing various traffic operations and vehicular interactions was used in this study to validate the PCU value determined with analytical methods. Finally, Optimization method is applied to optimize PCUs determined analytical to base flow determined in microscopic simulation analysis.

3.9.1 Speed-based method

In this study Speed-based method has adopted to determine the passenger car unit of individual vehicle at mid-block road section under study. This method is proposed by Chandra and found that the speed-based method is better for estimating the PCU values of different vehicle under heterogeneous traffic for both interrupted and uninterrupted traffic condition (Chandra et al. 1997). (Ararsa and Getu 2020) is also uses speed-based method to determine PCU values at road segment and conclude the method is far more reliable than other methods.

(Sharma and Biswas 2021) discussed that 'Speed Based Method' is the most popular approach to determine PCU when the traffic stream has a high degree of heterogeneity. This method uses relative speed and projected area. It was realized that consideration of 'influence area' of individual vehicles in place of its 'physical area' will be more appropriate and may lead to more accurate estimation of PCU.

According to this method, PCU is directly proportional to speed ratio and inversely proportional to the projected area ratio with respect to the standard vehicle equation 2.3. The projected rectangular area of vehicle is determined from average similar vehicles and average width of similar vehicles at the place using equation 3.2.

3.9.2 Headway method

In case of signalized intersection, headway ratio method has used in this study to determine the passenger car unit of individual vehicles under study. (HCM 2010a) defined headway as "the time between two successive vehicles as they pass a point on the roadway, measured from the same common feature of both vehicles (for example, the front axle or the front bumper". In this method, headways of the vehicles crossing the stop line of the intersection are used to calculate the PCU values.

(Shalini and Kumar 2014) discussed that the headway ratio method is the most used method for measuring PCEs at signalized intersections. It 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 and speed characteristics through a single parameter" (Saha et al. 2009).

(Bhattacharya and Mandal 1980), (Saha et al. 2009), (Sarraj 2012) used this method to determine PCU at signalized intersection. And (Asaithambi et al. 2017) modified and developed the condition to be satisfied given in equation 2.1 to use headway method for PCU determination. For the headway that do not fulfil the condition, a corrective factor (C) using the least square method is applied and it is given by: -

$$C = \frac{abcd\,(w-x-y-z)}{abc + abd + acd + bcd} \quad \text{......(3.3)}$$

Where; a: Number of headways for car following car, b: Number of headways for car following type x vehicle, c: Number of headways for type x vehicle following car, d: Number of headways for type x vehicle following type x vehicle; w = Mean headways for car following car; x = Mean headways for car following type x vehicle; y = Mean headways for type x vehicle following car; z = Mean headways for type x vehicle following type x vehicle.

Then the adjusted mean headways calculated as:

$$h_{A\,(c\text{-}c)} = U - \frac{C}{Number\ of\ headways\ car\ following\ car} \quad \ldots(3.4)$$

$$h_{A\,(x\text{-}x)} = U - \frac{C}{Number\ of\ headways\ vehicle\ type\ X\ following\ Vehicle\ type\ X} \quad \ldots(3.5)$$

Where; $h_{A(c\text{-}c)}$ = Adjusted mean headways for car following car; $h_{A(x\text{-}x)}$ = Adjusted mean headways for vehicle type x following vehicle type x., U = Uncorrected mean headway and C= Correction factor.

Hence; PCU of a vehicle is calculating by:

$$PCU_{x\text{-}x} = \frac{h\ A(x-x)}{h\ A(c-c)} \quad \ldots(3.6)$$

Where; $PCU_{x\text{-}x}$ is Passenger Car Unit of vehicle x type.

3.9.3 Microscopic simulation analysis

Microscopic simulation analysis using PTV Vissim was carried out to validate the PCU values estimated using speed-based method and headway ratio method at mid-block road section and signalized intersection, respectively. It gives us the advantage of replicating the reality of traffic condition on field that shows the dynamic variation of traffic characteristics with respect to time, composition, geometric, driving characteristics and simultaneous interactions of traffic stream (Bains et al. 2012). The author calibrated the simulation software PTV Vissim 2022 to macroscopic traffic stream parameter; speed with four-hour heterogeneous traffic data collected from four sample sites. The researcher used two macroscopic parameter output; speed and base flow from Vissim software simulated for 3600 seconds. Speed used to validate the base model developed to replicate field conditions; whereas, a base flow under the assumption of "All are car" traffic condition used to validate PCU value determined analytically.

(Mohan and Chandra 2017) validated the accuracy of determined PCU value by comparing the equivalent traffic flow with base capacity value resulted from simulation. The base model that replicating the field condition was developed as shown in figure 3.4.

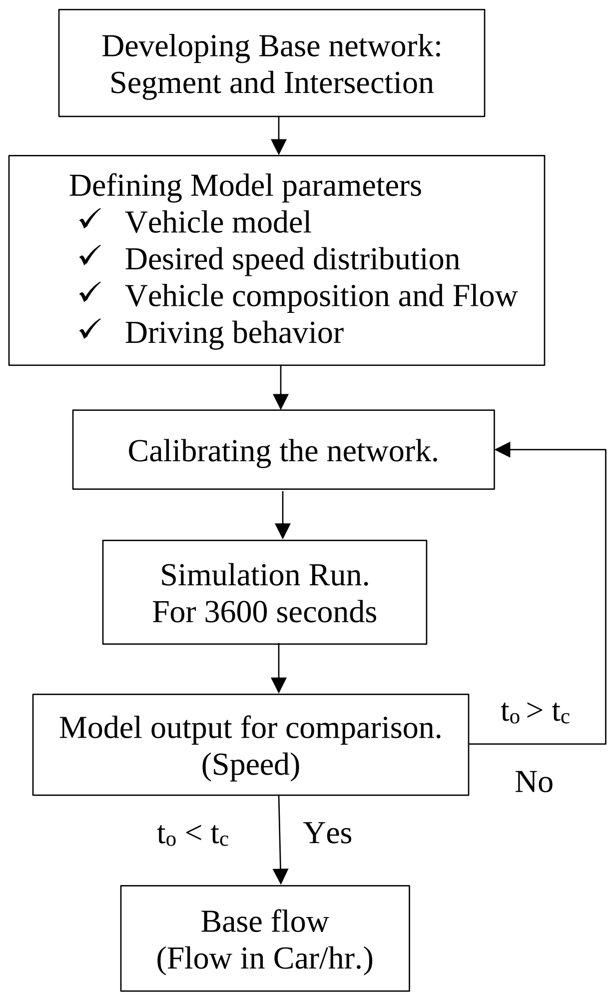


Figure 3.4: Base model development flow chart

Where; t_0 and t_c are t-statistical test parameters; null hypothesis value and critical value, respectively at 95% of confidence interval and 5% of standard error.

3.9.3.1 Developing base model

A model that accurately represents the design and operational characteristics of the study in simulation software is known as the 'base model' (Bains et al. 2012). The two basic element of this infrastructure modeling in VISSIM are links and connectors. The author developed a base model of midblock road section having the length of 500-meter, two-way major road with two lanes of 3.65m average width and maximum longitudinal gradient of 1.31% in Vissim software.

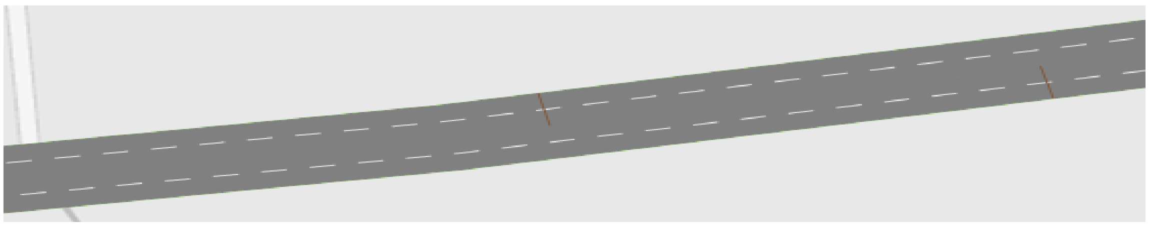


Figure 3.5: Midblock base model

In case of signalized intersection, the author developed four-legged pre-timed signalized intersection with two lanes of 3.50m average width and maximum approaching gradient of 1.5% along northwest bound. The model tested at 100-meter of approaching length from stop line along each approaching direction. East bound and West approaching are divided configurations, whereas southeast and northwest approaching are undivided configurations. The signal cycle time is 149s; amber time of 3s and green time of 40s for westbound, 35s for eastbound and 25s for southeast and northwest bound.

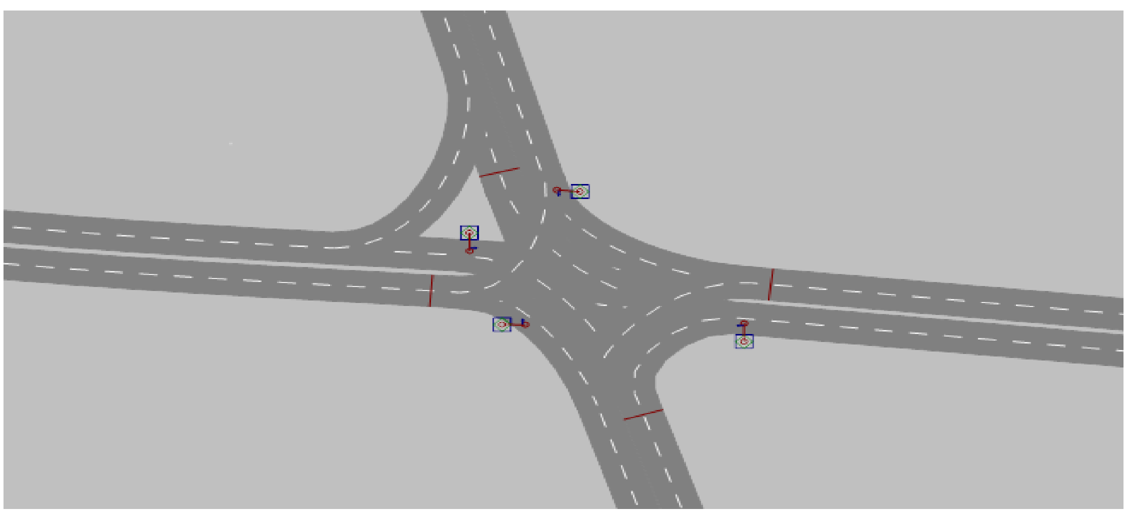


Figure 3.6: Signalized intersection base model

3.9.3.2 Model Parameters

PTV Vissim has three main building blocks, among these blocks the main traffic parameters considered as input for model simulation are discussed in following section.

Vehicle model: includes vehicle classes given in table 3.5 and physical dimensions of the vehicles given in table 3.6 were considered in Vissim.

Desired speed distribution: It is the maximum speed, minimum speed and the distribution nature between these values, defined graphically. The graph is generally ‘S’ shaped curve and it is the basic input parameters for Vissim calibration (Bains et al. 2012). In case of signalized intersection, the average speed distribution of each approach was used in software calibration. The desired speed distribution sample for bus and car at midblock and intersection, respectively defined in software as shown in figure 3.7

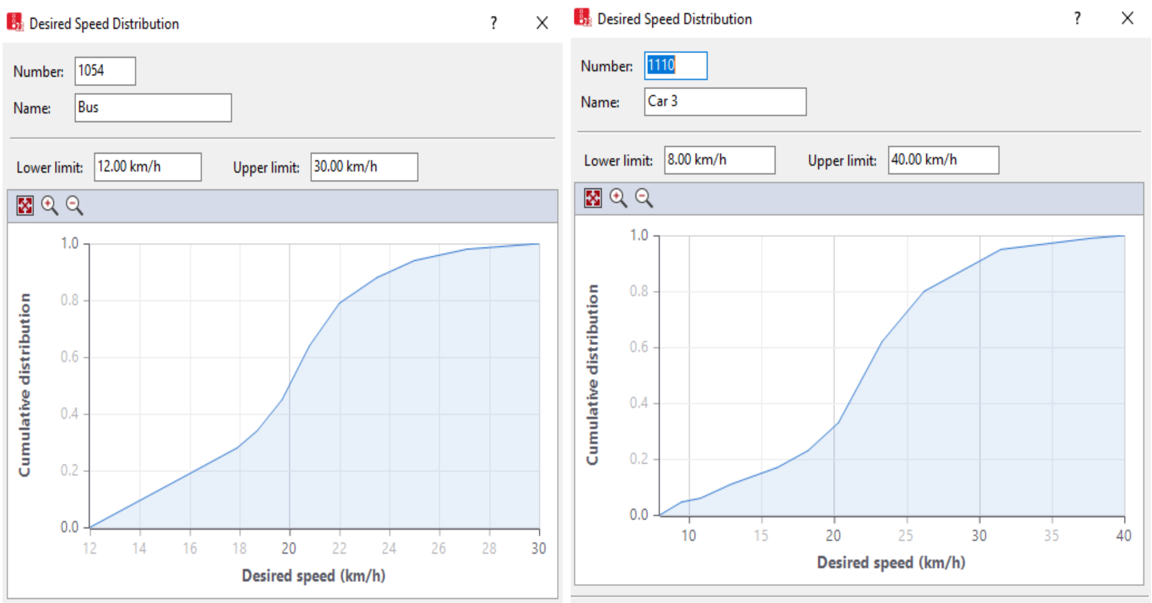


Figure 3.7: Sample speed distribution graph of bus and car

The desired speed distribution of all vehicle categories was defined in Vissim for each vehicle categories separately. Summary of maximum limit, minimum limit and desired speed shown in table 3.7 and graphical distribution is attached in appendix-G.

