ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING GRADUATE STUDIES

Capacity and Passenger Car Unit Estimation for Heterogeneous Traffic Stream of Trunk Roads

A Thesis submitted to school of Civil and Environmental Engineering of Addis Ababa Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering)

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FEBRUARY, 2020 G.C.

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DECLARATION

I hereby declare that this thesis entitled "*Capacity and Passenger Car Unit Estimation for Heterogeneous Traffic Stream of Trunk Roads*" was done by me, with the guidance of my main advisor and co-advisor and that the work contained herein is my own and has not been submitted, in whole or in part, for any other degree or professional qualification.

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ABSTRACT

The study was conducted on capacity and passenger car unit estimation for heterogeneous traffic stream of trunk roads on Addis Ababa to Holeta, Addis Ababa to Sendafa, Addis Ababa to Sululta and Addis Ababa to Sebata road sections to estimate the PCU for different categories of vehicles, to analyze the variation of PCU values with respect to different interval of traffic volume, to compare and contrast the PCU resulted by Chandra's and Homogenization coefficient methods and to estimate the road capacity. Different vehicle types occupy different spaces on the road, move at different speeds and start at different speeds. Especially in Ethiopia, this poses a problem when designing roads. A uniform measurement of vehicles is necessary to estimate the traffic volume and the capacity of roads with mixed traffic. This is difficult to achieve unless the different vehicle types are expressed in terms of a common standard vehicle unit. To attain these objectives on basic segment in flat terrain of selected study road sections, the data were collected by means of video recording by selecting favorable area on the study area. Depending on the concept of ERA manual, the vehicles are classified as standard car, 4WD, bus, truck and three wheeler. For each vehicle, data such as, vehicle class; number of vehicles and travel time were measured from vehicle travelled in study section between two thick white lines marked across the road width to provide reference line to arriving vehicles. The measured travel time was averaged for a fifteen minute time interval to determine the average mean speed. Density was computed from number of vehicle counted in given time interval and vehicle speed. The dimension of vehicles was obtained by physical measuring of the size of vehicles. From obtained data, traffic simulation were simulated by PTV VISSIM software and analyzed using SPSS and MS. Excel. The results indicate that, the PCU values for different types of vehicles were found to be different for different intervals of traffic volume. The result showed that value of PCU was decreasing as the volume of the road sections increase for all vehicles, except for three wheelers. The PCU resulted by Chandra's method for 4WD, bus, truck and three wheeler are (1.43, 3.96, 4.63 and 0.64) were greater than the PCU value resulted by Homogenization coefficient methods (1.27, 2.7, 3.13, 0.85) respectively for all types of vehicles, except for three wheelers. The Capacity of the trunk road was obtained from the average PCU by using Green shield's Model and Greenberg model for all road section depending on the direction of flow. The capacity resulted on each sections was lower than the value stated on the highway capacity manual 2010.

Key words: Capacity, Heterogeneous, PCU, Roads, Traffic Stream

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ABBREVIATIONS AND ACRONYMS

AA	Addis Ababa
CC0	Standstill headway between vehicles
CC1	Safety distance between vehicles
ERA	Ethiopian Road Authority
HCM	Highway capacity manual
PCU	Passenger car unit
PTV VISSIM	Planung Transport Verkehr-Verkehr in Städten Simulation Modell (German for "Traffic in cities- simulation model")
SPSS	Statistical Package for the Social Science
TRB	Transportation Research Board
RSN	Random Seed number
V/C	Volume to Capacity
kph	Kilometer per hour
4WD	Four Wheeler Driver

CHAPTER ONE: INTRODUCTION

1.1.Back ground

The flow of traffic on a given sections of roads may be composed of vehicles of different types, which have all different road–space requirements due to their respective size and vehicle performance characteristics. In order to permit this in highway capacity measurements, traffic volumes are expressed in passenger car units (PCUs) which represent the equivalent traffic impedance values of various types of vehicle as compared with a value of unity for the passenger car. Highway capacity is the maximum hourly rate at which vehicles can reasonably be expected to traverse appoint or a uniform section of a roadway during a given time period under prevailing road way and traffic condition (2010)

Rapid urbanization increases the number of vehicles on a road section significantly throughout Ethiopia. But the traffic in Ethiopia is purely heterogeneous. The traffic stream has the variety of vehicles like cars, heavy vehicles such as buses, trucks, truck and trailer, motorized two wheelers, three wheelers and non-motorized vehicles which comprise of the wide range of static and dynamic characteristics. The analysis of such mixed traffic stream is simple if the relative effect of each vehicle type can be expressed in terms of some common units (Mondal, 2017). The PCU or PCE is the universally unit of measurement of traffic volume or capacity and the value is derived by taking the passenger car as the standard vehicles.

Trunk roads serve the major traffic carrying corridor between Addis Ababa -Holeta, Sebata, Sendafa and Sululta road sections in Ethiopia. Because, there are many heavy vehicles which transport various agricultural produce and industrial product from countryside to Addis Ababa or vice versa using these road sections. The estimation of PCU of different categories of vehicles is also necessary for the design of different traffic facilities, operational analysis of roadway facilities, management of traffic regulation and control of traffic.

This study defines passenger car units as a function of static and dynamic performance of each type of vehicle from each stream, which is considered to be more realistic. There are two basic principles which should be applied to the estimation of PCUs values for any of the roadway types identified in capacity analysis procedure:

The first principle links the concept of passenger car equivalency to the level of service (LOS) concept. The second principle emphasizes the consideration of all factors that contribute to the overall effect of trucks on traffic stream performance.

In developing country like Ethiopia, road traffic in general is highly heterogeneous comprising vehicles of widely varying static and dynamic characteristics and the vehicles share the same road space without any separation. Knowledge of the basic traffic flow characteristics like traffic volume under such heterogeneous condition is fundamental, since traffic volume is the basic input variable in planning, design and operation of traffic systems. Expressing traffic volume as a number of vehicles passing a given section of road per unit time are inappropriate when several types of vehicles with widely varying static and dynamic characteristics are present in the road traffic volume. The problem of measuring volume of such heterogeneous traffic will be addressed by converting the different type of vehicles into equivalent passenger cars and expressing the volume as passenger car unit (PCU) per hour or passenger car equivalent (PCE) per hour.

PCU values are used as factors to convert a traffic stream composed of different vehicle types into an equivalent traffic stream composed exclusively of passenger cars (reference vehicles). Under homogeneous traffic conditions the volume or capacity may be expressed in terms of PCU per hour per lane. Since the pattern of occupancy of road space by vehicles under heterogeneous traffic condition differs significantly from that of homogeneous traffic, the volume of traffic has to be expressed taking the whole width of roadway as the basis. In this study, traffic comprising different categories of vehicles with wide ranging static and dynamic characteristics is dealt with. This study is concerned with estimation of PCU values for the different types of vehicles, under heterogeneous traffic conditions on two lane trunk road in Ethiopia, using Chandra's method, homogenization coefficient method and simulation technique (VISSIM) software.

1.2.Statement of the problem

During highway design, it is essential for the traffic engineer to convert different types of vehicles to passenger car equivalents to determine the capacity and the number of vehicles use the given road. In Ethiopia, the passenger car equivalents for different vehicles are taken from HCM 2010 while doing the operational analysis, the service flow rate, volume analysis, and the design analysis for the traffic flow. But HCM of 2010 warns the traffic engineer may find PCU at local level for the purpose of design and understand the differences. Related to this issue, different authors

(Girum, 2016) has done a research on express way considering grade length of road segments and determined the PCU for heavy vehicles. Similarly, Belay, 2018, has developed PCU for different intersection of Harar city and found the effect of three wheelers on the performance of different vehicles. The current study aimed to determine the PCU for different type of vehicles on flat terrain of two way two lane road sections on the road connected to Addis from four directions.

Due to widely varying static and dynamic characteristics of vehicles under mixed traffic condition, each vehicle is unique and cannot be compared with other vehicle types as it demonstrates distinct effects on behavior of traffic flow on varying composition. Hence, expressing traffic flow as number of vehicles passing a given section of roads per unit time is inappropriate. Due to this, the problem rises in designing roads and traffic operation in mixed traffic. To overcome this problems, a uniform measure of vehicles which converts a traffic stream with different types of vehicles into an equivalent traffic stream composed of exclusively passenger cars, with the same operational conditions and quality of service is necessary (Raj, 2017)

Since the operation, vehicle performance, speed limit of the given road, capacity of the given road and the size of vehicle are different from country to country and have their own effect on PCU, the traffic engineer should consider their effect during designing the road at local level. Most of the time in Ethiopia the volume of the given road is expressed as vehicle per hour which is inappropriate as (Ovi, 2013), this writers report that expressing traffic volumes as number of vehicles passing a given section of road or traffic lane per unit time will be inappropriate when several vehicles with widely varying static and dynamic characteristics are comprised in traffic. So according this study, the traffic stream of Ethiopia is also heterogeneous traffic which uses conversion factor. To solve such type of problem it is essential to express volume of the given road by passenger car equivalent per hour.

As different researcher of different country conduct research on PCU of different vehicles, they found different values of passenger car units on different roads under different road condition. For instance as (Saha, 2009) mentioned; the road traffic systems, travel patterns and other traffic characteristics are different for each country due to differences in available transport facilities for commuters, rate of development in the transport sector and so on. Consequently, many standard relations and factors used in one region may not be suited for others. The road condition and the type of vehicles in Ethiopia is also different from the other country as mentioned in (Saha, 2009) the speed of the given vehicle is affected by the road condition, type of vehicle in the traffic flow and ability of driver of different vehicles which has effects on the value of PCU in different countries. Overtaking of slower vehicles requires the use of the opposing lane where sight distance and gaps in the opposing traffic stream permit. As the volume increases, the ability to pass decreases, thus resulting in the formation of platoons in the traffic stream.

Two lane highways are used for a variety of functions, are located in all geographic areas, and serve a wide range of traffic requirements. Consideration of operating quality must account for these disparate traffic functions. So finding passenger car units for different types of vehicles which use two lane highways is important for traffic engineers to plan, design and forecast the capacity of the rural roads. The area consumed by heavy vehicles on the road is affects the speed of standard vehicles which use the same roads. All different vehicles have different speeds, size, load carrying capacities or passenger capacities etc. which affect the performance of the traffic facility.

In developing country like Ethiopia due to rapid growth of economy, there is high motor vehicle traffic increment and this traffic flow condition is highly heterogeneous in which small to big vehicles move on the road ways without following any lane discipline among them (Henok, 2018). In rural area of Ethiopian, two way two- lane highways; the vehicles overtakes by using the opposite lane; which have its own influence on the standard vehicles or passenger cars. Since, Passenger Car Unit (PCU) is a metric used in Transportation Engineering, to assess traffic-flow rate on a highway. A Passenger Car Unit is a measure of the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single standard passenger car. As the country tends to developing, the number of vehicles are also increase on the road section which creates congestion. So, to manage such type of problem, studying the passenger car unit of different vehicles is very important in developing country.

In general there are different factors, which influence passenger car equivalents and some of these are length of vehicle, and traffic flows (volume demand, percentage of vehicle types, and vehicle speeds) which are considered in this study to solve the challenges which phase traffic Engineers during highway design.

1.3. Objective

1.3.1. General objective

This study was aimed to estimate the road capacity and PCU values for different categories of vehicles under heterogeneous traffic condition on Addis Ababa –Holeta trunk road, Addis Ababa –Sebata, Addis Ababa- Sululta and Addis Ababa Sendafa trunk road where two way two lane road sections exist.

1.3.2. Specific objective

- ✓ To estimate the passenger car unit for different categories of vehicles under heterogeneous traffic stream.
- ✓ To analyze the variation of PCU values with respect to different interval of traffic volume for the study areas.
- ✓ To compare and contrast the passenger car unit obtained from different methods
- ✓ To find the road capacity of the study areas

1.4. Research Questions

This thesis aims to address the following questions:

I. What are the PCU of different categories of vehicles under heterogeneous traffic stream of Addis Ababa to Mennagesha, Sululta, Sendafa, Sebata and Mennagesha to Holeta road?

II. What are the similarity and dissimilarity of the Passenger car unit of the selected section obtained by selected model?

III. What is the Capacity of Addis Ababa to Mennagesha, Sululta, Sendafa, Sebata and Mennagesha to Holeta road section?

IV. What are the variations of PCU values under different level of traffic volume?

1.5. Scope of the study

This paper deals with the determination of Capacity and the PCU of different types of vehicles on the Addis Ababa-Holeta trunk road, Addis Ababa-Sebata trunk road, Addis Ababa–Sululta trunk road & Addis Ababa-Sendafa trunk roads. To calculate the PCU of these roads, the following factors were considered:

1. The segment taken is in the flat terrain

2. The space speed of a given vehicles
3. The projected rectangular area of different vehicles
4. The time taken to cover the segment distance of 60m.
5. The length of different vehicles

1.6. Significance of the study

This study mainly deals with the capacity and passenger car unit estimation of the roads which connected to Addis Ababa from:-Holeta, Sululta, Sendafa and Sebata. Passenger car unit of different types of vehicles is significant in the study of mixed traffic particularly for studies concerning capacity, signal design, parking lots etc. So the following are listed as the significance of the study. The result of the study would be helpful to get the information about the capacity and the PCU values of different categories of vehicles of the selected road sections. Gives information for ERA as finding Capacity and PCU values for different vehicles are important at local level. To recommend the ERA to have their own HCM. It helps to conduct further research regarding to capacity and PCU values of different types of vehicles.

1.7. Structure of the thesis

This thesis consists of five chapters and appendix. Chapter one is an introduction, which include the background, statements of problems, objective of the study, scope of the study, significance of the study and structure of the thesis. Chapter two is the literature review, which discus the theoretical frame work for the study. Chapter three discusses the methodology used to answer the specific objectives. Chapter four discusses with the results and analysis of study. Chapter five deal with the conclusion and recommendation of the study. The general concept of this thesis is putted by using the following charts.