Table 3.7: Desired speed distribution input

Road section	Vehicle class	Max Speed (kph)	Min Speed (kph)	Desired speed (kph)
Midblock segment	3Wheeler	23	9	15.35
	Car	23	8	15.83
	4WD	23	12	16.06
	Bus	30	12	17.74
	Truck	30	8	16.37
Signalized Intersection	3Wheeler	27	11	13.83
	Car	40	8	14.81
	4WD	27	8	15.45
	Bus	28	9	14.52
	Truck	30	10	17.14

Vehicle composition and its flow: Vehicle flow and its composition on field stated in table 3.2 and 3.3 was given as an input to simulation model.

Driving behavior characteristics: The driving behavior characteristics consists two main modeling features, car-following behavior and lateral distance behavior. Car-following model has the parameters safety distance during standstill, gap time distribution and others. The lateral distance model consists mainly the minimum lateral distance of vehicles during standing and moving at desired speed. The psycho-physical driver behavior based Wiedermann-99 Car-following model was used for simulating the vehicle following behavior and all parameters of both models were given as inputs in simulation for each vehicle types separately. Ten parameters of Wiedermann-99 Car following model are:

Standstill distance (CC0)

Gap time distribution (CC1)

Following distance oscillation (CC2)

Threshold for entering following (CC3)

Negative speed difference (CC4)

Positive speed difference (CC5)

Distance dependency of oscillation CC6

Oscillation acceleration (CC7)

Acceleration from standstill (CC8)

Acceleration at 80kmp (CC9)

(Mehar et al. 2014) found that Vissim is sensitive to two parameters among ten Wiedermann-99 driving behavior parameters, they are CC0 and CC1. Therefore, CC0 and CC1 were modified for each vehicle and default values are used for the others. 0.4m and 1.2m minimum lateral distances between vehicles at standing and travelling at 50 km/h were used as input in Vissim simulation respectively.

Table 3.8: Car following model parameter input

Parameters	Calibrated CC0, CC1				
	3Wh	Car	4WD	Bus	Truck
CC0 (m)	1	1.5	1.5	1.32	1.32
CC1 (s)	0.5	0.9	0.9	1.5	2
CC2 (m)	4	4	4	4	4
CC3	-8	-8	-8	-8	-8
CC4	-0.35	-0.35	-0.35	-0.35	-0.35
CC5	0.35	0.35	0.35	0.35	0.35
CC6	11.44	11.44	11.44	11.44	11.44
CC7 (m/s^2)	0.25	0.25	0.25	0.25	0.25
CC8 (m/s^2)	3.5	3.5	3.5	3.5	3.5
CC9 (m/s^2)	1.5	1.5	1.5	1.5	1.5

3.9.3.3 Calibrating the model

Microscopic simulation software was not calibrated to local data in Ethiopia; hence it is difficult to applying it directly to traffic analysis. Therefore, calibration of software carried out systematically, changing the sensitive parameters through iteration process up to it replicates the real field condition. In this study, the author calibrated the base model to field speed through systematic adjustment to desired speed distribution, driving behavior characteristics and minimum lateral data until it replicates the observed speed.

3.9.3.4 Model output

Two basic macroscopic traffic parameter, speed and volume were taken from Vissim simulation. Space mean speed in case of midblock and time mean speed in case of signalized was used to validate the model in comparison with real speed on site. Whereas, traffic flow (base flow) output from calibrated Vissim under "All are Car" condition was used to validate determined PCU value in comparison with equivalent traffic flow on site.

3.9.4 Optimization technique

(Wright 2023) discussed that "optimization, collection of mathematical principles and methods used for solving quantitative problems in many disciplines, including engineering". It is also known as mathematical programming. This method has typically three fundamental elements. The first is a single numerical quantity, or objective function, that is to be optimized. The second element is a collection of variables, which are quantities whose values can be manipulated to optimize the objective. And the third element of an optimization problem is a set of constraints, which are restrictions on the values that the variables can take.

Equivalent traffic flow determined using analytical PCU values and field traffic flow was optimized to base flow determined from calibrated simulation model under ‘All are Car” condition using equation (3.7). The base flow was used as objective function whereas, PCU_i values were used as manipulating variables.

Base flow = $\sum(PCUi * Ni)$………………………………………..………….....(3.7)

Subjected to:

1. A constraints
   - ✓ $q_{3wheeler}$ = (< = >) $PCU_{3Wheeler}*N_{3Wheeler}$
   - ✓ q_{Car} = (< = >) $PCU_{Car}*N_{Car}$
   - ✓ q_{4WD} = (< = >) $PCU_{4WD}*N_{4WD}$
   - ✓ q_{Bus} = (< = >) $PCU_{Bus}*N_{Bus}$
   - ✓ q_{Truck} = (< = >) $PCU_{Truck}*N_{Truck}$
2. Non-negative restriction
   - ✓ $PCU_i >= 0$

Where: PCU_i and N_i are determined PCU value and corresponding number of 3Wheeler, Car, 4WD, Bus and Truck determined on field and q is flow per hour.

CHAPTER FOUR

Results and Discussions

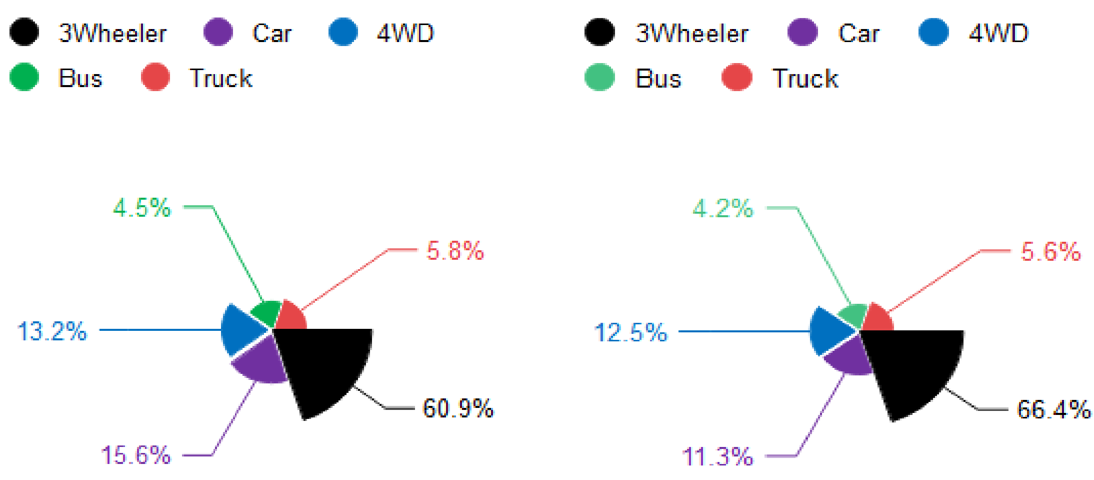
4.1 Overview

This chapter has covered the results and discussions under five section for midblock and signalized intersection. These sections are; nature of traffic heterogeneity in terms of vehicle composition, estimation of PCU values using analytical method, Validation of PCU values using microscopic simulation analysis, Optimization of PCU values using optimization technique and finally the comparison of final PCU value with international manual and other literatures done at national level.

4.2 Vehicle Composition

In Ethiopia, Jimma city roadway traffic flow is heterogeneous in nature and poor in lane discipline specially along midblock. Hence, it is difficult to aggregate the flow into its flow direction, therefore the author carried out traffic analysis in both travel direction together to recognize the interaction between vehicles in both directions. The total traffic flow extracted from recoded video, aggregated into simply study categories which is Car, 4WD, Bus, Truck and 3Wheeler according to ERA-2013 vehicle classification method. The researcher collected total number of 2430 Veh. /hr. and 3759 Veh. /hr. at midblock and signalized intersection, respectively.

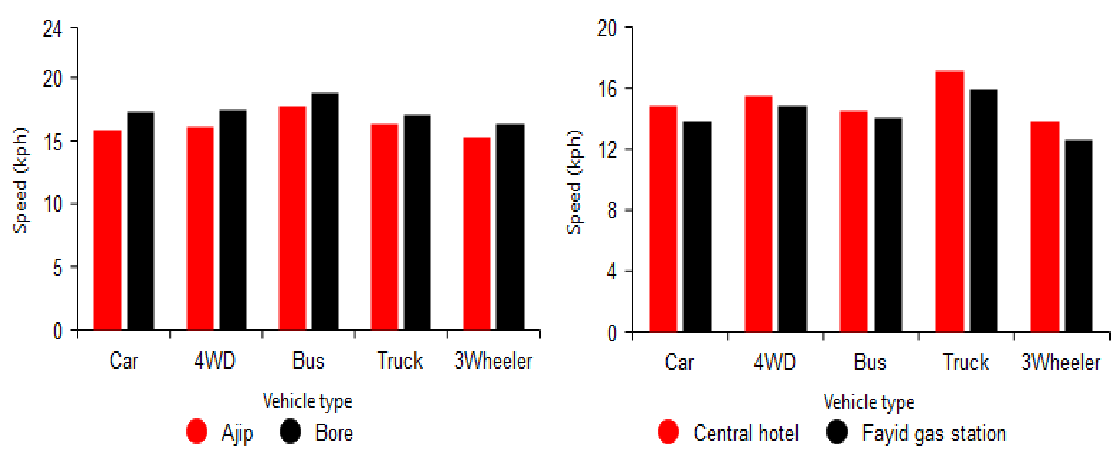
In both section, Bus was the minimum composition and 3Wheeler was the maximum composition in the flow. The ratio of heterogeneous traffic composition was determined, in the ratio of vehicle classes to the minimum composition that was Bus in both sections. Hence, in case of midblock road section heterogeneous ratio became 1: 1.3: 2.9: 3.5: 13.6 for Bus: Truck: 4WD: Car: 3Wheeler, where as in case of signalized intersection it became 1: 1.3: 2.7: 3: 15.8 for Bus: Truck: Car: 4WD: 3Wheeler. The compositions of each vehicle classes are shown in figure 4.1.



(a) Midblock road section (b) Signalized intersection

Figure 4.1: Vehicles composition

The study found that, Bus traveled with higher space mean speed at midblock section, whereas Truck traveled with higher through discharge speed at signalized intersection. The speed distribution of vehicles at midblock and signalized intersection are shown in figure 4.2 (a) and (b), respectively.



(a) Midblock section (b) Signalized intersection

Figure 4.2: Speed distribution of vehicles.

4.3 Passenger Car Unit estimation

Road facilities design and operational analysis is carried out properly, if only heterogeneous traffic flow is converted to equivalent homogeneous traffic flow using proper conversion factor called PCU. The propriety of this value has mainly subjected to the roadway condition it is determined for and the methods applied to determined it. The author of this study determined the PCU value for five vehicles classes, namely 3Wheeler, Car, 4WD, Bus and Truck with proper analytical methods in the following road section.

4.3.1 Mid-block road section

The PCU value of studied vehicles at road segment was determined from two midblock road section data using speed-based method. This method is the most popular and most accurate method of estimating PCU values for different vehicle under heterogeneous traffic for both interrupted and uninterrupted traffic condition. Hence, this study adopted speed-based method to determine the PCU values of studied vehicles at midblock road section as tabulated in table 4.1 using equation (2.3).