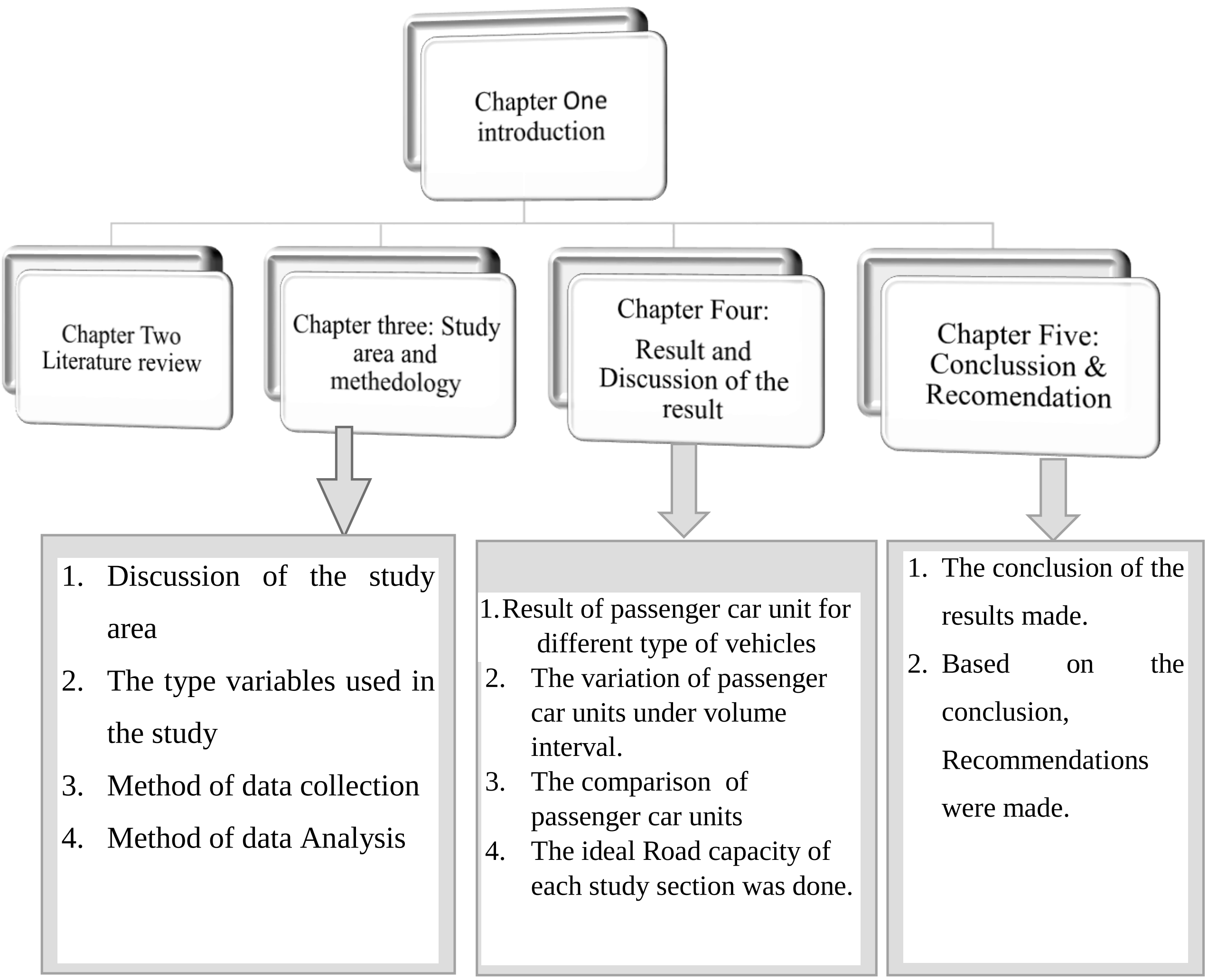


Figure 1: General concept of the thesis part.

CHAPTER TWO: LITERATURE REVIEW

This chapter presents some background information of the available literature related to the definition of two lane highways, estimation of passenger car unit by different methods and capacity determination by using different methods. The first section deals with overall definition of two lane highway and the second deals with description of passenger car unit by different methods. The third section focuses on description of capacity.

2.1.Two lane highway

According (2010)the term two lane highways was defined as "a road way with a two lane cross section, one lane for each direction of flow, on which passing maneuvers must be made on the opposing lane." As it was mentioned in highway capacity manual as volume and geometric restrictions increase the ability to pass decrease and platoons form. Motorists in platoons are subject to delay because they are unable to pass. Two lane highways are a key element in the highway systems of most countries. They perform a variety of functions, are located in all geographic areas and serve a wide range of traffic.

As it was mentioned by (MESSER, n.d.) The basic HCM equation for the conversion of a mixed-traffic-stream volume to an all-passenger-car volume for two-lane highways is as follows:

$SV_L = 200*(v/c)_L*W_L*T_L*B_L$---2.1

Where: SV_L =maximum volume for a given level of service (LOS) L (total for both directions).

$(V/C)_L$=volume-to-capacity ratio at LOS L,

W_L= adjustment factor for lane width and lateral clearance at LOS L,

T_L= truck adjustment factor at LOS L, and

B_L= bus adjustment factor at LOS L.

The truck adjustment factor (T_L) is calculated by using the following equation.

$$TL = \frac{1}{[1+\mathrm{Pt}(\mathrm{Et}-1)]} \quad \text{-----} 2.2$$

Where: $P_{T=}$ is the decimal fraction of trucks in the traffic stream and

$E_{L=}$ is the PCE for trucks at LOS L.

2.2. Classification of two lane highway

As it was discussed in (2010) two lane highways are categorized into two classes for analysis:

1. Class-I these are two lane highways on which motorists expect to travel at relatively high speeds. Two lane highways that are major intercity routes, primary arterials connecting major traffic generators, daily commuter routes, or primary links in state or national highway networks generally are assigned to class-I. class –I facilities most often serve long distance trips or provide connecting links between facilities that serve long distance trips.

2. Class II - these are two lane highways on which motorists do not necessarily expect to travel at high speeds. Two lane highways that function as access routes to class I facilities, serve as scenic or recreational routes that are not primarily arterials, or pass through rugged terrain generally are assigned to class II. Class II facilities most often serve relatively short trips, the begging and ending portion of longer trips ,or trips for which sightseeing plays a significant role.

2.3. Types of analysis in two lane highway

As it was discussed in (Roess, 2004) analysis of two lane rural high ways operations be limited to a composite analysis of both direction. There are currently two different methodologies for analysis of two lane highways:

1. Single – directional analysis of general extended section in level or rolling terrain.
2. Single – direction analysis of specific grades.

For specific grades, single-direction analysis of both grade is particularly important because these tend to differ significantly. In what is usually referred as “mountainous" terrain, all analysis is on the basis of specific grades regarding that terrain. Any grade of 3% or more at least 0.6 miles long must be addressed using specific grade procedures.

As it is noted in the (Roess, 2004) for two lane highways, all composite grades are treated using the mean grade of the analysis section. The mean grade for any segment is the total change in elevation divided by the length of the segment.

2.4. Free flow speed

As it was discussed in (Roess, 2004) the free flow speed of a two lane highway is a significant variable used in estimating expected operating condition. The free flow speed is estimated by the following formulae.

$$FFS = BFFS - f_{LS} - f_{A} \qquad (2.3)$$

Where: FFS = free-flow speed for the facility, km/h

BFFS = base free-flow speed for the facility, km/h

f_{LS} = adjustment for lane and shoulder width, km/h

f_{A} = adjustment for access point density, km/h

Unfortunately, the HCM is not provide any detailed criteria for BFFS. It is limited to a range of 45 to 65 km/h, with Class one highways usually in the 55 to 65 km/h range. Class two highways are usually in the 45 to 50 km/h range. Design speed and statutory speed limits may be used as inputs to establishing an appropriate value for BFFS.

2.5. Estimating Demand Flow Rate

As it was mentioned in (Roess, 2004) estimation of demand flow rate requires that an hourly volume reflecting prevailing conditions be adjusted to reflect maximum flow rates within the hour and base conditions. For two-lane highways, this adjustment is made as following formulae:

$$v = \frac{V}{PHF * fhv * fg} \qquad (2.4)$$

Where: v = demand flow rate, pc/h

V = hourly demand volume under prevailing conditions, veh/h

PHF = peak hour factor

f_{HV} = adjustment for heavy vehicle presence

f_{G} = adjustment for grades

2.6.Determining the Heavy-Vehicle Adjustment Factor

The heavy-vehicle adjustment factors for both types of speed determinations are found from passenger-car equivalents as follows:

$$\text{fhv} = \frac{1}{1+Pt(Et-1)+\Pr(Er-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Where f_{HV} = heavy-vehicle adjustment factor

P_t= proportion of trucks and buses in the traffic stream

P_r = proportion of recreational vehicles in the traffic stream

E_t = passenger-car equivalent for trucks and buses

E_r = passenger-car equivalent for recreational vehicles

2.7.A brief overview on basic terms used in Traffic flow theory

Traffic flow theory is one of the disciplines of traffic engineering which uses mathematical analysis and modelling to explain highway traffic flow mechanisms. In (HCM, 2010)Three basic variables—volume or flow rate, speed, and density—can be used to describe traffic on any roadway. In HCM 2010, volume is a parameter common to both uninterrupted- and interrupted-flow facilities, but speed and density apply primarily to uninterrupted flow. Some parameters related to flow rate, such as spacing and headway, also are used for both types of facilities; other parameters, such as saturation flow or gap, are specific to interrupted flow. As it was discussed in (Twagirimana, December 2013)In order to establish these relationships on two-lane highways, it is important to understand those parameters for which the steady- state flow fundamental relationship is shown in the following equation:

$$Q = U_S * K \quad ---------- 2.6$$

Where:

Q= Flow (Veh /h)

U= Macroscopic speed (Km/h)

K= Density (Veh/km)

Different terms used in analysis of traffic flow are defined in the following part as described in the Highway Capacity Manual (HCM, 2000). These terms are grouped into two types, according to the relative approach in which they are used, as shown in Figure 2.1.

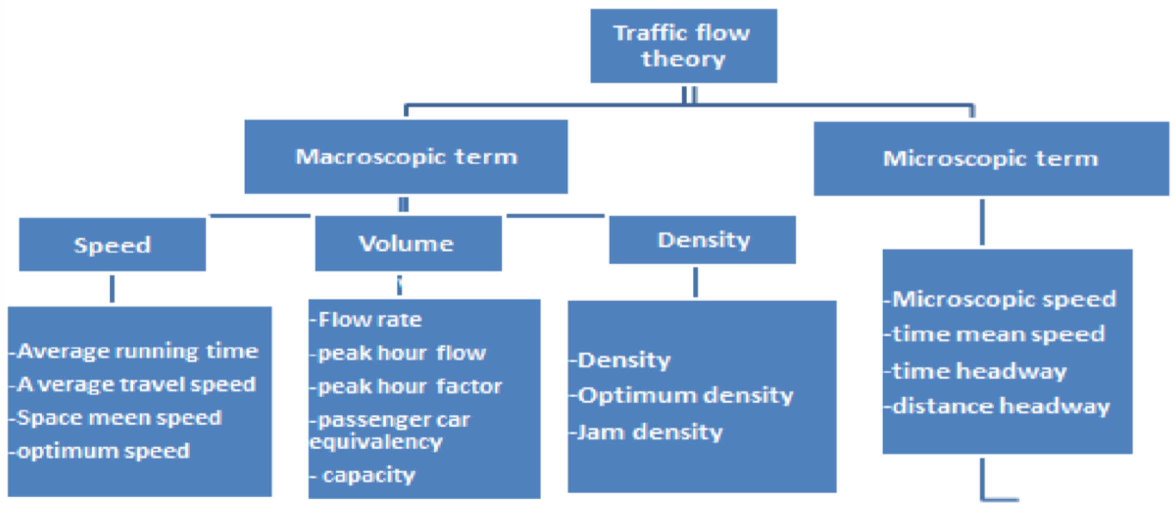


Figure 2: most used terms in traffic theory (Source. (Twagirimana, December 2013))

2.7.1 Macroscopic Approach

When traffic is studied at the macroscopic level, the following traffic characteristics are Considered:

Speed

Speed can be defined as the rate at which vehicles move along a given roadway. A typical unit is kilometer per hour (km/hr). It is the inverse of time taken to traverse a given length of road sections.

In the analysis of traffic stream, following speed parameters can be considered depending on the purpose of the study (Twagirimana, December 2013):

- ✓ Average running speed is a speed calculated when vehicles are only in motion and is resulted by dividing the length travelled by the time a platoon of vehicles uses to travel a given length.
- ✓ Average travel speed is the speed resulted by dividing the distance travelled by the average travel time required for a stream of vehicle not excluding the time the vehicles were stopped.
- ✓ Free-flow speed is defined as the mean speed of vehicles moving over a roadway, measured under low-volume traffic conditions, that is, when density and flow rate on specific section of the roadway are both zero. In this case, the drivers are free to drive at their desired speed and are not embedded by the presence of others.

- ✓ Space mean speed is defined as a speed of a traffic stream measured under basis of the mean travel time of vehicles traveling over a given segment. This speed draws this name from the fact that the mean travel time weights the average to the time each vehicle spends in a given roadway. The following formulae is used to get the space mean speed:

$$\text{Us} = \frac{n}{\sum(\frac{1}{Ui})} = \frac{nL}{\sum ti} \qquad \text{2.7}$$

Where: Us= Space mean speed (km/h); n = Number of vehicles (vehicles);   =the time it takes the individual vehicle i to travel a given highway section (sec);   = speed of the individual vehicle i (m/sec); L = length of section of the highway (m)

Volume

Traffic volume or traffic flow rate which is often used interchangeably as intensity, traffic flow etc. Flow is often estimated over the course of an hour, in which case the obtained value is typically referred to as volume. Thus, when the term “volume” is used, it is generally understood that the corresponding value is in units of vehicles per hour (veh/h). The definition of flow is more conceptualized to account for the measurement of vehicles over any period of time ((Mannering, 5th edition).

Density

Density is defined as number of vehicles that take place a given length of road section/ lane and is generally explained as vehicle per kilometer [veh/km]. The measurement of density is tedious but can be computed from other macroscopic parameters (speed and volumes) or estimated (Roess, 2004).

Following density parameters are of very essential in defining relationship between traffic characteristics:

- ➢ Optimum density can be explained as, a density which corresponds to the peak flow.
- ➢ Jam density is defined as the Peak density that may be found on any road. This density is obtainable for stopped type of car on a given road, that is, when Volume is zero.