Table 4.1: PCU at mid-block Road section

Passenger Car unit at mid-block road segment for two directional flows								
Segment ID	Longitudinal grade (%)	Vehicle classes	Speed (m/s)	Flow (Veh/hr.)	Area (m^2)	V_c/V_i	A_C/Ai	PCU value
Bore	1.6 (+, -)	3Wheeler	4.56	1317	3.783	1.06	1.58	0.67
		Car	4.82	201	5.977	1.00	1	1.00
		4WD	4.86	226	8.745	0.99	0.68	1.45
		Bus	5.21	43	22.46	0.93	0.27	3.48
		Truck	4.73	107	22.81	0.97	0.26	3.72
Ajip	1.31 (+, -)	3Wheeler	4.26	1481	3.783	1.03	1.58	0.65
		Car	4.40	379	5.977	1.00	1	1.00
		4WD	4.46	320	8.745	0.99	0.68	1.44
		Bus	4.93	109	22.46	0.89	0.27	3.36
		Truck	4.55	140	22.80	0.97	0.26	3.69

The result shown that the value of PCU decreased as traffic flow increased and speed decreased for midblock road section. As traffic flow increased, the speed of vehicles gets decreased; consequently, as speed decreased, the interaction between vehicles became decreased, hence PCU value became decreased.

In terms of carriageway width, the average width of AJIP midblock carriageway is wider than Bore Midblock carriageway width. However, PCU value of all vehicles has negative correlation as PCU at Bore midblock were higher. Different literatures found that, PCU and carriageway width has different correlation direction. This correlation was positive as (Chandra and Sikdar 2000; Arasan and Arkatkar 2010), negative as cited in (Sharma and Biswas 2021) and zero correlation as (Rakha et al. 2007). This study found that there is a negative correlation between PCU value and width of carriageway.

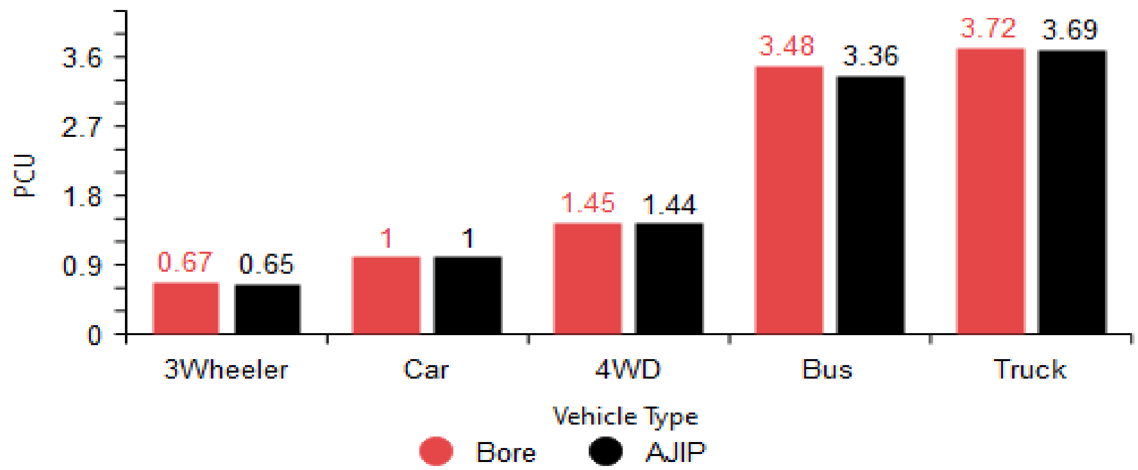


Figure 4.3: PCU value comparison at midblock road section.

4.3.2 Signalized intersection

In case of signalized intersection, headway ration method was adopted to determine the PCUs value of vehicle under study. This method is the most used method for measuring PCUs at signalized intersections and preferred over others as it utilizes such a dynamic characteristic of traffic stream, headway which can explain driver behavior, roadway surroundings, traffic volume and speed characteristics through this single parameter. The effective green at each approach of intersection is determined as:

Effective green time (G_{Eff}) = Actual green time +Amber time – lost time…………(4.1)

Each intersection has four approaching legs and different PCU value was resulted as traffic volume, signal timing, pavement condition and gradients are slightly different along each leg. The variation in result shown that PCU value is not static for a given vehicle, it is dynamic even for the same intersection but different approaching legs.

The PCU at Central hotel signalized intersection was higher for 3Wheeler and Truck, whereas lower for 4WD and Bus compared to Fayid gas station signalized intersection. Even though, volume, composition, speed, geometry, and pavement condition can contribute different correlation direction with PCU of vehicles, the variation in PCU between two intersection is insignificant as shown in figure 4.4.

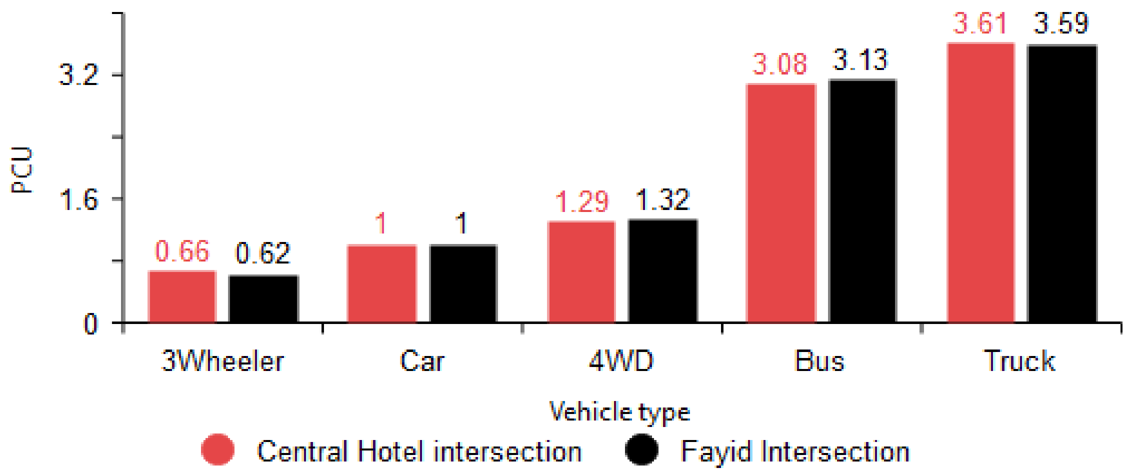


Figure 4.4: PCU value comparison at signalized intersection

The PCU value of vehicle classes was determined on two signalized intersection as following table using equation (3.3) to equation (3.6). Detail is attached at Appendix C.

Table 4.2: PCU at signalized intersection.

Intersection	Approach	Grade (%)	G_{Eff} (Sec)	Vehicle	ha c-c *100 (sec)	ha x-x *100 (sec)	PCU
Central Hotel	EB	0	36	3Wheeler	0.041	0.028	0.67
				Car	0.035	0.035	1
				4WD	0.068	0.089	1.308
				Bus	0.072	0.221	3.076
				Truck	0.065	0.234	3.626
	WB	0	36	3Wheeler	0.06	0.04	0.66
				Car	0.05	0.05	1
				4WD	0.08	0.10	1.26
				Bus	0.09	0.27	2.87
				Truck	0.08	0.28	3.47
	NWB	-1.5	26	3Wheeler	0.05	0.03	0.68
				Car	0.03	0.03	1
				4WD	0.05	0.06	1.33
				Bus	0.05	0.15	3.23
				Truck	0.06	0.21	3.65
	SEB	1.2	26	3Wheeler	0.04	0.03	0.63
				Car	0.03	0.03	1
				4WD	0.06	0.08	1.28
				Bus	0.05	0.17	3.15
				Truck	0.04	0.15	3.68
Fayid Signalized Intersection	EB	0	31	3Wheeler	0.04	0.02	0.58
				Car	0.03	0.03	1.00
				4WD	0.05	0.07	1.33
				Bus	0.05	0.16	3.13
				Truck	0.05	0.18	3.71
	WB	0	31	3Wheeler	0.06	0.03	0.62
				Car	0.04	0.04	1.00
				4WD	0.06	0.08	1.23
				Bus	0.08	0.23	2.96
				Truck	0.07	0.24	3.48
	NB	-0.80	26	3Wheeler	0.04	0.03	0.61
				Car	0.03	0.03	1.00
				4WD	0.05	0.06	1.33
				Bus	0.05	0.15	2.87
				Truck	0.04	0.14	3.53
	SB	1	26	3Wheeler	0.05	0.03	0.68
				Car	0.03	0.03	1.00
				4WD	0.05	0.07	1.39
				Bus	0.05	0.17	3.54
				Truck	0.06	0.21	3.63

PCU values were determined for all studied vehicles in both midblock sections and signalized intersections separately as table 4.3. Finally, the author used the single average PCU value for each vehicle classes for further analysis.

Table 4.3: Average PCU value

Vehicle Class	Central Hotel intersection	Fayid intersection	Mid-block road section		Average PCU value	
	All approach	All approach	Bore	Ajip	Intersection	Segment
3Wheeler	0.66	0.61	0.67	0.65	0.64	0.66
Car	1.00	1.00	1.00	1.00	1.00	1.00
4WD	1.29	1.32	1.45	1.44	1.31	1.45
Bus	3.08	3.12	3.48	3.36	3.10	3.42
Truck	3.61	3.59	3.72	3.69	3.60	3.70

Total traffic volume measured on field in vehicle per hour was converted into equivalent flow in passenger car per hour using the average PCU value in table 4.3. This equivalent flow was validated in microscopic simulation analysis in comparison with base flow determined from simulation model under 'All are car' condition.

Table 4.4: Equivalent traffic flow

Road section	Vehicle Classes	Volume (Vehicle/Hr.)	Average PCU	Volume in PCU/Hr.
Midblock road Segment (both direction)	3Wheeler	1481	0.661	979
	Car	379	1.00	379
	4WD	320	1.45	463
	Bus	109	3.42	373
	Truck	140	3.70	519
Equivalent flow in PCUs/Hr.				2714
Signalized Intersection /All Approach/	3Wheeler	2488	0.644	1602
	Car	431	1.00	431
	4WD	479	1.30	625
	Bus	158	3.10	490
	Truck	204	3.60	736
Equivalent flow in PCUs/Hr.				3882

4.4 Validation of PCU values

Microscopic simulation analysis using PTV Vissim software was carried to collect two macroscopic traffic stream parameters; speed and flow, they were used for the calibration of the model and validation of PCU values determined using analytical method, respectively. The model was calibrated using four-hour traffic data collected at midblock road section and signalized intersection until it replicates the field condition.

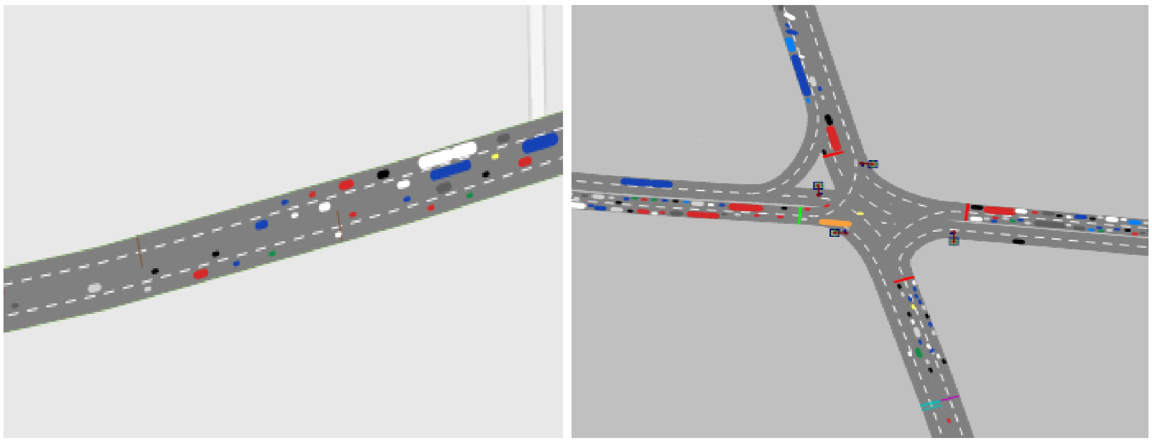
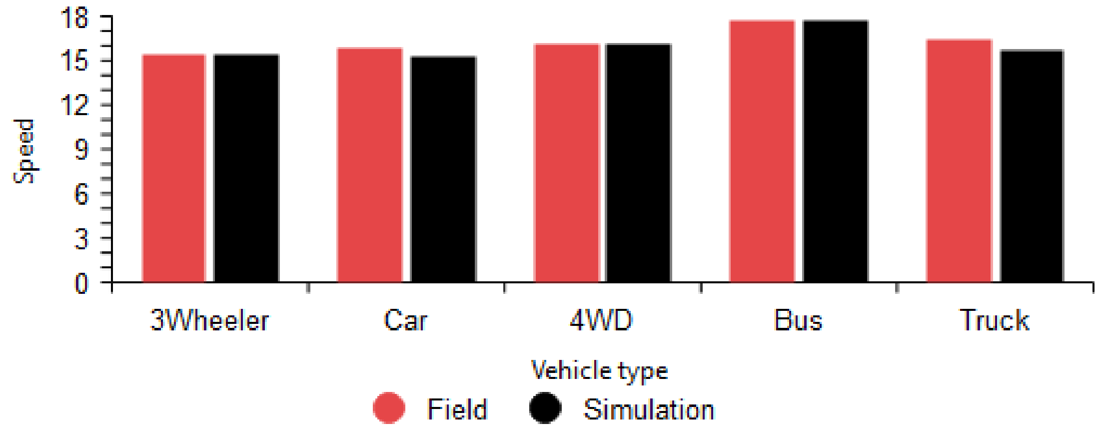


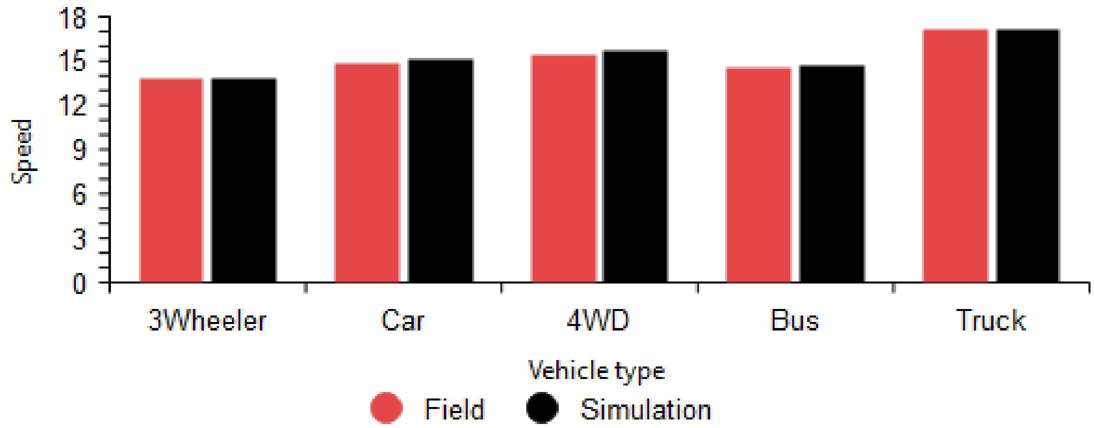
Figure 4.5: Simulation model of midblock and intersection

4.4.1 Calibration of simulation model

Simulation model was validated by checking the results of calibrated model in comparison with field data. In case of midblock road section, the total length of the model was divided into equal length of 50m and simulated for 3600s. The model was run six times and average speed of all vehicle categories under each six runs in both flow direction was noted as final output of the model. In case of signalized intersection, the model was simulated for 3600s and run for ten times. The average speed of all vehicle categories in all approach legs and connectors under each ten run was noted as final output of the model. Detail speed output from simulation is attached in Appendix-E.



(a) Midblock road section



(b) Signalized intersection

Figure 4.6: Comparison of field and simulation speed

Statistical test; t-test was applied to validate field speed and simulated speed are statistically matched. All t-test values (t_o) are less that critical t-value (t_c) at 95% confidence interval and 5% standard error, implies that the difference between field speed and simulated speed are statistically insignificant. Therefore, calibrated model was accepted statistically as shown in table 4.5.

Table 4.5: Field speed and model speed comparison

Facility	Vehicle	Observed Speed	Simulation Speed	D/ce	St.dev	t-test		Model Condition
						t_o	t_c	
Midblock segment	3Wheeler	15.35	15.42	0.07	0.05	-0.267	2.12	Accepted
	Car	15.83	15.32	-0.51	0.36	-0.12	2.12	Accepted
	4WD	16.06	16.13	0.07	0.05	-0.337	2.12	Accepted
	Bus	17.74	17.69	-0.05	0.04	0.37	2.18	Accepted
	Truck	16.37	15.68	-0.69	0.49	-0.09	2.14	Accepted
Signalized intersection	3Wheeler	13.83	13.87	0.04	0.03	1.6	2.16	Accepted
	Car	14.81	15.135	0.33	0.23	-1.06	2.12	Accepted
	4WD	15.45	15.726	0.28	0.19	-1.72	2.13	Accepted
	Bus	14.52	14.651	0.13	0.09	0.93	2.18	Accepted
	Truck	17.14	17.094	0.05	0.03	1.74	2.12	Accepted

4.4.2 Equivalent and base flow comparison

Analytical method applied to determine PCU is quick and simple method, but did not cover all the interaction of traffic movement in roadway. Nowadays, microscopic simulation analysis is the most popular method since it can cover all traffic interaction and dynamic nature of the traffic movement. However, all parameter of the software needs to be calibrated with massive local data. This study used both analytical and simulation method together, to have the advantage of both methods. The equivalent flow determined analytically was compared and optimized to base flow output from calibrated model under 'All are car' traffic condition. Calibrated model was simulated for 3600s and average flow was collected at 50m and 10m for midblock road section in both direction and signalized intersection in all approach, respectively. Detail base flow is attached in appendix-F.

Table 4.6: Flow from field and simulation model

Facility	Observed flow (PCU/hr.)	Simulation flow (Car/hr.)	Difference	St. Dev.	Condition
Segment	2714	2591	123	61	Optimization applied
Intersection	3882	3733	149	74	Optimization applied

The table shown that passenger car unit was overestimated in both sections. There is 123 PCU/hr. and 149 PCU/hr. difference between observed equivalent flow and flow from simulation under "All are car" traffic condition at midblock and intersection, respectively. Therefore, the author optimized equivalent flow to base flow resulted from simulation, with manipulating PCU value of vehicles as section below.

4.5 Optimization of PCU values

Equivalent flow was optimized to base flow from simulation model using equation 3.7 for both midblock road and signalized intersection in following, respectively. Generalized Reduction Gradient (GRG) nonlinear method using excel data solver was used to optimize the model.

$2591 = 1481PCU_{3Wheeler} + 379PCU_{Car} + 320PCU_{4WD} + 109PCU_{Bus} + 140PCU_{Truck}$ …..(4.2)

$3733 = 2488PCU_{3Wheeler} + 431PCU_{Car} + 479PCU_{4WD} + 158PCU_{Bus} + 204PCU_{Truck}$ ..…(4.3)

Equation (4.2) and (4.3) are respectively, subject to a constraint:

$958 => 1481\ PCU_{3Wheeler}$

$379 = 379\ PCU_{Car}$

$445 => 320PCU_{4WD}$

$425 => 109PCU_{Bus}$

$512 => 140PCU_{Truck}$

$1602 => 2488\ PCU_{3Wheeler}$

$431 = 431\ PCU_{Car}$

$625 => 479PCU_{4WD}$

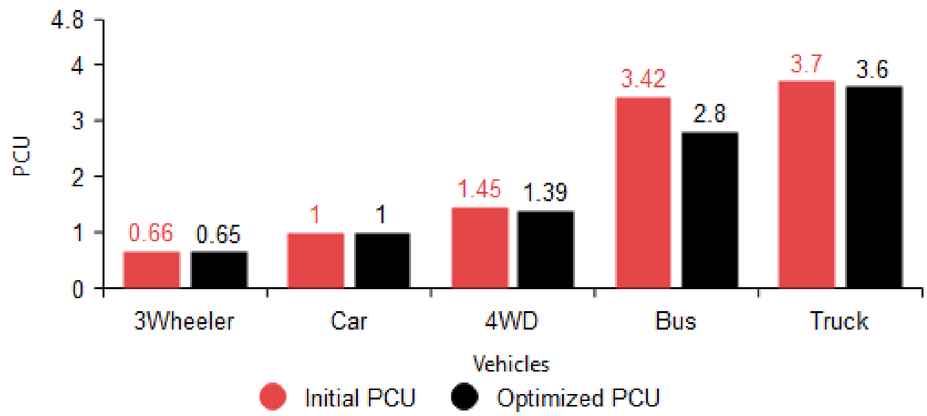
$590 => 158PCU_{Bus}$

$736 => 204PCU_{Truck}$

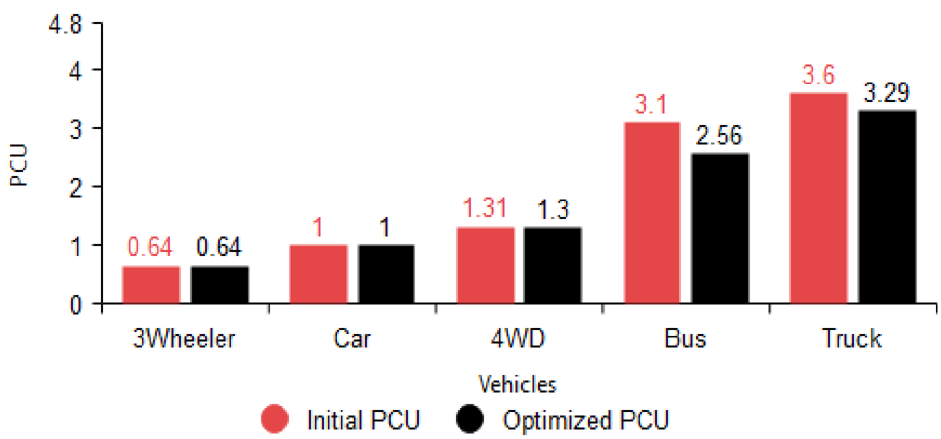
Table 4.7: Optimized PCU value

Facility	Vehicle	3Wheeler	Car	4WD	Bus	Truck
Midblock Section	PCU	0.65	1	1.39	2.80	3.60
	Model	1481	379	320	109	140
Signalized Intersection	PCU	0.64	1.00	1.30	2.56	3.29
	Model	2488	431	479	158	204

Optimization method was optimized the PCU values of 3Wheeler, 4WD, Bus and Truck at midblock road section and signalized intersection to 0.65, 1.39, 2.80, 3.60 and 0.64, 1.30, 2.56, 3.29, respectively.



(a) Midblock road section



(b) Signalized intersection

Figure 4.7: Initial and Optimized PCU

The results shown that, analytically determined PCU value was overestimated with 5% and 4% at midblock road section and signalized intersection, respectively. Bus subjected to higher reduction in optimization since its composition in overall traffic flow is less in both case and its sensitivity in constraints is also less.

The author of this study found that, all vehicles applied less effect at signalized intersection compared to midblock section, as traffic characteristics are controlled and drivers are less aggressive at controlled section. Signal control gives sequential movement at signalized intersection, but at undivided midblock section the driver become autonomous to have desired speed and choose any lane which leads poor lane discipline and higher interaction between the vehicles.