2.7.2. Relationship between traffic flow characteristics

First, in order to simplify the representation of r/ship behind traffic flow parameters, the basic stream flow relationships were developed under the idea of a linear relationship between speed and density.

The resulting Speed-Density relationship is shown in the following equation:

$u = u_f(1 - \frac{k}{k_j})$---2.8

Where U=space mean speed, u_f=free flow speed (km/hr.) k_j=jam density (veh/km), K= density (veh/km)

Speed flow models

Applying the basic flow relationship between traffic parameters Equation (2-6) to the linear speed-density relationships equation (2-7), the dawn ward parabolic shaped speed-flow curve was gained as shown below:

$q = k_f(u - \frac{u^2}{u_j})$---2.9

Flow density models

The flow density model, which is a relationship between flow on a cross section and the corresponding density, is fundamental diagram of traffic flow. Theoretically, this graph can be gained as shown in equation (2-8); it is derived by the equation (2-6) to the speed-density relationship shown in equation (2-7).

$\boldsymbol{q = u_f(k - \frac{k^2}{k_j})}$……………………………………..……………………………………2.10

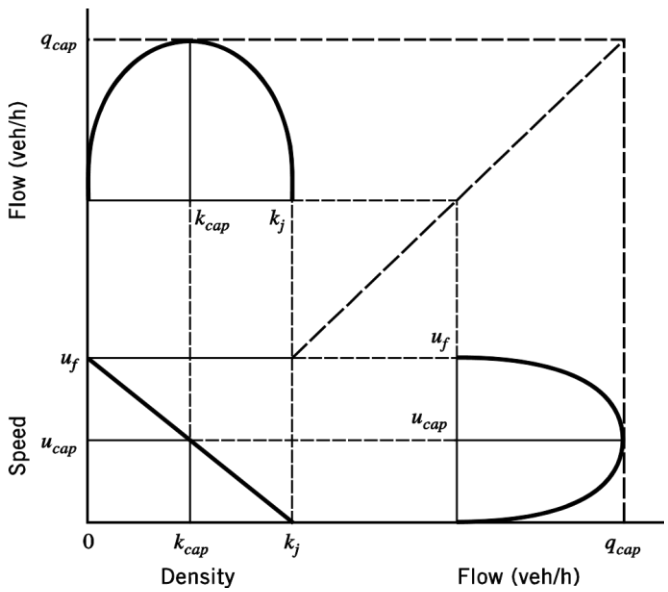


Figure 3: Flow-density, speed-density, and speed-flow relationships (assuming a linear speed-density model) (source principle of highway Engineering and Traffic analysis 5th edition 2013)

2.8. Determination of passenger car equivalents

2.8.1 Definition of passenger car

In (2010) the term passenger car Equivalent was defined as “The number of passenger cars displaced by a one heavy vehicle of a particular type under specified roadway, traffic, and control conditions.”

In (Anon., 2010) the term passenger car equivalent was also defined as “the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions”.

As it was discussed in (Mondal, 2017) the term passenger car unit (PCU) was first introduced in the 1965 US HCM (TRB) and took for grades of specific length and percent ,proportion of trucks, and level of service (A-E). As it was cited in the paper of (Girum, 2016)Passenger Car Equivalent defined in HCM 2010 as “the number of passenger cars that will result in the same operational conditions as a one heavy vehicle of a particular type under specified roadway, traffic and control conditions”. There are many studies available in literature to estimate the passenger car unit of different categories of vehicles under heterogeneous traffic condition. Passenger car equivalent or passenger car unit can be determined by using different methods. Most of these methods were developed for the case of multilane highways, some methods were used at road intersections and also some are used for two lane rural highway. Some of these methods are the following:

1. Modified density method
2. Chandra's method
3. Method based on relative delay
4. Headway method
5. Multiple linear regression method
6. Simulation method
7. Homogenization coefficient method
8. Flow rates and density method

2.8.2. Passenger car unit based on head way

The concept using the headways is that headway is a measure of space occupied by a vehicle. This is the most known method used for measuring PCU at signalized intersection. As it was cited by (Sarraj, 2012) Green shields et al, 1947) estimated PCU value by the following equation which is known as basic head way method.

$$PCUi = \frac{\mathrm{Hi}}{Hc} \qquad \text{------------} 2.11$$

Where PCU_i = passenger car unit of vehicle type i.

H_i = average headway of vehicle type i, (sec).

H_c = average headway of passenger car, (sec)

And it was also cited by (Sarraj, 2012) Werner and Morrall, 1976 suggested that the head way method is the best method to determine PCUs at low level of service. The PCU is calculated as:

$$\mathrm{Et} = \frac{\frac{Hm}{HB} - Pc}{Pt} \qquad \text{------------} 2.12$$

Where H_M = is the average headway for a sample including all vehicle types,

H_B = is the average headway for a sample of passenger cars only,

P_C = is the proportion of cars, and

P_T = is the proportion of trucks.

E_t = is truck equivalent

As (Sarraj, 2012) analysis the results of passenger car unit for lorry and buses data was collected from three representatives intersection in Gaza city and their average result was shown in the following table.

Table 2.1: PCU values for Buses and animal driven carts in Gaza city by using headway methods source (Sarraj, 2012).

	AL-Azher Intersection	AL- Samer Intersection	Asqoula Intersection	Average Value of PCU
PCU of a Bus	1.90	2.03	2.01	2.01
PCU of a cart	1.77	1.51	1.59	1.7

As (Sarraj, 2012) was discussed in his paper under conclusion part analysis of PCU values for buses and animal driven carts or lorry in Gaza, Palestine, using the headway method. This method was selected by Sarraj, because of its simplicity and suitability to determine PCU values on level terrain at a low level of service. To conduct this analysis the work group selects three main signalized intersection sites. The three sites are located in Gaza city, Palestine. All locations were with through lanes, and they were carefully selected so that there was no known deficiency of roadway or traffic condition that would affect the estimated PCU value. The data were collected under dry weather conditions and during morning and afternoon periods.

2.8.3. Chandra’s Method

This method uses two factors namely velocity of vehicle and its projected rectangular area to calculate PCU values.

$$\text{PCU } i = \frac{Vc/Vi}{Ac/Ai} \text{--} 2.13$$

Where: V c & V i = are mean speed of car and type of vehicle i respectively

Ac & Ai = are projected rectangular area of car & vehicle type i respectively.

According the discussion done by (Chad, 2018) passenger car units are estimated for both hilly and plain condition by using various methods namely density method, Chandra method and head way method .comparison of passenger car units values has been done and finally Chandra method is observed to give more true and realistic results in both plain and hilly topography on road section of Visakhapatnam city. The table shown below shows the results obtained by (Chad, 2018) from three methods for both plain and hilly road section in Visakhapatnam city.

Table 2: Estimation of passenger car unit's source from Journal of (Chad 2018)

Type of Vehicles	Plain terrain			Hilly terrain		
	Headway Method	Density Method	Chandra Method	Headway Method	Density Method	Chandra Method
Bus/Truck	10.80	2.7	3.63	9.38	2.57	3.66
3-W	2.07	0.73	0.58	1.89	0.57	0.60
LCV	4.02	1.28	1.21	4.33	1.80	1.31
2-W	0.32	0.25	0.21	0.3	0.27	0.21

From the above table it can be observed that there is not much change in the PCU values which are obtained using different methods with a change in the terrain. They are almost same for plain and hilly terrains. Results obtained from Chandra's method indicate that the method is far more reliable than other methods.

In (Hitakshi Barve*, 2018)the capacity estimation of road and PCU estimation of different vehicles under heterogeneous traffic condition was estimated. This mentioned in the paper the data was collected at five main highways around in Khandwa city using video recorder. The detailed extraction of traffic volume and speed were made for every five minute time interval, covering both the peak and non- peak period. Comparison of PCU values was been done and finally Chandra's method was observed to give more reliable and realistic results.

The result obtained by Hitakshi Barve at different section was mentioned in the following table.

The passenger unit value for different vehicles can be determined at unique section of the highways. This indicates, it is required to adopt the mixed traffic into homogeneous by using common unit, which is termed as passenger car equivalent. Density method and Chandra's model has been used to determine the passenger car unit for different vehicle groups. For instance, the Comparison of PCU for Bombay bazaar road by density and Chandra method will be shown below.

Table3: Comparison of PCU for Bombay bazaar road by density and Chandra method source from journal of HitakshiBarve

Vehicle Type	9:00 am-10:00 am		5:00 pm- 6:00 pm		9:00 pm -10:00 pm	
	Density method	Chandra's Method	Density method	Chandra's Method	Density method	Chandra's Method
Car	1	1	1	1	1	1
Truck	-	-	-	-	2.62	3.80
Bus	-	-	-	-	2.11	5.20
2 wheeler	0.50	0.28	0.64	0.25	0.55	0.23
3 wheeler	0.82	1.02	1.26	0.75	1.04	0.70
Trailer	0.54	3.83	0.83	2.82	0.66	2.80
LCV	1.18	2.61	1.94	1.80	1.33	2.07
Bicycle	0.04	0.56	0.05	0.42	0.05	0.40

These outcomes is indicates the importance of growth the lane areas. It's far determined that PCUs of different categories of automobile are inversely associated with length of passenger (automobile). PCU values relevant to moderate day conditions need to be developed instead of depending at the vintage PCU values given in code. As it was discussed by (A.R.Khanorkar1, 2014) the development of passenger car unit was done by using Chandra's methods in Nagpur city. This guy collects data from four sites and finds the passenger car units depending on the effects of traffic volume, carriage width and shoulder width of the two lane roads and conclude that the capacity and passenger car units are affected by the volume of traffic, carriage width and shoulder width of the given road section.

Nguyen Cao, uses Chandra's Method to find the value of Motor car Unit (MCU) by using the modified formula of Chandra's method by the following formulae

$$MCU\ k = \frac{Vmc}{Vk} * \frac{Sk}{Smc} \quad \text{------------------------------} 2.14$$

Where MCU k = motor cycle equivalent unit of type k vehicle.

Vmc, Vk = the mean speed of motor cycle vehicle and type k vehicle respectively

Smc, Sk= the mean effective space for motor cycle and type k vehicle respectively

In Ethiopian Context the PCU was determined in Harar city for different type of vehicles at different intersection by using Chandra's method (BELAY, 2018) the result obtained in this study is shown in table below.

Table 4: Passenger car unit estimated at Harar city source dissertation of (BELAY, 2018))

Study area				Arategna Intersection		Sash Garage Intersection		Sillassie Intersection	
Veh. Type	Length(m)	Width(m)	Area(m^2)	Av. speed	PCU	Av. Speed	PCU	Av. speed	PCU
Bajaj	2.6	1.2	3.12	17.48	0.76	21.44	0.81	21.40	0.67
Cars and Taxi	3.72	1.45	5.39	23.00	1.00	30.00	1.00	24.80	1.00
4WD	4.60	1.77	8.11	26.30	1.31	35.00	1.29	24.80	1.50
Mini Bus	5.80	1.9	11.02	30.00	1.57	38.00	1.61	32.70	1.55
Medium Bus	7.10	2.1	14.91	21.50	2.96	28.20	2.90	25.00	2.70
Large Bus	12.30	2.43	29.65	20.20	6.26	25.00	6.60	23.40	5.82
M/Truck	7.60	2.35	17.63	24.30	3.09	31.00	3.16	30.00	2.70
L/Truck	9.16	2.5	22.88	24.00	4.06	26.80	4.75	28.00	3.76
T/T 43.75	17.50	2.5	17.80	-------	-----	--------	------	-------	------

2.8.4. Method based on Modified Density method

As it was mentioned by (Swetha, 2016) Modified density method assumes the homogeneous traffic and it is used by adjusting the method to handle heterogeneous traffic and is based on traffic entity and speed of the vehicle. For estimating PCU values using modified density method, all traffic entities that comprised the heterogeneous traffic at 4 types of roads and vehicles of all classes as it was discussed by this guy. PCU value of a vehicle class from modified density method is as calculated from below formulae.

$\text{PCU} = \frac{Kcar/Wcar}{Ki/Wxi}$---2.15

Where,

Ki = density of a particular vehicle class

K car = density of the car

qi = flow of the corresponding vehicle class

ui = speed of the corresponding vehicle class

W car = width occupied by cars in heterogeneous traffic condition

W xi = width occupied by corresponding vehicle class in heterogeneous traffic condition

As PCU was calculated by (Swetha, 2016) to calculate passenger car units of different class of vehicle he use three method which are: relative density method, homogenization coefficient methods and Chandra methods. The data was gathered from Four major traffic corridors were identified for carrying out the study that are corridor is subjected to disruption of smooth flow of traffic, Entity of different class of vehicles will be obtained, a very high volume of traffic plying on it especially during peak hours, topography of roads was different, which account in variation of static characteristics of vehicles. The data analysis for modified density method was Average spot speed of vehicles in (kmph). An average of spot speed of 25 numbers of vehicles was taken to calculate the speed of the corresponding vehicle class. Spot speeds are determined by enoscope method. Vehicular speeds are determined and are recorded. Observing the records on an average two wheelers move with a maximum velocity (35.58kmph) and heavy vehicles move with a minimum velocity (27.67kmph) on selected corridors of the city. The data of this particular care hospital road is consider due to higher volume of traffic and represented in table below.

Table 5: from Swetha, 2016 for Care hospital road- Analysis by Modified Density Method

Vehicle Type	Number of vehicles(N)	Flow qi Veh/hr	Speed ui km/hr	Density ki=qi/uiveh/km	Wxi (m)	Kcar/wcar (1)	Ki/wxi (2)	PCU (1/2)
HV	17	34	16.60	2.05	2.4	4.7	0.85	5.53
LCV	43	86	24.85	3.46	7.0	4.7	0.5	9.40
Car	558	1116	31.46	35.47	4.5	4.7	4.7	1.0
Two-wheeler	1600	3200	27.50	116.36	7.0	4.7	16.63	0.30
Three wheeler	469	938	25.71	36.50	7.5	4.7	4.9	0.96

The result obtained for modified density method for the all section of this paper as it was discussed by (Swetha, 2016) is mentioned as the following.