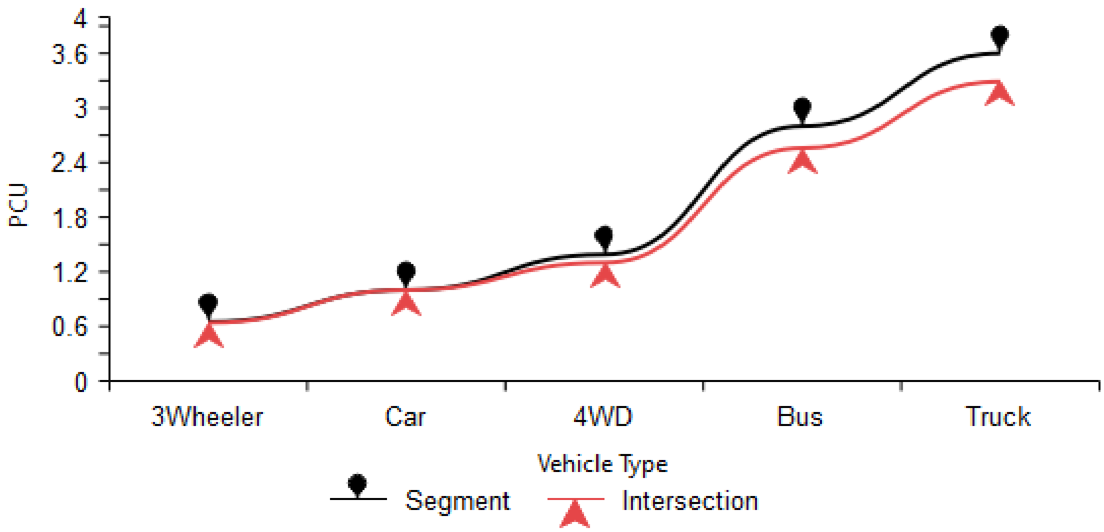


Figure 4.8: Midblock and signalized intersection comparison

HCM 2010 did not set clear procedure and methodology to determine PCU values of different vehicle types, unless it recommended international user to estimate it at local level. Its provided PCU values were only for trucks, buses, and recreational vehicles. For level terrain segment, 1.5 was recommended for bus and truck, while 1.2 for a recreational vehicle. In case of signalized intersection, the manual recommended 2.0 for all heavy vehicles where no distinction has made between trucks, recreational vehicles, buses, and other vehicles.

In Ethiopia context, (Ararsa and Getu 2020) determined PCU values of different vehicles on four trunk road using speed based, homogenization coefficient and microscopic simulation and recommending PCU values obtained through simulation. The author obtained 0.62, 1.44, 4.23 and 4.53 for 3Wheeler, 4WD, bus and truck respectively. (Belay 2018) determined PCU values of different vehicles at three signalized intersections in Harar city using speed-based method, and found that the average PCU value 0.75, 1.37, 3.55 and 3.59 for 3Wheeler, 4WD, bus and truck, respectively.

Generally, the results of PCU values obtained from this study are different from the values recommended by HCM-2010, the manual underestimates the values of PCU compared to locally determined values at both midblock and signalized intersection. Relevant literatures were estimated PCU values at local level using either analytical method or microscopic simulation or in combination of both methods, but none author optimized the results, they exaggerated the PCU values of the vehicle types. Unlike HCM and other literatures, this study found the PCU values which can be represent local traffic condition through applying additional optimization technique. Hence, it is realistic to apply it in planning, designing and traffic operation analysis.

Table 4.8: Comparison of the optimized PCU values with manual and literatures.

S/N	Vehicle category	This Study		(HCM 2010)		(Ararsa and Getu 2020)	(Belay 2018)
		Segment	Inters*.	Segment	Inters*	Segment	Intersection
1	3Wheeler	0.65	0.64	-	-	0.64	0.75
2	Car	1	1	1	1	1	1
3	4WD	1.39	1.30	1	1	1.43	1.37
4	Bus	2.80	2.56	1.5	2	3.96	3.55
5	Truck	3.60	3.29	1.5	2	4.63	3.59

Finally, the author of this study has summarized the finding of the study under three methods; analytical method, microscopic simulation analysis and optimization techniques as shown in figure 4.9.

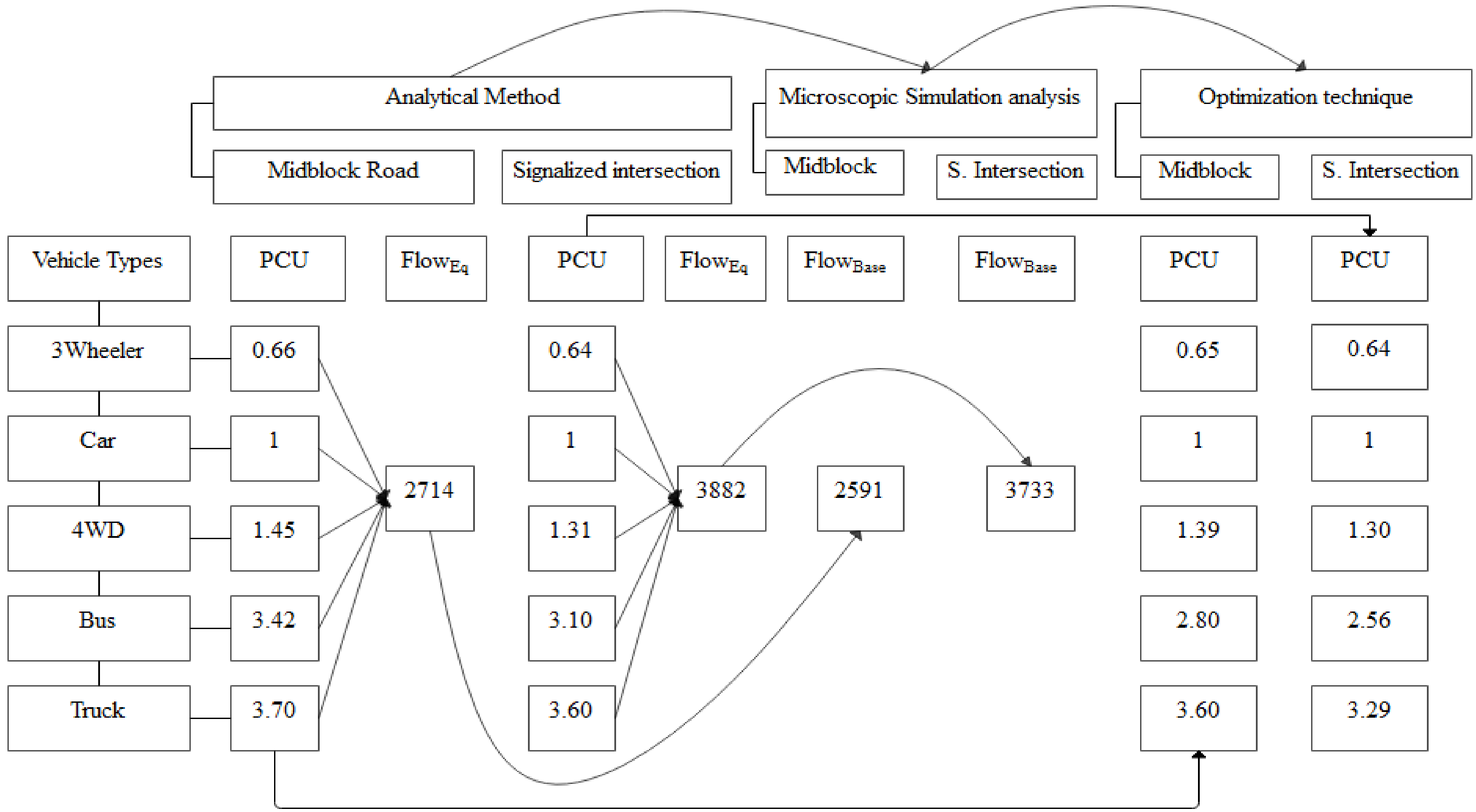


Figure 4.9: Summary of this study results.

CHAPTER FIVE

Conclusion and Recommendation

5.1 Conclusion

This study aims to estimate PCU values of different vehicle types at midblock road section and signalized intersection under heterogeneous traffic system. Research data were collected on two undivided midblock section and two pre-timed signalized intersection located in Jimma city, Ethiopia. Three analysis methods were applied; analytical method, microscopic simulation analysis and optimization technique to estimate PCU value for 3Wheeler, 4WD, Bus and Truck vehicle classes. The following conclusions have drawn: -

1. In midblock road section and signalized intersection, Bus was the minimum composition and 3Wheeler was the maximum composition in the flow stream. The ratio of heterogeneous traffic composition was done, taking the ratio of each vehicle classes to the minimum composition in stream in both sections. Hence, in case of midblock road section heterogeneous ratio became 1: 1.3: 2.9: 3.5: 13.6 for Bus: Truck: 4WD: Car: 3Wheeler, where as in case of signalized intersection it became 1: 1.3: 2.7: 3: 15.8 for Bus: Truck: Car: 4WD: 3Wheeler.
2. The analytical methods; speed based and headway ratio method, were estimated the PCU value for 3-Wheeler, 4WD, Bus and Truck as 0.66, 1.45, 3.42, 3.70 at midblock section, while 0.64, 1.31, 3.10, 3.60 at signalized intersection. Equivalent traffic flow was determined based on this analytical result as 2714 PCU/hr. at midblock section and 3882 PCU/hr. at signalized intersection.
3. The author applied microscopic simulation analysis to validate PCU values estimated analytically at midblock and signalized intersection. Calibrated base model was simulated under flow condition of “All flows are cars” and resulted base flow of 2591 Car/hr. at midblock section and 3733 Car/hr. at signalized intersection. The result comparison shown that analytically determined equivalent flow was overestimated with 123 PCU/hr. at midblock section and 149 PCU/hr. at signalized intersection.

4. The author applied Optimization technique to optimize the equivalent traffic flow resulted from analytical method to base flow resulted from microscopic simulation analysis, hence PCU values were optimized with manipulating the values as unknown parameters. The general gradient reduction non-linear optimization method was applied; and found that optimum PCU value for 3wheeler, 4WD, Bus and Truck are 0.65, 1.39, 2.80, 3.60 at midblock road section and 0.64, 1.30, 2.56, 3.29 at signalized intersection, respectively. The results were shown that the PCU value determined analytically was overestimated with 5% at midblock road section and 4% at signalized intersection. Bus is a vehicle subjected to higher reduction in optimization since its composition in overall traffic flow was lower in both case and its sensitivity in constraints was also less, in contrast 3Wheeler is a vehicle subjected to lower reduction in optimization since its higher in composition and sensitivity in constraint criteria.
5. The author found that the value of PCU decreases as traffic flow increases and flow speed decreases.
6. Generally, the author of this study found the optimum dynamic PCU value for 3Wheeler, 4WD, Bus and Truck at midblock road section and signalized intersection through optimization technique within analytical and microscopic simulation methods. Hence, it is realistic to apply it in planning, designing and traffic operation analysis unlike HCM-2010 and other literatures done at national level.

5.2 Recommendation

The author of this study made the following summarized recommendation.

1. Analytical traffic analysis method overestimates the value of PCU, when it used alone. Hence, it is better to use in combination with other analysis like microscopic simulation method and proper optimization method.
2. Microscopic simulation analysis gives proper result, if only its parameters are calibrated with national data. Hence, the future researcher may calibrates the simulation software with national data.

3. PCU values obtained in optimization method for 3Wheeler, 4WD, Bus and Truck as 0.65, 1.39, 2.80, 3.60 at midblock while 0.64, 1.30, 2.56, 3.29 at signalized intersection are recommended by the author for future traffic studies.
4. The author studied the PCU values of vehicles at midblock road section and signalized intersection only, further studies at unsignalized intersection, roundabout and other road section in considering gradient effects will be carried out with future researchers.

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Appendices

Appendix-A: Traffic data

Midblock road section traffic data					
Segment Id: Bore					
Time/Vehicle	Car	4WD	Bus	Truck	3W
6:00 – 6:15	24	50	8	23	295
6:15 – 6:30	32	46	6	18	312
6:30 – 6:45	39	42	7	17	274
6:45 – 7:00	26	39	9	21	302
PHF	0.78	0.89	0.83	0.86	0.95
Flow rate (Veh./hr.)	201	226	43	107	1317
Average Travel Time (Sec)	10.4	10.3	9.6	10.6	11
Average Speed (m/s)	4.82	4.86	5.21	4.73	4.56
Composition (%)	10.6	11.9	2.3	5.7	69.5
Segment Id: Ajip					
Time/Vehicles	Car	4WD	Bus	Truck	3W
6:00 – 6:15	75	63	6	22	346
6:15 – 6:30	83	68	5	29	321
6:30 – 6:45	69	52	15	26	332
6:45 – 7:00	64	48	7	19	294
PHF	0.88	0.85	0.55	0.83	0.93
Flow rate (Veh./hr.)	379	320	109	140	1481
Average Travel Time (Sec)	11.4	11.2	10.1	11	11.7
Average Speed (m/s)	4.40	4.46	4.93	4.55	4.26
Composition (%)	16	13	4	6	61

Signalized intersection traffic data						
Intersection Id: Central Hotel signalized intersection						
Approach	Time/Vehicle	Car	4WD	Bus	Truck	3Wheeler
EB/ Ajip	6:00 – 6:15	26	29	3	9	165
	6:15 – 6:30	24	16	3	6	161
	6:30 – 6:45	22	33	7	4	153
	6:45 – 7:00	30	29	8	10	188
	PHF	0.85	0.81	0.65	0.725	0.88
	Arrive Flow (Veh./hr)	141	163	49	55	690
	Avg speed (TMS)	4.29	4.50	4.24	5.84	4.37
	Through flow (%)	90	98	9	26	414
	Turning Right (%)	28	49	12	18	172
	Turning Left (%)	23	16	28	11	103
	Composition (%)	13	15	4	5	63
WB/ Markato	6:00 – 6:15	31	30	2	6	164
	6:15 – 6:30	29	27	2	4	170
	6:30 – 6:45	30	26	5	8	171.0
	6:45 – 7:00	31	24	2	5	168
	PHF	0.97	0.89	0.55	0.71875	0.98
	Arrive Flow (Ve./hr)	127	135	36	45	695
	Avg speed (TMS)	3.92	4.03	4.10	4.43	3.57
	Through flow (%)	69	73	24	23	417
	Turning Right (%)	25	27	10	17	174
	Turning Left (%)	33	35	2	4	104
	Composition (%)	12	13	4	4	67
NB/ Awetu	6:00 – 6:15	14	16	2	7	134
	6:15 – 6:30	16	21	3	3	128
	6:30 – 6:45	13	19	6	3	142
	6:45 – 7:00	11	22	2	4	139
	PHF	0.84	0.88	0.54	0.61	0.95
	Arrive Flow (Ve./hr)	76	99	44	46	594
	Avg speed (TMS)	4.07	4.57	3.84	4.39	3.84
	Through flow (%)	46	60	26	24	416
	Turning Right (%)	8	10	6	5	101
	Turning Left (%)	15	20	12	18	77
	Composition (%)	9	12	5	5	69
	6:00 – 6:15	14	12	2	11	124
	6:15 – 6:30	18	16	2	5	122

	Time/Vehicle	Car	4WD	Bus	Truck	3Wheeler
SB/ Bore	6:30 – 6:45	14	17	4	9	120
	6:45 – 7:00	14	18	1	8	118
	PHF	0.83	0.875	0.5625	0.75	0.97
	Arrive Flow (Ve./hr)	86	82	28	59	508
	Avg speed (TMS)	4.18	4.07	3.96	4.39	3.58
	Through flow (%)	52	49	14	32	305
	Turning Right (%)	26	25	12	18	112
	Turning Left (%)	9	8	2	9	91
	Composition (%)	11	11	4	8	67
Intersection Id: Fayid signalized intersection						
Approach	Time/Vehicle	Car	4WD	Bus	Truck	3W
EB/ Nock	6:00 – 6:15	19	24	4	9	149
	6:15 – 6:30	22	11	5	10	146
	6:30 – 6:45	17	26	7	4	139
	6:45 – 7:00	23	25	10	12	171
	PHF	0.880	0.826	0.65	0.727	0.884
	Arrive Flow (Veh./hr.)	104	126	62	66	629
	Avg speed (TMS)	4.04	4.31	4.11	5.41	3.98
	Through flow (%)	67	75	9	32	377
	Turning Right (%)	17	38	12	21	157
	Turning Left (%)	21	13	28	13	94
	Composition (%)	11	13	6	7	64
WB/ Markato	6:00 – 6:15	27	25	3	7	147
	6:15 – 6:30	25	23	2	5	150
	6:30 – 6:45	25	21	6	9	151.0
	6:45 – 7:00	27	19	3	6	149
	PHF	0.962	0.88	0.58	0.75	0.988
	Arrive Flow (Veh./hr.)	112	114	41	48	611
	Avg speed (TMS)	3.64	3.86	3.97	4.11	3.25
	Through flow (%)	61	61	24	25	367
	Turning Right (%)	22	23	10	18	153
	Turning Left (%)	29	30	2	5	92
	Composition (%)	12	12	4	5	66
	6:00 – 6:15	11	13	3	8	124
	6:15 – 6:30	13	18	4	6	118
	6:30 – 6:45	10	16	7	4	143
	6:45 – 7:00	8	19	2	3	139

	Time/Vehicle	Car	4WD	Bus	Truck	3Wheeler
NB / C. Hotel	PHF	0.807	0.8684	0.571	0.656	0.9160
	Arrive Flow (Veh./hr)	64	88	49	49	624
	Avg speed (TMS)	3.78	4.38	3.72	4.07	3.50
	Through flow (%)	39	53	26	25	437
	Turning Right (%)	6	9	6	5	106
	Turning Left (%)	13	18	12	19	81
	Composition (%)	7	10	6	6	71
SB/ Bore	6:00 – 6:15	12	11	4	12	114
	6:15 – 6:30	16	15	4	6	102
	6:30 – 6:45	12	16	6	10	110
	6:45 – 7:00	11	17	2	9	108
	PHF	0.796	0.867	0.66	0.77	0.95
	Arrive Flow (Veh./hr)	80	78	36	62	479
	Avg speed (TMS)	3.88	3.90	3.83	4.07	3.26
	Through flow (%)	48	47	14	34	287
	Turning Right (%)	24	24	12	19	105
	Turning Left (%)	8	8	2	10	86
	Composition (%)	11	11	5	8	65

Appendix-B: Headway data

Intersection Id: Fayid signalized Intersection							
Approach	Vehicle Classes	Headway Category	Cycle	Flow (Veh./hr.)	Flow Used	Flow rejected	Headway (Sec) (Unadjusted)
EB/ Nock	Car	h C-C	27	104	84	20	2.5
	4WD	h 4W-4W	27	126	92	36	3.4
		h C-4W	27	64	50	14	8
		h 4W-C	27	82	60	22	5
	Bus	h B-B	27	62	48	14	7
		h C-B	27	34	21	13	7
		h B-C	27	28	18	10	7
	Truck	h T-T	27	66	50	16	10
		h C-T	27	42	29	13	6
		h T-C	27	38	30	8	9
	3Wheeler	h 3W-3W	27	629	520	109	1
		h C-3W	27	64	49	15	4
		h 3W-C	27	47	40	17	2
WB/ Markato	Car	h C-C	27	112	90	12	4
	4WD	h 4W-4W	27	114	98	16	4.7
		h C-4W	27	74	60	14	6
		h 4W-C	27	64	54	10	5
	Bus	h B-B	27	41	36	5	13
		h C-B	27	36	24	12	8
		h B-C	27	24	9	15	7
	Truck	h T-T	27	48	30	18	16
		h C-T	27	28	21	7	6
		h T-C	27	22	19	3	7
	3Wheeler	h 3W-3W	27	611	420	191	2
		h C-3W	27	64	42	12	3.3
		h 3W-C	27	58	50	18	3.2

	Vehicle Classes	Headway Category	Cycle	Flow (Veh./hr.)	Flow Used	Flow rejected	Headway (Sec) (Unadjusted)
NB/ C. Hotel	Car	h C-C	27	64	48	16	3.3
	4WD	h 4W-4W	27	88	72	16	4.7
		h C-4W	27	63	50	13	3.2
		h 4W-C	27	52	41	11	2.5
	Bus	h B-B	27	49	32	17	11
		h C-B	27	31	27	4	9
		h B-C	27	34	28	6	7
	Truck	h T-T	27	49	38	11	12
		h C-T	27	28	16	12	9
		h T-C	27	25	18	7	11
	3Wheeler	h 3W-3W	27	624	424	200	2
		h C-3W	27	42	30	12	3.5
		h 3W-C	27	39	30	9	4
SB/ Bore	Car	h C-C	27	80	68	12	2.9
	4WD	h 4W-4W	27	78	64	14	3.9
		h C-4W	27	54	44	10	4
		h 4W-C	27	48	30	18	3
	Bus	h B-B	27	36	31	5	13
		h C-B	27	28	20	8	7
		h B-C	27	25	17	8	8
	Truck	h T-T	27	62	48	14	9.8
		h C-T	27	42	34	8	3.2
		h T-C	27	38	29	9	2.2
	3Wheeler	h 3W-3W	27	479	370	109	1.8
		h C-3W	27	49	40	9	2.5
		h 3W-C	27	52	41	11	3

Appendix-C: Headway Adjustment

Central H. Intersection leg	Vehicle	Headway Category	Number of Cycle	Flow Rate (Veh./hr)	Flow Used	Flow rejected	Headway (*100Sec) (Unadjusted)	C-value	Headway (*100Sec) (Adj. for hac-c & hax-x respectively)
EB/ Ajip	Car	h C-C	25	141	98	59	0.035		0.068
	4WD	h 4W-4W	25	163	114	70	0.045	-0.568	0.089
		h C-4W	25	68	54	14	0.092		
		h 4W-C	25	47	40	7	0.045		0.072
	Bus	h B-B	25	49	20	19	0.116	-0.634	0.221
		h C-B	25	21	16	5	0.069		
		h B-C	25	32	24	8	0.081		0.065
	Truck	h T-T	25	55	38	17	0.132	-0.509	0.234
		h C-T	25	48	30	18	0.066		
		h T-C	25	42	32	10	0.100		0.041
	3Wheeler	h 3W-3W	25	690	516	174	0.022	-0.112	0.028
		h C-3W	25	109	80	29	0.025		
		h 3W-C	25	98	80	18	0.019		
WB/ Markato	Car	h C-C	25	127	100	65	0.050		0.077
	4WD	h 4W-4W	25	135	90	51	0.062	-0.461	0.097
		h C-4W	25	101	87	14	0.059		
		h 4W-C	25	67	54	13	0.049		0.094
	Bus	h B-B	25	36	18	17	0.160	-0.438	0.270
		h C-B	25	22	14	8	0.087		
		h B-C	25	18	12	6	0.082		0.080
	Truck	h T-T	25	45	30	15	0.178	-0.301	0.279
		h C-T	25	36	24	12	0.063		
		h T-C	25	28	18	10	0.070		
	3Wheeler	h 3W-3W	25	695	604	200	0.023	-0.074	0.057
		h C-3W	25	87	70	17	0.033		0.038
		h 3W-C	25	68	56	12	0.035		

	Vehicle	Headway Category	Number of Cycle	Flow Rate (Veh./hr)	Flow Used	Flow rejected	Headway (*100Sec) (Unadjusted)	C-value	Headway (*100Sec) (Adj. for hac-c & hax-x respectively)
NB/ Awetu	Car	h C-C	25	76	68	8	0.029		0.064
	4WD	h 4W-4W	25	99	84	15	0.036	-0.2603	0.082
		h C-4W	25	56	50	6	0.080		
		h 4W-C	25	48	37	11	0.070		0.053
	Bus	h B-B	25	44	36	8	0.095	-0.1616	0.167
		h C-B	25	32	20	12	0.080		
		h B-C	25	28	20	8	0.100		0.040
	Truck	h T-T	25	46	33	13	0.103	-0.1616	0.146
		h C-T	25	31	25	6	0.032		
		h T-C	25	34	24	10	0.022		0.042
	3Wheeler	h 3W-3W	25	594	502	92	0.018	-0.2631	0.027
		h C-3W	25	54	44	10	0.025		
		h 3W-C	25	64	50	14	0.030		
SB/ Bore	Car	h C-C	25	86	80	6	0.033		0.048
	4WD	h 4W-4W	25	82	72	10	0.044	-0.6009	0.064
		h C-4W	25	72	60	12	0.032		
		h 4W-C	25	74	58	16	0.025		0.048
	Bus	h B-B	25	28	21	7	0.100	-0.288	0.154
		h C-B	25	17	12	5	0.090		
		h B-C	25	16	13	3	0.070		0.057
	Truck	h T-T	25	59	50	9	0.120	-0.1283	0.208
		h C-T	25	46	38	8	0.090		
		h T-C	25	41	30	11	0.110		0.049
	3Wheeler	h 3W-3W	25	508	460	48	0.021	-0.1539	0.033
		h C-3W	25	73	61	12	0.035		
		h 3W-C	25	67	54	13	0.040		