- ✓ National Highway-16 On this road sections the resulted PCU is abnormally high as it was mentioned by Swetha.
- ✓ Care Hospital road- The PCU values resulted on this road section is high due the low density of the road.
- ✓ Jagadamba road – The PCU resulted on this road section is near the basic values.
- ✓ CMR road-Urban road. The PCU values resulted on this road section is show that as the value of the PCU heavy vehicle is equal with car.

2.8.5. Based on flow rate and Density method

As it was discussed by (John and Glauz, 1976) and cited by (Shalini1, 2014) in transportation engineering, the term traffic flow rate is used to indicate the equivalent hourly rate of vehicles passing a point per unit of time. PCE is computed based on grade percentage, mixed vehicle flow, and truck volume to capacity ratio by using the following formula.

$$\text{PCE} = \frac{qB - qM(1-PT)}{qM*PT} \qquad \text{------} 2.16$$

Where: q_B =equivalent passenger car only flow rate for a given v/c ratio,

q_M= mixed flow rate,

P_T= truck proportion in the mixed traffic flow

As it was cited by (Shalini1, 2014)Huber (1982) suggested a model for estimating PCE values for vehicles multilane conditions, under free flowing. PCE-values are related to the ratio between the volumes of two streams at some common level of impedance. He has given equation to calculate PCE value is

$$PCE = \frac{1}{PT} * \left(\frac{qB}{qM} - 1\right) + 1 \text{-----} 2.17$$

Where q_B = equivalent passenger car only flow rate for a given v/c ratio,

q_M = mixed flow rate,

P_T= truck proportion in the mixed traffic flow

It was also cited by (Shalini1, 2014) that the (Rahman and Nakamura, 2005) used A deterministic model of traffic flow to estimate the impedance-flow relationship. They also suggested that PCE-values are related to speed and length of subject vehicles and to vary with the proportion of trucks in the traffic stream. Sumner et al., (1984) further developed Huber's method by including more than one truck type in the traffic stream.

$$PCE = \frac{1}{\nabla P}\left(\frac{qB}{qS} - \frac{qB}{qM}\right) + 1 \text{-----} 1.18$$

Where q_S=additional subject flow rate,

∇P = proportion of subject vehicles

The PCE formula proposed by Demarchi and Setti (2003) as cited by (Girum, 2016) to avoid the possible error for mixed heavy vehicles in the traffic stream, including interaction between multiple trucks types. The relationship formulated as:

$$Et = \frac{1}{\sum_i^n Pi}\left(\frac{qB}{qM} - 1\right) + 1 \text{-----} 2.19$$

Where: E_T = Passenger equivalent of trucks

Pi = Proportion of trucks of type i out of all trucks n in the mixed traffic flow

q_B= base flow rate (passenger cars only)

q_M = mixed flow rate (passenger cars + trucks)

2.8.6. Simulation method

As it was discussed in (2010) simulation model should be considered when the desired study of performance of a traffic situation is not explicitly covered by highway capacity manual methodologies or when the traffic situation is very difficult to analysis using empirical and analytical model.

The estimation of PCU for the capacity analysis using simulation technique was done by (Hazoor, 2016)this guy studied PCUs of different type of vehicles found on urban roads in Quetta at different volume-capacity (v/c) ratios. Traffic simulation software VISSIM is used to generate traffic flow and vehicle speeds under different conditions. A network model is created in VISSIM to replicate field conditions of study area and important VISSIM parameters are adjusted to reflect heterogeneous traffic conditions of study area which is further validated with field data.

As it was discussed by (Giuffrè, 2015) Simulation data were used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of passenger cars only with a mixed fleet characterized every time by different percentages of heavy vehicles. The conclusion of this paper is conclude the value of passenger car equivalent as “ PCE estimations are small at low flow rates and increase with increased flow rates due to low volumes there are few passenger cars that can be influenced by heavy vehicles”.

VISSIM Simulation is also discussed by (Srikanth, 2017) as VISSIM consist of some simulation parameters which have the direct influence on traffic flow, speed and capacity. VISSIM works based on car-following driver behavior model developed by Widemnann. Apart from driving behavior model, VISSIM consists of simulation parameter such as Random Seed number (RSN). The default value of RSN parameter is 42 and any change in RSN values significantly affect the distribution of vehicle generation into the network or in other words; it changes the inter-arrival time of vehicles.

2.8.7. Multiple linear regression method

Charles Anum Adams (2014) this writer estimated the passenger car unit in Tamale at signalized intersection by multiple regression analysis between saturation time and vehicle types. This study was aimed at evaluating the local equivalents values for passenger cars that can be used in the design of traffic intersections to improve the performance of signaled intersections in Tamale. Two identified intersections with fixed time control along one of the busiest corridors were studied. Manual counts were used to collect data from three hour video recordings of each intersection under saturation current conditions played on a laptop computer. The values of the passenger car units (PCU) were estimated using multiple regression analysis between saturation times and vehicle types. PCU values for motorcycles, tricycles, cars and buses / trucks have been evaluated. It was recommended that a special area should be prepared in front of the signalized intersection stop lines in the metropolis to accommodate the high volumes of motorcycles in the traffic (Adams, 2014)

2.8.8. Passenger car equivalent based on delay

This method based on the relative capacity reducing effect of heavy vehicle is directly related to the additional delay caused by such vehicle when compared to the all passenger car case.as it was cited by (Shalini1, 2014)Werner and Morrall, (1976) used Walker method to determine PCE values. A basic assumption in the Walker method is that faster vehicles are not hindered in passing as they overtake slower vehicles, so queues do not form and passenger car unit is determined by using the following formulae.

$$PCEi = \frac{\left(\frac{OTi/VOLi}{VOLi}\right)\left[\frac{1}{SPM}\right]-\left[\frac{1}{SPB}\right]}{\left(\frac{OTLPC}{VOLLPC}\right)\left[\frac{1}{SPpc}\right]-\left[\frac{1}{SPB}\right]} \text{--} 2.20$$

Where: OT_i= the number of overtaking of vehicle type i by passenger cars,

VOL_i = the volume of vehicle type i,

OT_{LPC} = the number of overtaking of lower performance passenger cars by passenger cars,

VOL_{LPC} = the volume of lower performance passenger cars,

SP_M = the mean speed of the mixed traffic stream,

SP_B = the mean speed of the base traffic stream with only high performance passenger car,

SP_{PC} = the mean speed of the traffic stream with only passenger cars.

2.8.9. Passenger car unit based on travel time

As it was studied by (Shalini1, 2014)Keller &Saklas (1984) suggested a PCE for heavy vehicles on an urban arterial network; the estimated PCEs are functions of traffic volume, vehicle classification, and signal settings. The method is based on the premise “that reduction in capacity is directly related to the additional delay caused by large vehicles in the traffic stream”. PCE is measured as the ratio of the total travel times of heavy vehicles and passenger cars traveling through an urban network. This can be expressed mathematically as

$$PCE = \frac{TTi}{TTo} \qquad 2.21$$

Where: TT_i= total travel time of vehicle type i over the network in hours and

TT_o= total travel time of the base vehicle over the network in hours

2.8.10. Estimation of Passenger car unit based on Homogenization Coefficient method

As it was studied by (Swetha, 2016)lengths of the vehicles are determined by using the measuring tape and an average of lengths of corresponding vehicles are taken n recorded. The example for homogenization coefficient method is represented in the following table.6.

Table 6: PCU resulted by homogenization coefficient method taken from (Swetha, 2016)

vehicle type	length of car (lc)(m)	length of the vehicles (li)(m)	speed of car uc		speed of vehicle ui		lc/uc(1)	li/ui(2)	pcui(2/1)
			km/hr.	m/s	km/hr.	m/s			
Hv	3.7	8.40	31.46	8.74	16.6	4.61	0.42	1.82	4.30
Lcv	3.7	4.50	31.46	8.74	24.84	6.9	0.42	0.65	1.55
Car	3.7	3.7	31.46	8.74	31.46	8.74	0.42	0.42	1.00
two-wheeler	3.7	2.10	31.46	8.74	27.50	7.64	0.42	0.24	0.64
three-wheeler	3.7	2.85	31.46	8.74	25.71	7.14	0.42	0.40	0.95

2.9. Capacity estimation

2.9.1. Definition of capacity

Capacity is defined in (2010) as “the capacity of the facility is the maximum hourly rate at which persons or vehicles was reasonably can be expected to traverse a point or a uniform section of a lane or roadway a given time period under prevailing roadway, traffic, and control conditions.”

It is also mentioned as the vehicle capacity is the maximum number of vehicles that can pass the given point during specified period under prevailing roadway, traffic, and control condition. This assumes there is no influence from the downstream of the traffic operation, such as the backing up of traffic stream into the analysis point. Persons per hour, passenger cars per hour and vehicles per hour are measures that can defines capacity, depending on the type of facility and type of analysis.

2.9.2. Estimation of capacity under mixed traffic flow

As it was written by (PRASETIJO, 2005) the capacity at mixed traffic situation in Indonesia, e.g. for 2/2 UD (two way-two lane undivided) roads was estimated in such ways:

a. Direct observation of speed and flow rate average per 5 min. Only a few observations can be made due to lack of road sections with maximum flow that could be clearly identified as representing the capacity of the road section itself. The highest ranged value from 2,800 to 3,000 LVU/h (light vehicle unit/hour LVU, is used instead of PCU).
b. Observation of flow rates during short periods of simultaneous bunching conditions in both directions (headways < 5 sec). The capacity found to be ranging from 2,800 to 3,100 LVU/h.
c. Theoretical estimation from speed-flow density modeling that showing capacity of about 3,000 LVU/h.

The capacity of a road segment is determined as follows:

$$C=CO*FC_{W}*FC_{KS}*FC_{SP}*FC_{SF}*FC_{CS} \qquad (2.22)$$

Where: C = capacity (pcu/h)

C 0 = base capacity (pcu/h)

FC W = adjustment factor for carriageway width

FC KS = adjustment factor for kerb and shoulders

FC SP = adjustment factor for directional split or median

FC SF = adjustment factor for side friction

FC CS = adjustment factor for city size

2.9.3. Capacity determination by using VISSIM Calibrated

As it was discussed by (Arpan Mehar*, 2014) VISSIM software was used to determine the capacity of road section by developing speed-flow model by using VISSIM software. Under this study the primary used data for calibration is directly collected from field. This data are speed, type of vehicles, composition of vehicles, Volumes and other road data are gathered from fields. The comparison of capacity resulted by field data and simulated data was done in this study. It is also state that VISSIM software overestimate the capacity of the given road section when compared with the capacity resulted by field data. As it was mentioned in this journals Driver behavior parameters CC0 and CC1 are first determined.

2.10. Research Gap

By considering the concept of highway capacity manual the passenger car unit can be developed in the by considering different factors depending study area by considering the condition in the local environment. According to this concept different researcher develops research on the estimation of the passenger car unit by considering different factors which affect PCU values in different countries on different roads. In this study the passenger car unit is estimated on two-way two –lane highways, which connected to Addis Ababa from different country sides. To Estimate this passenger car units traffic volume, speed of different vehicle types and dimension of different vehicles was considered on the flat terrain of the road sections and the ideal capacity of the selected road section was estimated.

CHAPTER THREE: DATA COLLECTION AND METHODOLOGY

3.1. Description of the Study Area

This study was conducted on four trunk roads which connected to Addis Ababa from Holeta, Sebata, Sendafa and Sululta. These four roads are selected because of different types of vehicles use these roads to transport agricultural products and industrial finished products to Addis Ababa and vice versa. The description of each road is as follows:

3.1.1. Description of Addis Ababa-Holeta Trunk Road

The road section is started from Addis Ababa region, Addis Ketama sub-city, and specific location of bus station and extended to the west direction of Addis Ababa to Holeta town. Two segment are selected for this trunk road based on varies criteria such as the segment should have wide variation in proportion of different categories of vehicles, free from the effects of road side friction, intersection, parking facilities, bus stop, pedestrian movements, curvature, and gradient etc. the reason of selection of this road is that this road is connect Addis Ababa and Holeta town. There are different vehicles which uses this road. These vehicles come from different zones of Oromia region and Benishangul Gumuz region. There are also different industries from which different industrial products are transported to Addis Ababa. For instance, different vehicles are transport cement from Mugar cement industry to Addis Ababa, different vehicles transport sugar from Fincha sugar industry to Addis Ababa etc. So due to this all reasons Holeta Addis Ababa road is one of the selected road section. There are also different vehicles which transport people from different town to Addis Ababa city. For instance, from Ambo to Addis Ababa, from bako to Addis Ababa, from Shambu to Addis Ababa, From Nekemte to Addis Ababa, from Gimbi to Addis Ababa and from Asosa to Addis Ababa. So to find the PCU of different vehicles, two segments were selected. The selected segment study areas are:

- ✓ Between Addis Ababa &Mennagesha
- ✓ Between Mennagesha & Holeta

The location of this two segments are shown on the figure below which is taken from the Google map.

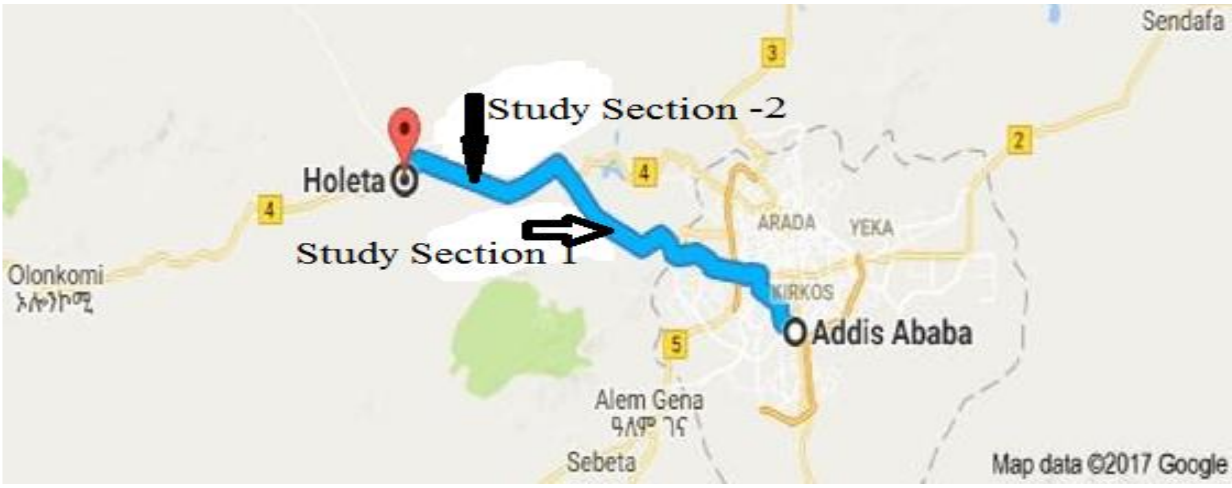


Figure 4: Road profile of Addis Ababa to Holeta (Source: Internet)

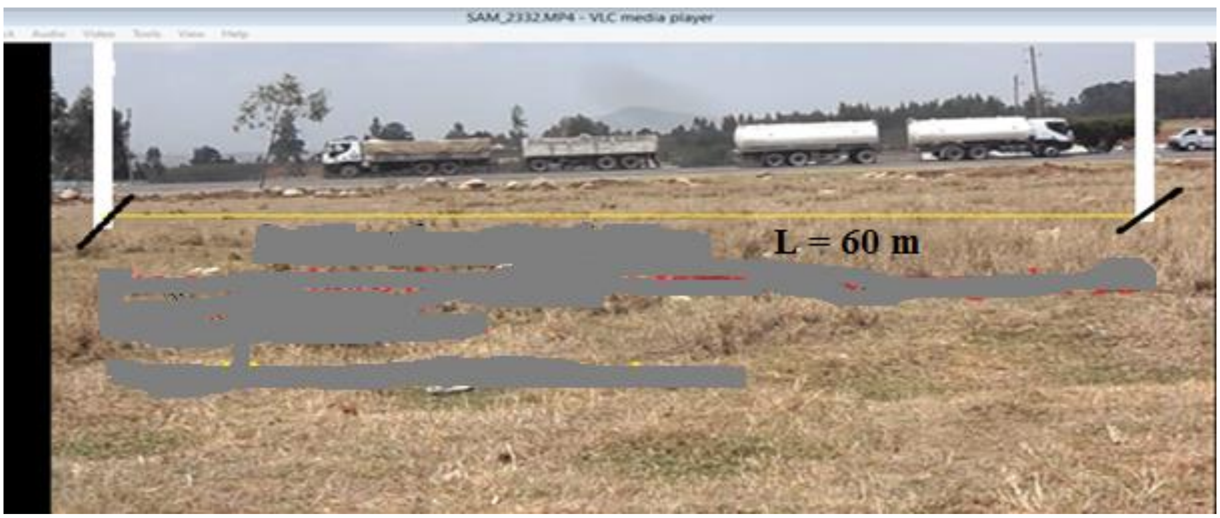


Figure 5: Picture taken from field for Mennagesha-Holeta segment.

Figure 6: picture taken from field for AA-Mennagesha road section.

3.1.2. Location

The geographical location of Addis Ababa – Holeta Trunk road is found between Addis Ababa 9.0686 North latitude & 38.665 East longitude and Holeta geographical location of 9.0633 North latitude& 38.490 East longitudinal. In administrative terms, it saturated in west Shewa zone, Oromia regional state, 38.6 km from Addis Ababa up to Holeta.

3.1.3 Description of Addis Ababa Sebata Trunk road

This road is the road which connects Addis Ababa city and Sebata town. It is located on the south-west direction of Addis Ababa city. On this road one segment was taken to study the passenger car unit of different vehicles. The segment taken should full fill the following criteria such as the segment should have wide variation in proportion of different categories of vehicles, free from the effect of road side friction, intersection, parking facilities, bus stop, pedestrian movements, curvature, gradient and median opening etc. the selected segment study area is: between Addis Ababa and Sebata Specific area saint Mikael church. The length of the segment is 60m and the width of each lane is 3.5m.

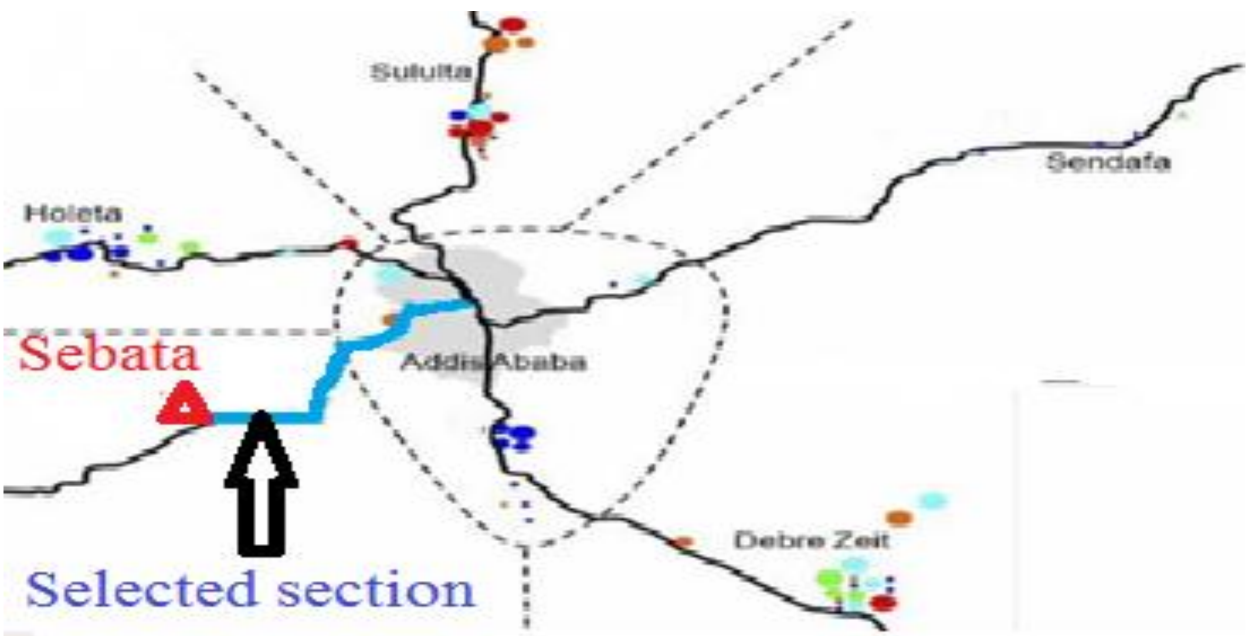


Figure 7: Profile of Addis Ababa to Sebata road from internet

Figure 8: Picture taken from field for Addis Ababa to Sebeta road.

3.1.4 Location

The geographical location of Addis Ababa-Sebata Trunk road is found between Addis Ababa 9.0686 North latitude & 38.665 East longitude and Sebata town which is separate woreda in central Ethiopia, and a suburb of Addis Ababa. Located in the Oromia Special Zone

Surrounding Finfinnee of the Oromia Region, this town has a latitude and longitude of 8°54′40″N 38°37′17″E and an elevation of 2,356 meters (7,730 feet) above sea level.

3.1.5. Description of Addis Ababa Sendafa Trunk road

This road is the road which connects Addis Ababa city and Sendafa town. It is located on the east direction of Addis Ababa city. On this road one segment will be taken to study the passenger car unit of different vehicles. The segment taken should full fill the following criteria; such as the segment should wide variation in proportion of different categories of vehicles, free from the effect of road side friction , intersection, parking facilities, bus stop, pedestrian movements, curvature, gradient and median opening etc. The length of the segment taken is 60m and the width for each lane is 3.5 meter.

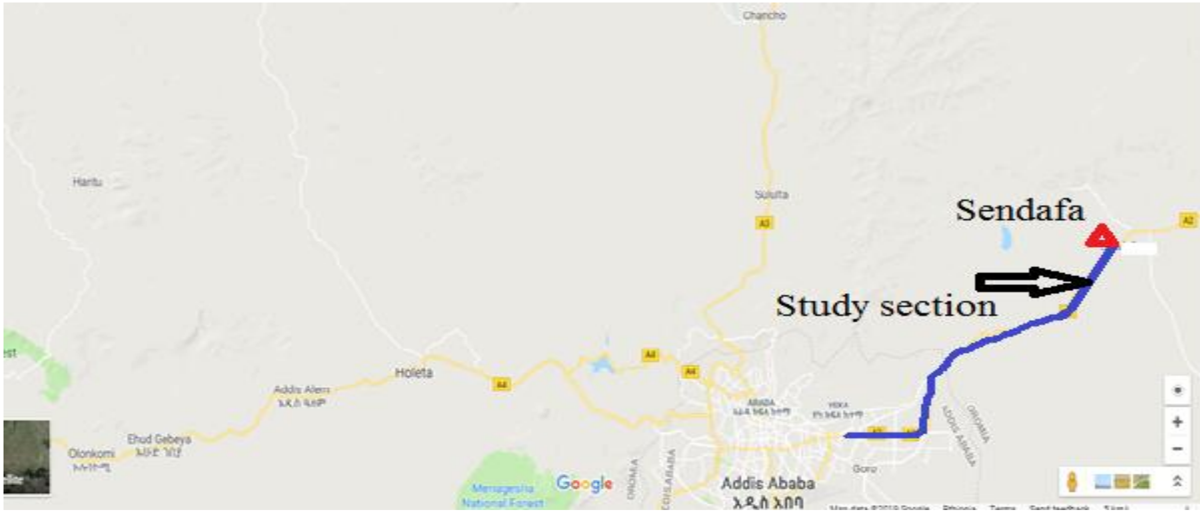


Figure 9: Addis Ababa - Sendafa road profile from internet.

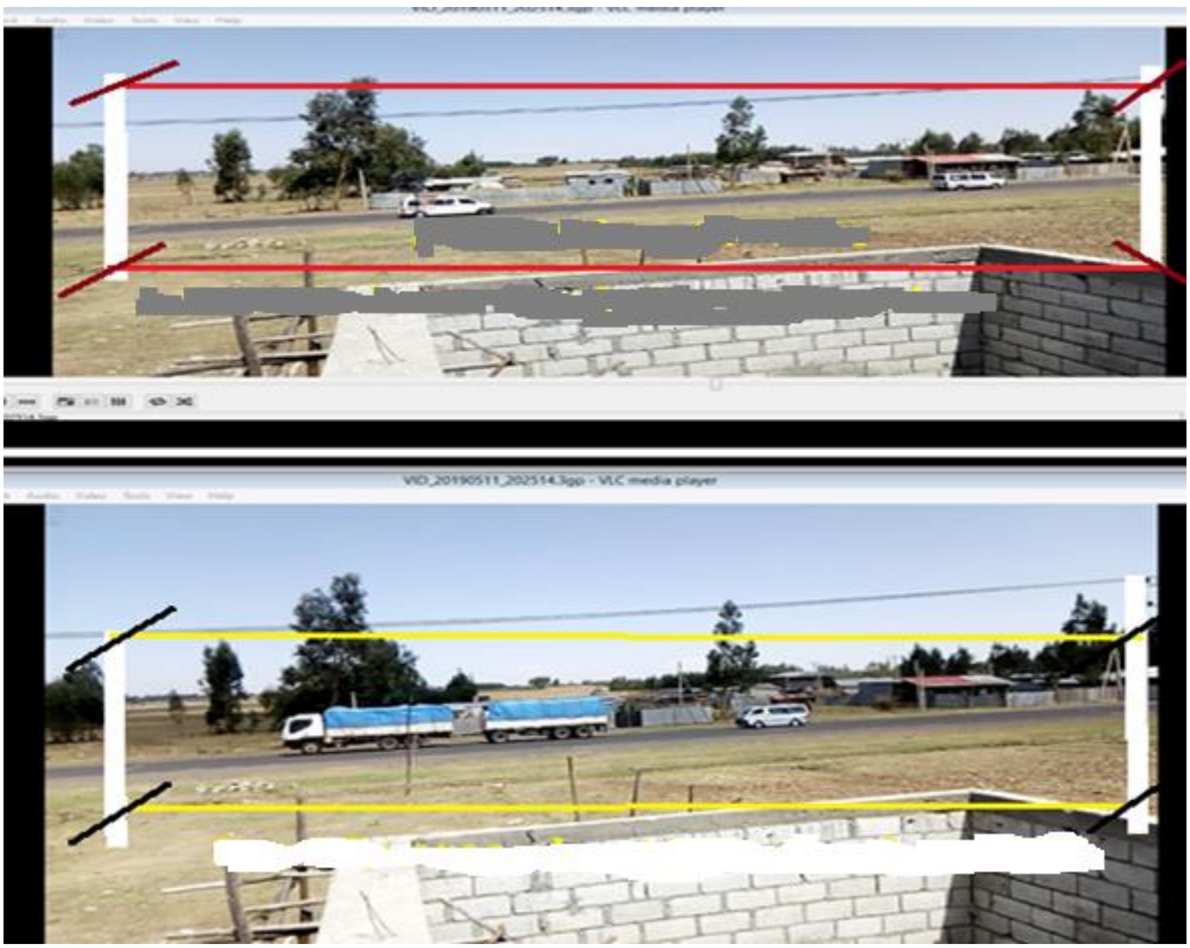


Figure 10: Picture taken on the field for Addis Ababa to Sendafa road section

3.1.6. Location

The geographical location Addis Ababa-Sendafa Trunk road is found between Addis Ababa

9.0686 North latitude & 38.665 East longitude and Sendafa has a latitude and longitude of 9°09′N 39°02′ECoordinates: 9°09′N 39°02′E with an elevation of 2514 meters above sea level.

3.1.7. Description of Addis Ababa –Sululta Trunk road

This road is the road which connects Addis Ababa city and Sululta town. It is located on the North direction of Addis Ababa city. On this road one segment will be taken to study the passenger car unit of different vehicles. The segment taken should full fill the following criteria; such as the segment should wide variation in proportion of different categories of vehicles, free from the effect of road side friction , intersection, parking facilities, bus stop, pedestrian movements, curvature, gradient and median opening etc.