Fayid Intersection approach	Vehicle	Headway Category	Number of Cycle	Flow Rate (Veh./hr)	Flow Used	Flow rejected	Headway (*100Sec) (Unadjusted)	C-value	Headway (*100Sec) (Adj. for hac-c & hax-x respectively)
EB/ Nock	Car	h C-C	27	104	84	20	0.025		0.054
	4WD	h 4W-4W	27	126	92	36	0.034	-0.495	0.072
		h C-4W	27	64	50	14	0.08		
		h 4W-C	27	82	60	22	0.05		0.051
	Bus	h B-B	27	62	48	14	0.07	-0.359	0.159
		h C-B	27	34	21	13	0.07		
		h B-C	27	28	18	10	0.07		0.050
	Truck	h T-T	27	66	50	16	0.10	-0.347	0.185
		h C-T	27	42	29	13	0.06		
		h T-C	27	38	30	8	0.09		0.038
	3Wheeler	h 3W-3W	27	629	520	109	0.01	-0.184	0.022
		h C-3W	27	64	49	15	0.04		
		h 3W-C	27	47	40	17	0.02		
WB/ Markato	Car	h C-C	27	112	90	12	0.04		0.065
	4WD	h 4W-4W	27	114	98	16	0.047	-0.425	0.080
		h C-4W	27	74	60	14	0.06		
		h 4W-C	27	64	54	10	0.05		0.078
	Bus	h B-B	27	41	36	5	0.13	-0.307	0.232
		h C-B	27	36	24	12	0.08		
		h B-C	27	24	9	15	0.07		0.068
	Truck	h T-T	27	48	30	18	0.16	-0.227	0.238
		h C-T	27	28	21	7	0.06		
		h T-C	27	22	19	3	0.07		0.056
	3Wheeler	h 3W-3W	27	611	420	191	0.02	-0.132	0.035
		h C-3W	27	64	42	12	0.03		
		h 3W-C	27	58	50	18	0.032		

	Vehicle	Headway Category	Number of Cycle	Flow Rate (Veh./hr)	Flow Used	Flow rejected	Headway (*100Sec) (Unadjusted)	C-value	Headway (*100Sec) (Adj. for hac-c & hax-x respectively)
NB/ C. Hotel	Car	h C-C	27	64	48	16	0.033		0.049
	4WD	h 4W-4W	27	88	72	16	0.047	-0.272	0.068
		h C-4W	27	63	50	13	0.032		
		h 4W-C	27	52	41	11	0.025		0.049
	Bus	h B-B	27	49	32	17	0.11	-0.181	0.175
		h C-B	27	31	27	4	0.09		
		h B-C	27	34	28	6	0.07		0.057
	Truck	h T-T	27	49	38	11	0.12	-0.262	0.206
		h C-T	27	28	16	12	0.09		
		h T-C	27	25	18	7	0.11		0.049
	3Wheeler	h 3W-3W	27	624	424	200	0.02	-0.174	0.033
		h C-3W	27	42	30	12	0.035		
		h 3W-C	27	39	30	9	0.04		
SB/ Bore	Car	h C-C	27	80	68	12	0.029		0.047
	4WD	h 4W-4W	27	78	64	14	0.039	-0.306	0.063
		h C-4W	27	54	44	10	0.04		
		h 4W-C	27	48	30	18	0.03		0.052
	Bus	h B-B	27	36	31	5	0.13	-0.281	0.151
		h C-B	27	28	20	8	0.07		
		h B-C	27	25	17	8	0.08		0.039
	Truck	h T-T	27	62	48	14	0.098	-0.123	0.139
		h C-T	27	42	34	8	0.032		
		h T-C	27	38	29	9	0.022		0.043
	3Wheeler	h 3W-3W	27	479	370	109	0.018	-0.172	0.026
		h C-3W	27	49	40	9	0.025		
		h 3W-C	27	52	41	11	0.03		

Appendix-D: Sample field speed extraction method

Sample discharge speed extraction at Central Hotel signalized Intersection												
Discharge Time mean speed of vehicles at each Legs. (It is the speed determined from time between front and back pass, and length of subjected vehicles from standard specification)												
Approach	Car (L= 4.3075m)				Bus (L= 9.505m)				3Wheeler (L= 2.635m)			
	Time (Second)			Speed (m/sec)	Time (Second)			Speed (m/sec)	Time (Second)			Speed (m/sec)
	Entry	Exit	Change		Entry	Exit	Change		Entry	Exit	Change	
EB/ Ajip	2.24	2.253	1.3	2.85	4.37	4.388	1.8	5.28	0.36	0.365	0.5	5.27
	2.32	2.324	0.4	10.77	10.03	10.06	3	3.17	0.42	0.427	0.7	3.76
	2.43	2.44	1	4.31	28.39	28.41	2	4.75	2.28	2.289	0.9	2.93
	4.1	4.108	0.8	5.38	54.3	54.33	3	3.17	2.34	2.348	0.8	3.29
WB/ Markato	1.41	1.43	2	2.15	43.24	43.26	2	4.75	1.46	1.47	1	2.64
	1.58	1.593	1.3	3.31	47.24	47.257	1.7	5.59	1.49	1.498	0.8	3.29
	2	2.012	1.2	3.59	48.52	48.56	4	2.38	1.57	1.575	0.5	5.27
	2.07	2.085	1.5	2.87	52.06	52.079	1.9	5.00	2.11	2.121	1.1	2.40
	4.16	4.17	1	4.31	54.43	54.453	2.3	4.13	6.52	6.526	0.6	4.39
NB/ Awetu	4	4.015	1.5	2.87	13.53	13.55	2.20	4.32	8.48	8.489	0.9	2.93
	14.04	14.05	1	4.31	22.57	22.59	2.00	4.75	11.32	11.324	0.4	6.59
	18.25	18.261	1.1	3.92	28.28	28.31	3.00	3.17	12.43	12.437	0.7	3.76
	18.38	18.395	1.5	2.87	36.49	36.52	3.00	3.17	15.12	15.131	1.1	2.40
SB/ Bore	10.43	10.439	0.9	4.79	26.12	26.15	3	3.17	0.46	0.47	1	2.64
	15.51	15.517	0.7	6.15	36.32	36.34	2	4.75	3.13	3.135	0.5	5.27
	20.21	20.23	2	2.15	54.48	54.494	1.4	6.79	3.32	3.326	0.6	4.39
	20.31	20.325	1.5	2.87	54.56	54.59	3	3.17	5.44	5.448	0.8	3.29
	28.2	28.209	0.9	4.79	59.27	59.32	5	1.90	5.46	5.471	1.1	2.40

Appendix-E: Average speed output from Simulation model

Midblock section	Time (Sec)	Link length	Speed* (Car)	Speed* (Truck)	Speed* (Bus)	Speed* (4WD)	Speed* (3wheeler)
Segment in direction 1	0-3600	1-0-50	10.19	11.81	11.7	11.3	11.19
	0-3600	1-50-100	9.9	11.38	11.42	10.8	10.84
	0-3600	1-100-150	10.1	11.28	12.85	11	11.04
	0-3600	1-150-200	10.71	12.59	13.84	12.38	11.99
	0-3600	1-200-250	15.96	14.66	13.62	16.5	15.83
	0-3600	1-250-300	18.94	19.61	19.61	20.02	19.32
	0-3600	1-300-350	19.05	20.21	21.63	19.73	19.8
	0-3600	1-350-400	19.25	20.09	20.71	19.7	19.77
	0-3600	1-400-450	18.88	19.95	21.19	19.02	19.59
	0-3600	1-450-500	19.36	20.4	21.04	19.92	20.09
Segment in direction 2	0-3600	2-0-50	10.44	10.4	12.13	11.32	11.15
	0-3600	2-50-100	10.04	9.76	11.51	11.05	11.01
	0-3600	2-100-150	10.28	10.21	11.06	11.22	11.2
	0-3600	2-150-200	11.02	11.01	12.1	11.89	11.6
	0-3600	2-200-250	13.12	12.52	15.05	14.02	13.89
	0-3600	2-250-300	16.18	12.96	13.06	15.25	16.14
	0-3600	2-300-350	19.62	18.95	20.13	19.92	20.13
	0-3600	2-350-400	19.37	19.49	21.55	19.77	19.94
	0-3600	2-400-450	19.76	19.31	21.22	20.03	20.01
	0-3600	2-450-500	19.77	19.25	22.39	20.79	20.3
Average speed (kph)			*15.32*	*15.68*	*16.69*	*16.13*	*16.02*

	Time (Sec)	Cycle	Speed* (Car)	Speed* (Truck)	Speed* (Bus)	Speed* (4WD)	Speed* (3Wheeler)
Signalized intersection	0-3600	1	32.45	24.55	17.93	22.43	17.76
	0-3600	2	12.71	14.95	12.89	11.43	13.85
	0-3600	3	11.66	15.02	5.18	13.51	10.31
	0-3600	4	9.22	12.19	24.12	0.45	7.15
	0-3600	5	8.56	14.42	28.93	13.19	23.21
	0-3600	6	11.64	9.73	9.43	15.18	13.43
	0-3600	7	12.21	19.62	7.3	8.84	8.41
	0-3600	8	16.48	18.25	18.42	17.42	14.44
	0-3600	9	13.9	17.71	7.76	22.39	14.78
	0-3600	10	22.52	24.5	14.55	32.42	15.36
Average speed (kmp)			15.135	17.094	14.651	15.726	13.87

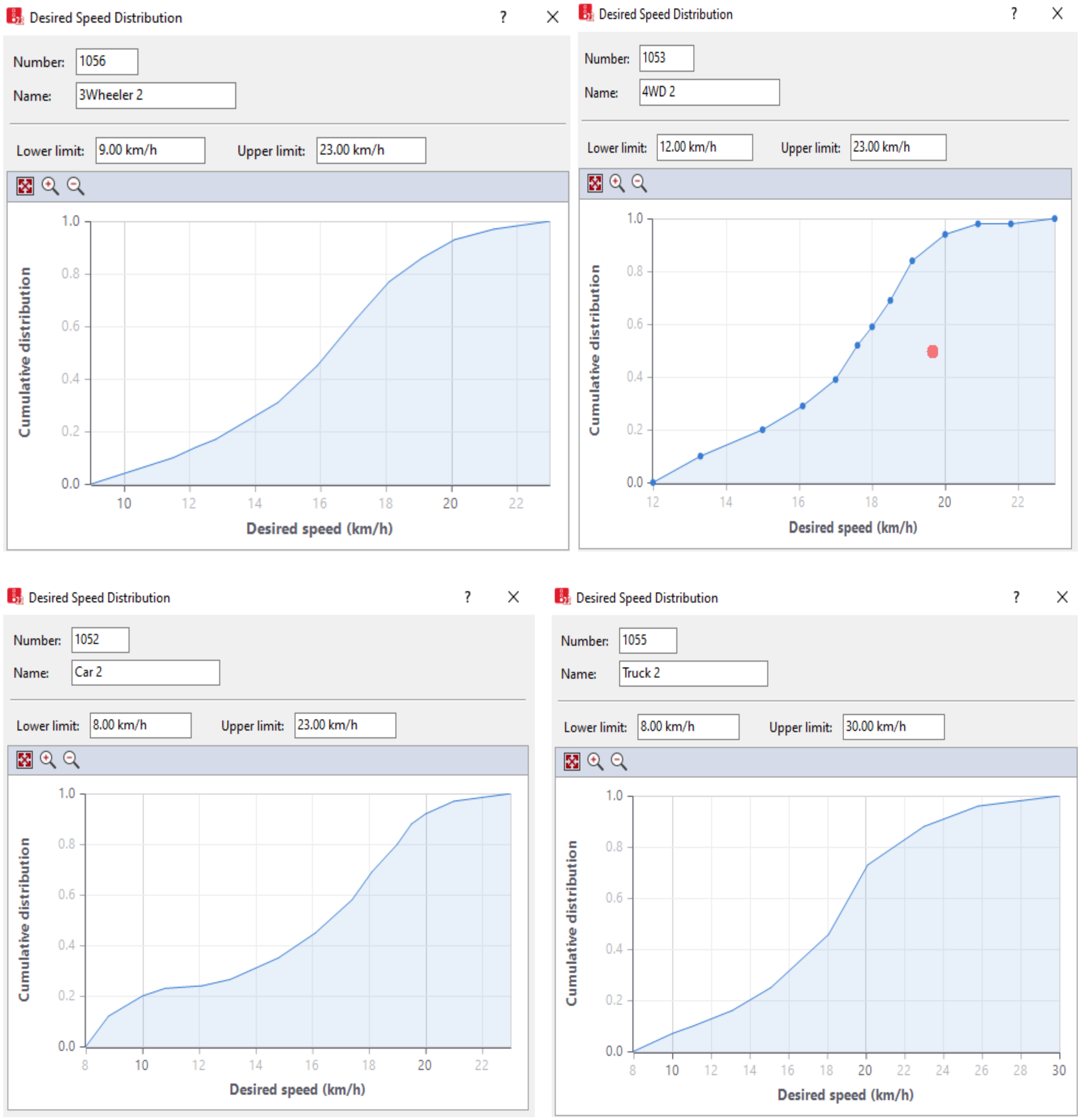
*Speed is average of all vehicle in the same category over link length and along all approach in case of signalized intersection.