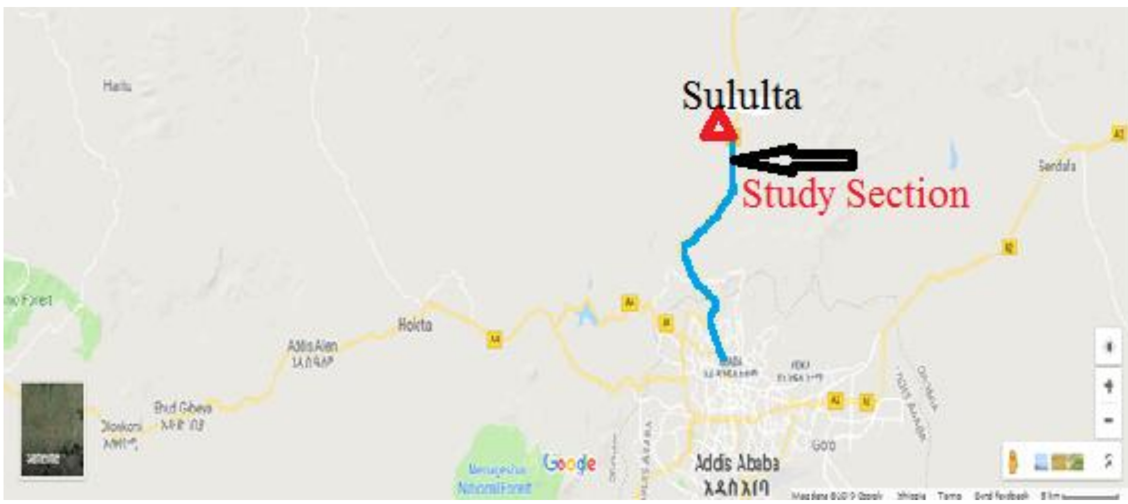


Figure 11: Addis Ababa Sululta road profile (source from internet)

Figure 12: Picture taken from the field for Sululta road section

3.1.8. Location of Addis Ababa –Sululta road

This road is situated between Addis Ababa city and Sululta town. The geographical location of this road is found between Addis Ababa 9.0686 North latitude & 38.665 East longitude and Sululta situated in North West Shewa, Oromia, Ethiopia and its geographical coordinates are 9° 11' 0'' North, 38° 45' 0'' East.

3.2. Type of data collected

3.2.1. Primary data collection

In this thesis work, the data was collected from the field by using video recording camera. To collect the data, two appropriate segments between Addis Ababa –Holeta route were used (i.e. Addis Ababa – Mennagesha and Mennagesha – Holeta) and the other segments were between Addis Ababa – Sebata, Addis Ababa –Sendafa and Addis Ababa – Sululta on the segment length of 60m for each road sections was selected. At the time filming sessions, the camera was setup some distance away from the road sections to obtain enough segment lengths, and to prevent that the influence of speed change vehicle due to action taken by driver. For the purpose of examine the traffic data was taken at minimum for five hour on each of the selected road. During the selection of the segment, there are some factors which affect the passenger car unit; these are the projected rectangular area of a given vehicle, the speed of a given vehicle, the length of the given vehicles and the variation of the volume. Due to this, the selected segment areas are on level terrain for the reason that the values of PCU are varies as the terrain of the road section varies and among this terrain this study concentrated on the variation occurred on the flat terrain by considering the traffic volume, speed, length of different classes of vehicles and the area occupied by different type of vehicles (Mondal, 2017). The speed of different vehicles and the area consumed by the different vehicles are the important data in this study with variation of traffic volume on the selected segments. For each vehicle, data were recorded with respect to travel direction and during analysis both directions are considered separately for each two lane selected road. The recorded data are: vehicle class, number of vehicles and travel time measured from the time taken between the selected two lines which were marked at each of the segment selected for the study purpose. The measured travel time was averaged for fifteen minute time interval to determine the average space mean speed. In same way, the flow was computed from number of vehicles counted in given time interval and vehicle speeds were extracted from the selected distance and the time taken to cross that distance.

At each place, the data was collected at minimum five hour as mentioned above to determine the traffic volume, speed of different type of vehicles and composition of traffic stream. The data was collected under dry weather condition and during day time only. To collect the data five days are selected. These days are Monday, Tuesday, Thursday, Friday and Saturday. Among the selected days two days were used for Holeta route segment (i.e. Addis Ababa – Mennagesha and Mennagesha – Holeta) and one day for each of the other selected road sections. The road segment, days, date and times at which the data was recorded is mentioned as listed in the table below.

Table 7: Traffic field data collection on each road segment

S.No.	Road segments	Days	Date	Times
1	Addis-Mennagesha	Tuesday	May,21/2019	9:00am-3:00pm
2	Mennagesha-Holeta	Thursday	May,16/2019	8:00am-3:00pm
3	Addis Ababa-Sebata	Friday	May,17/2019	8:00am-2:00pm
4	Addis Ababa-Sendafa	Saturday	May,11/2019	9:00am-3:00pm
5	Addis Ababa-Sululta	Monday	May,13/2019	8:00am-4:00pm

During traffic data collection by using camera, the segment length was measured first by meter and white color was paint at both ends of the length selected for data collection. The white color was used to mark the segment across the asphalt length. The purpose of painting the two lines selected at both ends of the segment section by white color is to see when the given vehicle enter &leave from the selected segment length. As mentioned on the figure below.

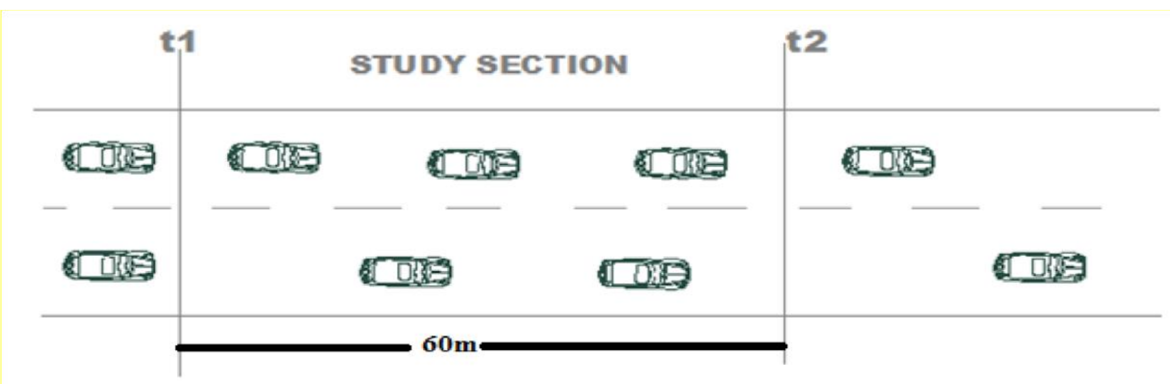


Figure 13: Symbolic representation of road segment with marked lines for transverse time readings

3.2.2. The dimension of vehicles

For this study vehicles were classified in to five main classes based on AASHTO vehicle classification scheme and Ethiopian Road Authority Manual with little modification (ERA, 2013). Car is classified into two Standard car and 4WDs. Ethiopian Road Authority Manual (ERA, 2013) Classifies minibus as 4WD (four wheel drive).Vehicle classification are discussed below.

1. Standard vehicles/passenger cars: this includes all vehicles manufactured primarily for the purpose of carrying passengers, these passenger cars are: Automobile, Toyota corolla, Vitz and Yaris etc. having average length and width of 3.7 m and 1.6m respectively.
2. 4WDs: This class includes all two axles, four tire vehicles other than passenger cars which include pickup, Nissan, ambulance, land cruiser Toyota haice dolphin, High roof and 5-L minibus etc. the size of this type of vehicle was measured in field by taking the average of maximum and minimum values for both length and width.
3. Bus: These are motor vehicles designed to carry more people than Toyota haice dolphin, high roof 5-L minibus which can carry more than 27 passengers. Size of bus was measured in field by taking average of maximum and minimum values for both length and width. For this study Small bus and large which include all the vehicles manufactured to carrying about more than 27 passenger and they has two axles and six tires or three axles. The sizes of buses were measured in field by taking average of value of large bus of different type and small bus.
4. Trucks: This class includes all the vehicles on single frame which have two axles, three axle, four axle, five axle etc. Size of truck was measured in field by taking the average value of different truck. Under this type of vehicles Small Truck, Medium Truck, Large truck and truck Trailer are included.
5. Three wheeler:-is a vehicle which has three wheelers and its dimensions are 2.6m long and about 1.2m width.

The dimension of vehicle type used for the study is described in the table below:

Table 8: Average Dimension of different vehicle types

Type of Vehicle	Included vehicles	Average Length(m)	Average Width(m)	Average Area(m^2)	Area ratio of standard car to vehicle type
Standard car	Vitz, Toyota Corolla, Tax, Yaris, etc.	3.7	1.6	5.92	1.00
4WD	5L, land cruiser, Hilux, high roof, dolphin, etc.	4.7	1.8	8.46	0.69
Bus	Small bus and L. bus	9.05	2.35	21.28	0.28
Truck	Small truck, medium truck, large truck, truck trailer etc.	9.84	2.367	23.28	0.25
Three wheeler	Three wheeler	2.6	1.2	3.12	1.89

3.3. Description of the study variables

3.3.1 Dependent Variables

In this study, the dependent variables are:

Passenger car units of different types of vehicles and

Capacity of the selected road sections.

3.3.2 Independent variables

In this study, the independent variables are:

Speed of vehicles

Different vehicles, size of vehicles (length & width)

Travel Time which is the given vehicles taken to cover the segment length

Distance

Traffic volume

Traffic density

3.3.3. Description of the study variables

1. Vehicles: - are motors vehicles classified especially by ERA which use the selected road sections during traffic data collection. Vitz, car, land rover, small bus, large bus, small truck, medium truck, large truck and truck &trailer or by categorizing into five parts they are Standard car, 4WD, Bus, Truck and three wheeler.
2. Vehicle dimension: - is the dimension of each type of vehicles which is the length and width of the given vehicle and used to find the projected rectangular area of each categories of vehicles.
3. Speed of the vehicle - the distance per unit time of each vehicle to cross the selected distance. It can be spot speed or time mean speed and space mean speed.
4. Travel Time- Travel time studies involve recording the time it takes vehicles to traverse a specified length of roadway.
5. Distance – the selected segment length along the road length. For this study about 60m trap length is taken.
6. Traffic volume- it is the total number of vehicles or pedestrians that pass over a given point or section of lanes, or highway during a given time interval. It can vary considerably with time; it means the variation of traffic volume can be further identified within minutes, hourly, daily, weekly, monthly and seasons.

3.3.4. Study population

The vehicles used during traffic field data were the one which use road segments of Addis Ababa to Holeta road, Addis Ababa to Sebata road, Addis Ababa to Sendafa Road & Addis Ababa to Sululta road section. According to Ethiopian Transport Authority the numbers of the Ethiopian vehicles are about 831265 registered vehicles by the end of 2016/2017. The study area for the selected area is located in Oromia Region.

3.3.5. Sample size determination for traffic volume

As it was discussed on the (Anon., 2007).the sample size of the volume can be determined depending on the purpose of the study, and sample size can be vary from a fraction of an hour to 24 hours, a day, 365 days a year. Normally traffic counts are not taken on holiday nor day before or after holiday. Depending on this idea for this study the sample size was taken by 15minute time interval for each section of the road for both direction of flow.

3.3.6. Sample size determination for speed

As traffic volume count (Anon., 2007) states about the sample size of speed with a rule of thumb, at least 100 speeds will be collected within the time period under consideration. This will generally provide mean or 85th percentile speeds within ± 1 kph with 95% confidence. Sample must always be both random and representative. So by this case, by using the sample size determination of Cohran's formula for unknown population; exact number of vehicles which used the road section during data collection was not accurately known. It was assumed that the common traditional confidence level, 95%, +/- 5% (e) standard error for precision, and (P=0.5 assumed standard deviation) and hence, q= 1-p = 0.5. A 95% confidence level gives as Z value=1.96. So the approximate number of vehicles considered during data collection was obtained as followed:

$$N = \frac{P * \mathrm{q}Z^2}{e2} = \frac{0.5 * 0.5 * 1.96^2}{0.05 * 0.05} = 385$$

By using this formula; N= 385 for speed estimation. But the collected number of vehicle is more than the stated sample size on each section. This is most probably for the number of vehicles considered were determined by the length of time considered during data collections.

3.3.7. Data collection methods

The major primary data of this research were collected using video cameras in accordance with the clearly defined two lane road section and direct measurement of the different types of vehicle dimension.

3.3.8. Data collection instruments

The main equipment used in collecting necessary data for this research is videotaping recorder available on smart phones like Techno and Samsung camera. Traffic volumes can be counted by viewing videotapes recorded with a camera at a collection site. A digital clock in the video image can prove useful in noting time intervals. Then number of vehicles and travel time over a fixed distance can be extracted on the notepad on a required time interval. Other equipment which is frequently used is meter tapes for measuring the length of the trap.

3.4. Method of data analysis

The collected data for different parameters of the study were analyzed using different techniques. The most common methods used for data analysis were Chandra's Methods, Homogenization coefficient method and Simulation technique (VISSIM) software to calibrate traffic data to estimate passenger car units from simulated data and Green shield Model to determine the capacity of the road section.

3.4.1. Measuring Travel Time for a particular time interval

The pattern of each vehicle was observed and travel time of each vehicle was measured directly by from recorded video for the vehicle under observation enters the section and the time the vehicle arrives at the end point of the section. That is, the difference between the time when the front bumper of the vehicle reaches the entrance point and the time the same bumper reaches the exit point of the study section. The travel times of all individual vehicles in a given time interval (15 minutes in the case of this study) were then averaged.

3.4.2. Speed calculation

The space mean speed of this study was determined from the average travel time the given type of vehicles taken to cover the 60m distance. By using the average travel time of each type of vehicles the space mean speed was determined for each 15minute. By using the given distance and the average travel time different types of vehicles taken to cover the distance the space mean speed is calculated according to the following formula.

$$U_{si} = \frac{L}{Ti} \qquad \text{------} 3.1$$

Where U_{si} = space mean speed of vehicle i

L = distance of the given section.

Ti = the average travel time of vehicles i taken to cover the given section.

3.4.3. Determination of projected rectangular area

The numbers of vehicles by their types is categorized by playing the recorded video for 15minuties time interval for each segment to know the flow or volume. The projected vehicle rectangular area is calculated by taking the Length and width of the different types of vehicles by measuring the vehicles at the place where the given type of vehicle stand. Hence, taking the average length and width of similar vehicles the projected area of different types of vehicles is calculated as:

Area of vehicle type = Average length of similar vehicle * Average width of similar vehicle

3.4.4. Methods used to calculate passenger car units

For estimating passenger car unit value these study is adopted three methods. These methods used Chandra's method, Homogenization coefficient method and Simulation technique (VISSIM) by simulating data and estimating PCUi from obtained data

3.4.5. Chandra's method

Since the publication of HCM-1965, a number of studies have been taken up all over the world to determine PCU values for different types of vehicles in varying roadway and traffic conditions. Out of various available methods, the one proposed by Chandra is most suitable for mixed traffic prevailing condition in Ethiopia. According to Chandra PCU value for different vehicles under mixed traffic situation is directly proportional to the speed ratio and inversely proportional to the space occupancy ratio with respect to the standard design vehicle that is car. Chandra's method is one of the methods used to estimate the PCU values of vehicles in this study. In a heterogeneous traffic stream; the speed of vehicle is mostly affected by the other traffic stream parameter. In Chandra's methods speed is considered as the basic parameter for determination of PCU. Hence, Chandra's method is adopted as one of proposed methodology. In this study standard cars will be considered as the standard vehicle design. According to Chandra's method PCU of any vehicle type can be obtained by the following relationship.

$$\text{PCUi} = \frac{Vc/Vi}{Ac/Ai} \quad \text{--} 3.2$$

Where;

Vc & Vi denotes the mean speed of standard car and vehicle type i respectively and

Ac and Ai denotes their respective projected rectangular area.

The numerator in the above equation is the function of volume of traffic stream as the speed of any vehicle type depends upon its category, own volume and volume of other vehicles. Therefore, speed of any vehicle type is true representation of overall interaction of a vehicle type due to presence of other vehicle of its own category and of other types. The denominator represents the carriageway occupancy with respect to standard car. This method is one of the methods selected to find the passenger car unit of Addis Ababa –Holeta, Addis Ababa – Sebata, Addis Ababa – Sendafa trunk roads &Addis Ababa-Sululta. There are so many heavy vehicles using these roads to transport different things to Addis Ababa city. Thus, heavy vehicles consume large spaces when compared with standard vehicles and move slowly on these roads. Thus, the speed and area of different type of vehicles were used to calculate the PCU of different type of vehicle using Chandra's method. The variable of speed ratio in the equation is a function of roadway and traffic conditions. Any change in these conditions affects the speed of vehicles, which is reflected by the changes in the speed ratio. The speed of any vehicle type will be true representation of overall interaction of vehicle type due to presence of other vehicles of its own category and of other type. The second variable of space ratio represents pavement occupancy and indicates maneuverability of a vehicle with respect to car is a constant for a particular class of vehicle.

3.4.6. Homogenization coefficient method

The other method which is chosen to find passenger car unit of different types of vehicles is homogenization coefficient method in addition to Chandra's method. In homogenization coefficient method, PCU of a vehicle is resulted by comparing the theoretical maximum capacity when different types of vehicles are exclusively using the road. The method compares the "all car" and "all other than car type" capacity of traffic lanes. This method requires length and speed of vehicle to calculate PCU of different vehicles. Speed is calculated by distance per time required to cover the selected distance and then average of the fifteen minute taken for vehicles of different group or class. Length of the vehicles is calculated by manually calculated by averaging the length of the vehicles belonging to same group on an average of vehicles different class from the sample taken. PCU value of a type of vehicle class from homogenization coefficient method is as calculated from below formulae.

$$PCUi = \frac{\mathrm{Li/Ui}}{\mathrm{Lc/Uc}} \quad \text{--} 3.3$$

Where,

PCU_i = Passenger car unit for type "i" vehicle

Li = length of corresponding vehicle

L_c = length of the car

U_i= speed of the corresponding vehicle

U_c = speed of the car

3.5. Simulation Technique (VISSIM) model development

As it was discussed under chapter two by (Arpan Mehar*, 2014) in the same way, in this study a Simulation model was developed using PTV VISSIM. The data collected using video from study section of AA-Sebata was used to analyze and to build simulation model. The model was calibrated and validated for the selected section of the road which connected to Addis Ababa City from:- Sendafa, Sululta, and Holeta. The validated model used to estimate capacity and passenger car unit. The Table 8 below shows input data for traffic flow simulation.

Table 9: Input data for traffic Simulation

Road section	Vehicle type	Speed parameters				Number of vehicles	Traffic composition (%)
		Min	Max	Av. Speed(km/hr)	St. dev.		
AA-Sebata	S. Car	25.00	72.00	48.50	33.23	148.00	22.16
	4WD	27.42	83.08	55.25	39.35	316.00	47.31
	Bus	24.00	63.52	43.76	27.94	60.00	8.98
	Truck	27.34	56.84	42.09	20.86	64.00	9.58
	3W	17.42	52.68	35.05	24.93	80.00	11.97
Sebata-AA	S. Car	28.80	67.50	41.53	27.36	208.00	28.73
	4WD	25.41	80.00	40.71	38.60	316.00	43.65
	Bus	30.00	56.84	40.61	18.98	28.00	3.87
	Truck	21.18	60.00	40.71	27.45	96.00	13.26
	3W	26.67	72.00	40.78	32.05	76.00	10.50

Note: S. Car =Standard Car, AA= Addis Ababa, 3W = Three wheeler, St. Dev. =Standard deviation

3.5.1 Base model development

In this study, one lane of 3.5m width study section having a length of 1000m was created representing the study section and further 200m additional buffer links were provided for the purpose of vehicle warm up at the beginning and end of base line. Figure 14 below show snapshot of simulation run.

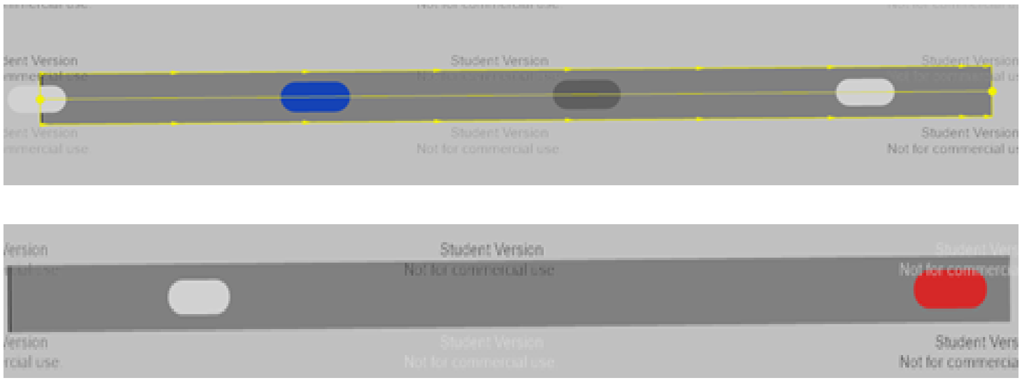


*Figure 14: Snap shot of simulation run in VISSIM

* = *In this road, overtaking is not considered during traffic data simulations by using PTV VISSIM soft wares, due to this, traffic simulation on two way two lane was done by considering only one direction.*

3.5.2 Model Parameter

a) Vehicle models

Vehicle model deals with defining the dimension of vehicle type that are playing on the test stretch and considered for simulation. The vehicle dimension, widths and lengths were used in this study as provided on the table 8.

b) Desired speed distribution

The desired speed distribution for each category was used as input for simulation model VISSIM. The minimum and maximum speeds and speed distribution between these values were defined in the model. Figure 15 below illustrates an example of 4WD desired speed distribution

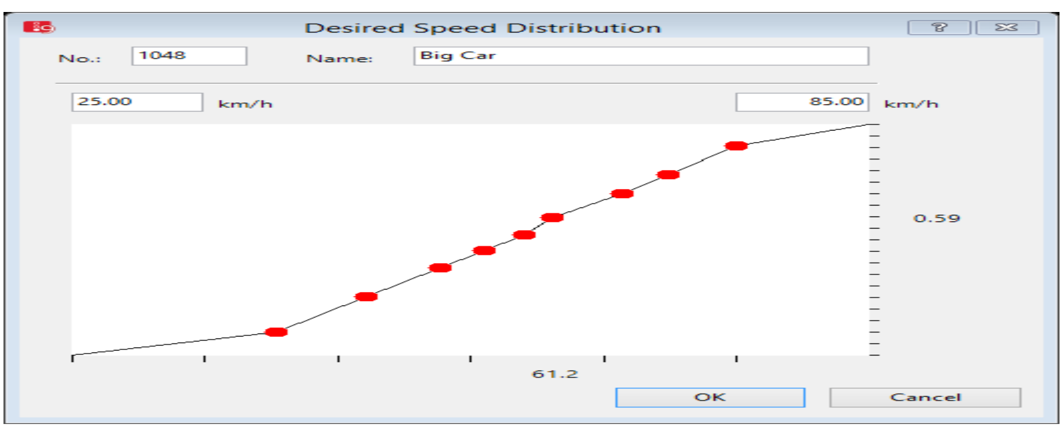


Figure 15: Desired speed distribution of 4WD considered in VISSIM

Driving behaviour based on Widemnann 99 car following model has been used for simulation of vehicle behaviour with some modification based on calibrations study (Arpan Mehar*, 2014). The parameter of this car following model including safety distance during standstill, minimum

c) Vehicle composition and vehicle flow

Vehicle composition and vehicle flow obtained from field observations is given as an input to simulation model for the given time interval.

d) Driving behavior characteristics

In this study, driving behaviour based on Widemnann 99 car following model has been used for simulation of vehicle behavior. The parameters (safety distance during stand still, minimum lateral headway) are used for this study (Arpan Mehar*, 2014).

3.5.3 Calibration of the simulation model

VISSIM works based on car-following driver behavior model developed by Widemnann, Some of the parameters have been found to be influential at capacity, and some of them affect the behavior of the driver only under car-following situations.

The present study is further targeted to the estimation of capacity by developing flow-density diagram. For estimation of capacity by using VISIM software developed by Wiedemann Model 99, there are ten different driver behaviour parameters (Standstill distance (CCO), Headway Time (CCI), 'Following' Variation (CC2), Threshold for Entering 'Following'(CC3), Negative ' Following' Threshold (CC4), Positive 'Following' Threshold (CC5), Speed dependency of Oscillation (CC6), Oscillation Acceleration (CC7), Standstill Acceleration (CC8), Acceleration at 80 km/h (CC9)). But, as the traffic flow reaches to capacity, CCO and CC1 parameters are found to be significant and these are therefore the two parameters which govern the safety distance between the vehicles in the simulation model. Default values of CC0 and CC1 parameters are 1.5 m and 0.9 sec respectively ((Arpan Mehar*, 2014) which was used in this study.

3.6. Capacity Estimation

As it was mentioned in HCM 2010, the capacity of a two lane highway under base conditions is established as 3200 PCU/hr. in both directions with a maximum of 1700 PCU/hr. in one direction. The base conditions for which this capacity is defined include the following cocepts

3.65- Meter (or greater) lanes
1.8m (or greater) usable Shoulders
Level terrain
No heavy vehicles
100% passing Sight distance available (no "No passing" Zone)
50/50 directional split of traffic
No traffic interruptions

As with all capacity values, these standard reflect "reasonable expectancy" (i.e., most two lane highway segments operating under base conditions should be able to achieve such capacity most of the time).

This study is used the Green shield's and Greenberg's model for estimation of capacity by considering the average PCU values of individual vehicle type on two lane trunk road. Macroscopic stream models represent how the behavior of one parameter of traffic flow changes with respect to another. The first and most simple relation between them is proposed by Green shield.

Green shield assumed a linear speed-density relationship. This relation is expressed as the following formula.

$$\mathrm{U} = Uf - \frac{Uf}{Kj} * K \text{------------------------------------} 3.6$$

Where U = speed of vehicles

U f = free flow speed

K = density

K j = jam density

By using the speed obtained from the above relation the capacity of the road section will be determined as the following.

$$\mathrm{q} = Kj * U - \frac{Kj}{Uf} * U^2 \text{------------------------------------} 3.7$$

Where q = maximum flow

K_j = jam density

U = speed

U_f = free flow speed

K = density

In the same way the capacity of the study section was found by using Greenberg model

3.6. Data analysis for vehicle classification and vehicle composition at each section

After collecting the field data from the selected site, the recorded data reduced to homogeneous category and tabulated the type of different vehicle types such as: Standard Car, 4WD, Bus, Truck and Three-wheeler was recorded from video for all the selected road section. A longitudinal section of 60 m length which has 3.5 meter width for one lane was chosen on straight portion of the highway having no influence of access point or intersection. The collected field data have been brought to work office to extract different traffic parameter from the recorded video for all selected road section for this study. The extracted traffic parameters was: traffic volume, vehicle compassion which used the selected road section, the time the given vehicle taken to cover the segment of the road section, & the point speed of the given road section.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Classified traffic Volume & Vehicle Composition

Classifying traffic volume was carried out by replaying the recorded video at the office. All vehicles in the traffic stream were grouped according to ERA 2013 manual for the classification of traffic. According to this study the vehicles in the traffic stream was classified into five categories these was: Standard Car, 4WD, Bus, Truck and three wheeler in these study three wheeler was included because the consideration of the static and dynamic characteristics of each type of different vehicles are considered. The classified vehicle count has been done manually at every 15 minutes interval and it was converted into hourly volume by adding the 15 consecutive minutes to get vehicles per hour volume. The graphs and the pie chart which shows the number of vehicles and composition of vehicle types are shown on the appendix -H. The following table is show that the peak hour volume and vehicle compositions of the selected road section.