Appendix-F: Flow output from simulation model

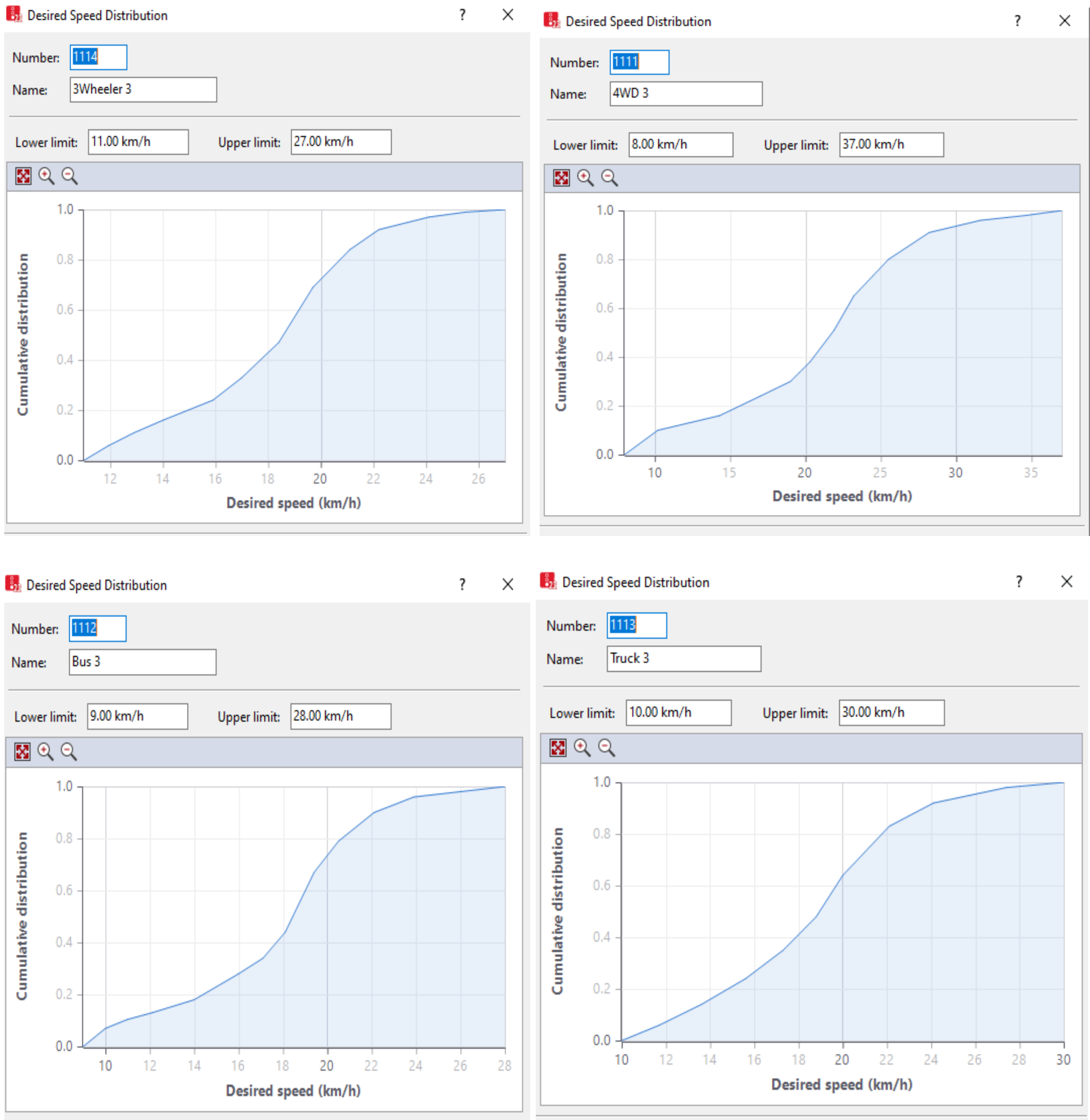
Time (Sec)	Midblock section			Signalized Intersection		
	Direction	Link length (m)	Volume (Car)	Total Cycle	Link length (m)	Volume (Car)
0-3600	1	1-0-50	1669	10	0-10	958
0-3600	1	1-50-100	1353	10	10-20	904
0-3600	1	1-100-150	1305	10	20-30	921
0-3600	1	1-150-200	1256	10	30-40	957
0-3600	1	1-200-250	1391	10	40-50	917
0-3600	1	1-250-300	1197	10	50-60	946
0-3600	1	1-300-350	1178	10	60-70	962
0-3600	1	1-350-400	1172	10	70-80	942
0-3600	1	1-400-450	1149	10	80-90	912
0-3600	1	1-450-500	1488	10	90-100	910
0-3600	2	2-0-50	1365	-	-	-
0-3600	2	2-50-100	1339	-	-	-
0-3600	2	2-100-150	1312	-	-	-
0-3600	2	2-150-200	1292	-	-	-
0-3600	2	2-200-250	1263	-	-	-
0-3600	2	2-250-300	1243	-	-	-
0-3600	2	2-300-350	1222	-	-	-
0-3600	2	2-350-400	1188	-	-	-
0-3600	2	2-400-450	1158	-	-	-
0-3600	2	2-450-500	1368	-	-	-
Average base flow both direction			2591Car/hr.	Average base flow for 4 approach (*4)		3733Car/hr.

Note: Volume in case of segment, the overall length divided into 50m and average along each link has taken. While, in case of signalized intersection overall approaching length has divided into 10m, then average value has used.

Appendix- G: Desired speed distribution graph

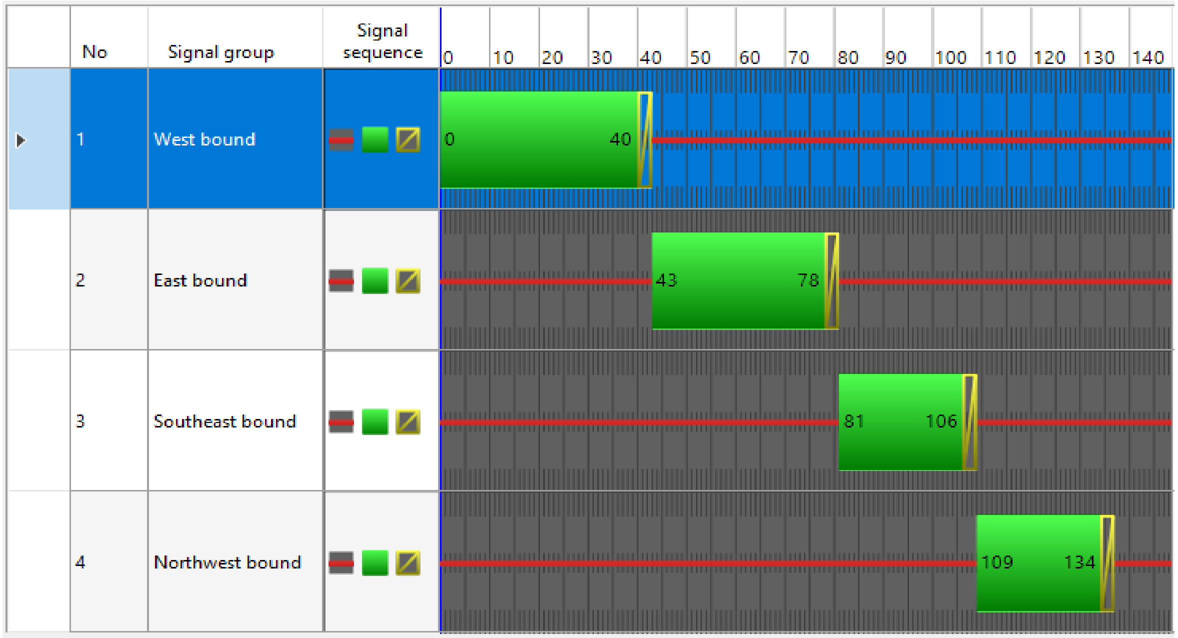


(a) At midblock road section

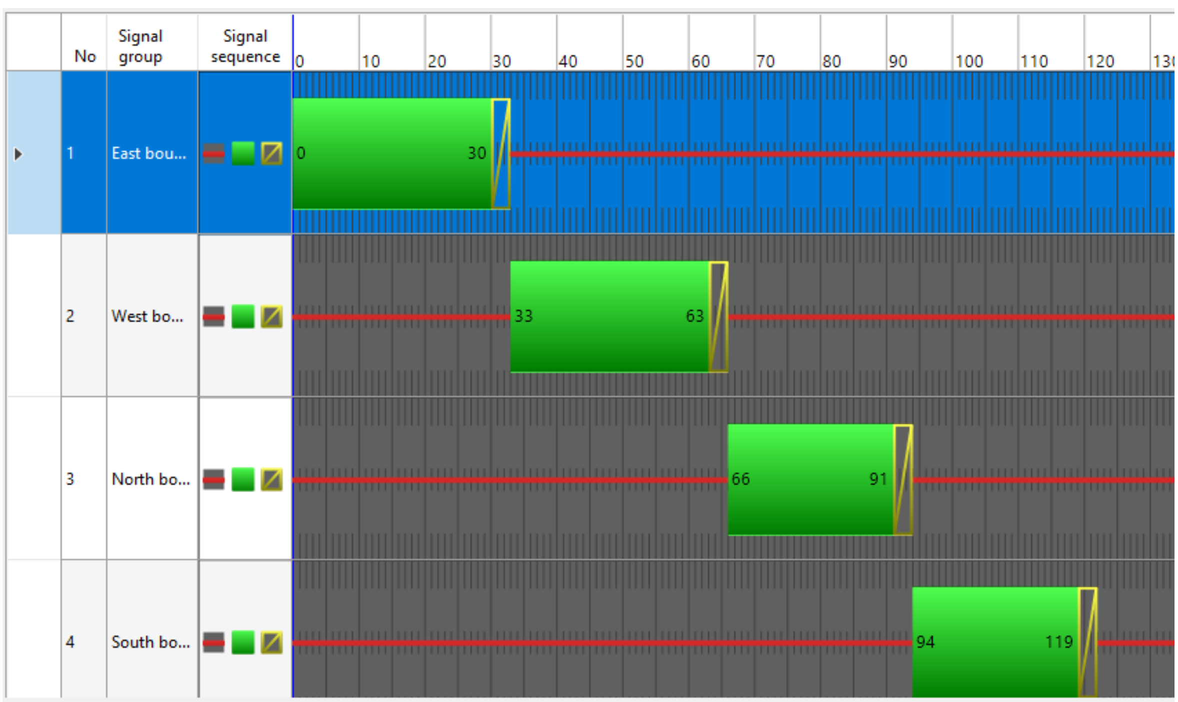


(b) At signalized intersection

Appendix- H: Intersection Signal program



(a) Central Hotel intersection



(b) Fayid intersection

Appendix- I: Optimization matrix

Midblock road section								
Objective = 1481a1 + 379a2 + 320a3 +109a4 + 140a5								
Vehicles	3Wheeler	Car	4WD	Bus	Truck			
Manipulated PCU	***0.65***	***1***	***1.39***	***2.80***	***3.60***	Product	Function	Available
1	1481	0	0	0	0	958	<=	958
2	0	379	0	0	0	379	=	379
3	0	0	320	0	0	445	<=	445
4	0	0	0	109	0	306	<=	425
5	0	0	0	0	140	504	<=	512
Model	1481	379	320	109	140	**2591**		

Signalized Intersection								
Objective= 2488a1 + 431a2 + 479a3 +158a4 + 204a5								
Vehicles	3Wheeler	Car	4WD	Bus	Truck			
Manipulated PCU	***0.64***	***1.00***	***1.30***	***2.56***	***3.29***	Product	Function	Available
1	2488	0	0	0	0	1602	<=	1602
2	0	431	0	0	0	431	=	431
3	0	0	479	0	0	625	<=	625
4	0	0	0	158	0	405	<=	590
5	0	0	0	0	204	671	<=	736
Model	2488	431	479	158	204	**3733**		

Where: a1, a2, a3, a4 and a4 are manipulated PCU values of 3Wheeler, Car, 4WD, Bus and Truck, respectively.

Appendix-J: Sample photos during data collection