Table 10 : Data analyzed for vehicle classification and vehicle composition at each section

Study area	Peak hour	Max.Veh	Vehicles composition (%)					
			S. car	4WD	Bus	Truck	3W	T. no. Veh.
AA-Sendafa	4:15-5:15	256	15%	47%	6%	25%	7%	1050
Sendafa-AA	4:45-5:45	252	12%	51%	8%	21%	8%	1101
AA-Sebata	2:00-3:00	636	18%	48%	5%	17%	12%	3136
Sebata-AA	5:15-6:15	653	20%	46%	5%	16%	13%	3386
AA-Sululta	7:45-8:45	319	12%	54%	3%	24%	4%	2305
Sululta-AA	2:15-3:15	343	17%	52%	5%	22%	4%	2374
AA-Menn	7:30-8:30	393	14%	57%	1%	26%	2%	1669
Menn-AA	5:15-6:15	299	17%	57%	1%	23%	2%	1580
Menn-Holeta	2:15-3:15	256	9%	58%	2%	24%	7%	1595
Holeta-Menn	4:45-5:45	251	9%	60%	2%	21%	8%	1539

4.2. Estimation of Passenger Car Unit

The estimation of PCU values resulted by Chandra's method and Homogenization coefficient method in the study areas are displayed in table 11-15 below. The PCU obtained by Chandra's method in all study areas are greater than the values of PCU resulted by Homogenization coefficient method for 4WD, Bus and truck; except for three wheelers, which is lower in all the study areas. This finding is agree with the findings of Chad and Hitakshi, 2018, who reported that; the PCU value of different vehicles resulted by Chandra's method is greater than values resulted by other methods and similarly, Swetha, 2016 also reported nearly the same PCU values resulted by homogenization coefficient method.

4.2. Estimation of PCU for different types of vehicles for the study road sections (by Chandra's and Homogenization coefficient method)

In order to develop a proper speed – flow equation to estimate capacity and design of traffic facilities for heterogeneous traffic, it is important to change the heterogeneous traffic into homogeneous by using a common unit, which is termed as PCU. Chandra's model and Homogenization coefficient method has been used to determine the PCU of different vehicle categories. It has been observed that speed of the individual vehicle class is different at different road section and PCU resulted at each place of road section have a little difference. The PCU values for different vehicles on each road section are displayed in the following tables.

Table 11: PCU of different vehicles for AA-Sendafa road section

Parameters	PCU calculation methods and Flow direction									
	AA-Sendafa Flow Direction(Chandra's method)					Sendafa-AA Flow Direction(Chandra's method)				
	Type of vehicles					Type of vehicles				
	S. Car	4WD	Bus	Truck	3W	S. car	4WD	Bus	Truck	3W
Area(m^2)	5.92	8.46	21.27	23.28	3.12	5.92	8.46	21.27	23.28	3.12
Av.Speed (km/hr.)	60.31	60.91	53.84	50.37	45.38	64.13	61.98	54.26	51.14	46.89
Vc/Vi	1	0.99	1.12	1.20	1.33	1	1.03	1.18	1.25	1.37
Ac/Ai	1	0.70	0.28	0.25	1.90	1	0.70	0.28	0.25	1.90
PCUi	1	1.41	4.02	4.71	0.70	1	1.48	4.24	4.93	0.72
Average PCUi obtained from both direction						1	1.45	4.13	4.82	0.71
	AA-Sendafa Flow Direction(Homogenization coefficient methods)					Sendafa-AA Flow Direction (Homogenization coefficient methods)				
	S. Car	4WD	Bus	Truck	3W	S. Car	4WD	Bus	Truck	3W
Length	3.70	4.70	9.05	9.84	2.60	3.70	4.70	9.05	9.84	2.60
av.Speed	60.30	60.91	53.84	50.37	45.38	64.13	61.98	54.26	51.14	46.89
Li/Vi	0.06	0.08	0.17	0.19	0.06	0.06	0.08	0.17	0.19	0.05
Lc/Vc	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
PCUi	1.00	1.26	2.74	3.18	0.93	1.00	1.31	2.89	3.33	0.96
Average PCUi obtained from both direction						1.00	1.29	2.81	3.26	0.95

Note: 3w = three wheeler, S. car = Standard car

Example: for bus Vc =60.31, vi=53.84, Ac= 5.92, Ai = 21.27, Vc/Vi = 60.31/53.84 =1.12, Ac/Ai = 0.28 PCUi = Vc *Ai/Vi *Ai = 4.02

Table 12: PCU of different vehicles for AA-Mennagesha road section

Parameters	PCU calculation methods and Flow direction									
	AA-Mennagesha Flow Direction(Chandra's method)					Mennagesha-AA Flow Direction(Chandra's method)				
	Type of vehicles					Type of vehicles				
	S. Car	4WD	Bus	Truck	3W	S. car	4WD	Bus	Truck	3W
Area(m^2)	5.92	8.46	21.27	23.28	3.12	5.92	8.46	21.27	23.28	3.12
Av.Speed (km/hr.)	76.40	75.97	70.11	65.33	66.20	67.60	69.99	61.61	56.97	58.39
Vc/Vi	1.00	1.01	1.10	1.17	1.15	1.00	0.97	1.10	1.19	1.16
Ac/Ai	1.00	0.70	0.28	0.25	1.90	1.00	0.70	0.28	0.25	1.90
PCUi	1.00	1.44	3.91	4.60	0.61	1.00	1.38	3.94	4.67	0.61
Average PCUi obtained from both direction						1.00	1.41	3.93	4.63	0.61
AA-Mennagesha Flow Direction(Homogenization coefficient methods)						Mennagesha-AA Flow Direction (Homogenization coefficient methods)				
	S. Car	4WD	Bus	Truck	3W	S. Car	4WD	Bus	Truck	3W
Length(m)	3.70	4.70	9.05	9.84	2.60	3.70	4.70	9.05	9.84	2.60
av.Speed (km/hr.)	76.39	75.97	70.11	65.33	66.19	67.60	69.99	61.61	56.97	58.39
Li/Vi	0.10	0.06	0.13	0.15	0.04	0.05	0.07	0.15	0.17	0.04
Lc/Vc	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
PCUi	1.00	1.27	2.66	3.11	0.81	1.00	1.23	2.68	3.15	0.81
Average PCUi obtained from both direction						1.00	1.25	2.67	3.13	0.81

Note: 3W= three wheeler, s. car = standard car. e.g.: for Truck Vc =76.39, vi =65.33, Ac= 5.92, Ai = 23.28, Vc/Vi = 76.39/65.33 = 1.17, Ac/Ai = 0.28 PCUi = Vc *Ai/Vi *Ai = 4.60

Table 13: PCU of different vehicles for Mennagesha-Holeta road section

Parameters	PCU calculation methods and Flow direction									
	Mennagesha-Holeta Flow Direction(Chandra's method)					Holeta- Mennagesha Flow Direction (Chandra's method)				
	Type of vehicles					Type of vehicles				
	S. Car	4WD	Bus	Truck	3W	S. car	4WD	Bus	Truck	3W
Area(m^2)	5.92	8.46	21.27	23.28	3.12	5.92	8.46	21.27	23.28	3.12
Av.Speed (km/hr.)	73.59	74.46	63.85	60.06	55.04	72.88	72.81	68.48	59.17	55.94
Vc/Vi	1.00	0.99	1.15	1.22	1.34	1.00	1.00	1.06	1.23	1.30
Ac/Ai	1.00	0.70	0.28	0.25	1.89	1.00	0.70	0.28	0.25	1.89
PCUi	1	1.41	4.14	4.82	0.70	1.00	1.43	3.82	4.84	0.69
Av.PCUi						1.00	1.42	3.98	4.83	0.69
Mennagesha-Holeta Flow Direction(Homogenization coefficient methods)						Holeta- Mennagesha Flow Direction (Homogenization coefficient methods)				
	S. Car	4WD	Bus	Truck	3W	S. Car	4WD	Bus	Truck	3W
Length (m)	3.7	4.7	9.05	9.84	2.60	3.70	4.70	9.05	9.84	2.60
av.Speed(km/hr)	73.59	74.46	63.85	60.06	55.04	72.88	72.81	68.48	59.17	55.94
Li/Vi	0.05	0.06	0.14	0.16	0.05	0.05	0.06	0.13	0.17	0.05
Lc/Vc	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
PCUi	1.00	1.25	2.82	3.26	0.94	1.00	1.27	2.60	3.27	0.91
Av.PCUi						1.00	1.26	2.71	3.26	0.92

Table 14: PCU of different vehicles for AA-Sululta road section

Parameters	PCU calculation methods and Flow direction									
	A-Sululta Flow Direction(Chandra's method)					Sululta-AA Flow Direction (Chandra's method)				
	Type of vehicles					Type of vehicles				
	S. Car	4WD	Bus	Truck	3W	S. car	4WD	Bus	Truck	3W
Area(m^2)	5.92	8.46	21.23	23.28	3.12	5.92	8.46	21.27	23.28	3.12
Av.Speed (km/hr.)	55.79	56.01	51.24	48.14	45.64	52.98	53.95	50.33	50.98	43.99
Vc/Vi	1.00	0.99	1.09	1.16	1.22	1.00	0.98	1.05	1.04	1.20
Ac/Ai	1.00	0.70	0.28	0.25	1.90	1.00	0.70	0.28	0.25	1.90
PCUi	1.00	1.42	3.91	4.56	0.64	1.00	1.40	3.78	4.07	0.63
Av.PCUi						1.00	1.41	3.84	4.31	0.63
AA-Sululta Flow Direction(Homogenization coefficient methods)						Sululta-AA Flow Direction (Homogenization coefficient methods)				
	S. Car	4WD	Bus	Truck	3W	S. Car	4WD	Bus	Truck	3W
Length(m)	3.7	4.7	9.05	9.84	2.60	3.70	4.70	9.05	9.84	2.60
av.Speed (km/hr)	55.79	56.01	51.24	48.14	45.64	52.98	53.95	50.33	50.98	43.99
Li/Vi	0.066	0.08	0.18	0.20	0.07	0.07	0.09	0.18	0.19	0.06
Lc/Vc	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
PCUi	1.00	1.26	2.66	3.08	0.86	1.00	1.25	2.58	2.77	0.85
Av.PCUi						1	1.26	2.62	2.92	0.85

Table 15: PCU of different vehicles for AA-Sebata road section

Parameters	PCU calculation methods and Flow direction									
	AA-Sebata Flow Direction(Chandra's method)					Sebata-AA Flow Direction (Chandra's method)				
	Type of vehicles					Type of vehicles				
	S. Car	4WD	Bus	Truck	3W	S. car	4WD	Bus	Truck	3W
Area(m^2)	5.92	8.46	21.27	23.28	3.12	5.92	8.46	21.27	23.28	3.12
Av.Speed (km/hr.)	45.22	43.13	40.74	39.28	42.37	44.37	43.97	40.84	38.22	42.56
Vc/Vi	1.00	1.05	1.11	1.15	1.07	1.00	1.01	1.09	1.16	1.04
Ac/Ai	1.00	0.70	0.28	0.25	1.90	1.00	0.70	0.28	0.25	1.90
PCUi	1.00	1.50	3.99	4.53	0.56	1.00	1.44	3.90	4.56	0.549
Av.PCUi						1	1.47	3.94	4.55	0.56
AA-Sebata Flow Direction(Homogenization coefficient methods)						Sebata-AA Flow Direction (Homogenization coefficient methods)				
	S. Car	4WD	Bus	Truck	3W	S. Car	4WD	Bus	Truck	3W
Length(m)	3.70	4.70	9.05	9.84	2.60	3.70	4.70	9.05	9.84	2.60
av.Speed (Km/hr)	45.22	43.13	40.74	39.28	42.37	44.37	43.97	40.84	38.22	42.56
Li/Vi	0.08	0.11	0.22	0.25	0.06	0.08	0.11	0.22	0.26	0.06
Lc/Vc	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
PCUi	1	1.33	2.71	3.06	0.75	1.00	1.28	2.66	3.09	0.73
Average. PCUi						1.00	1.30	2.68	3.07	0.74

4.3. Variation of passenger car unit

The effect of traffic volume on PCU has been studied by determining the PCU of different types of vehicles at different volume levels. It is observed from table (16-20) below that PCUs of large size vehicles such as 4WD (BC), bus, Truck, are decreasing and for small size vehicles such as three wheeler it is increase with increase in traffic volume on each two lane road. In a road section, as the traffic volume increases density is also increase and the vehicles move at a lower speed. The current study is agree with the Study done by Satjat Mondel, 2017 who study the estimation of PCU in heterogeneous traffic at Kolkata and conclude that the variation of PCU is occurred as the variation of volume is changed by interval. In this study even eve the volume of the road sections is less changes the value of PCU shows some varies among the variation of the volume interval. These variation is come from the Speed deference among the Standard car and other car. As the volume increase the speed recorded by the standard car and other vehicles are somewhat near to each other which minimize the ratio of Standard car Speed to other vehicles speed. When the volume is minimum the deference of the speed for standard car and other vehicles are become large.

Table 16: variation of PCU depending on volume interval for AA-Sendafa road section

PCU resulted in different volume interval by both methods						
Type of car	AA-Sendafa F. Di (Chandra's method)			Sendafa-AA Flow Direction (Chandra's method)		
	Average Volume interval (Vehicle/hr)			Volume interval (Vehicle/hr)		
	140-205	206-270	271-345	150-200	201-250	251-300
	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1
4WD	1.445	1.4	1.39	1.56	1.5	1.46
Bus	4.435	4.175	4.14	4.9	4.305	4.455
Truck	4.785	4.74	4.53	4.64	4.57	4.46
3W	0.7	0.725	0.73	0.63	0.72	0.78
AA-Sendafa Flow Direction (Homogenization coefficient method)				Sendafa-AA Flow Direction (Homogenization coefficient method)		
Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)		
Type of car	140-205	206-270	271-345	150-200	201-250	251-300
	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1
4WD	1.285	1.25	1.235	1.355	1.33	1.305
Bus	2.79	2.89	2.85	3.005	2.93	2.87
Truck	3.195	3.39	3.065	3.485	3.395	3.285
3W	0.93	0.97	0.975	0.84	0.96	1.025

Table 17: Variation of Passenger Car Unit depending on Volume interval for AA-Mennagesha Road Section.

PCU resulted in different volume interval by both methods								
Type of vehicles	AA-Mennagesha Flow Direction (Chandra's method)				Mennagesha-AA Flow Direction (Chandra's method)			
	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)			
	185-235	235-285	285-335	335-385	185-235	235-285	285-335	335-385
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.495	1.475	1.44	1.36	1.545	1.4	1.37	1.355
Bus	3.985	3.94	3.91	3.85	4.22	3.91	3.875	3.83
Truck	4.49	4.415	4.395	4.27	4.36	4.33	4.27	4.245
3W	0.58	0.6	0.63	0.65	0.695	0.515	0.625	0.64
AA-Mennagesha Flow Direction (Homogenization coefficient method)					Mennagesha-AA Flow Direction (Homogenization coefficient method			
Volume interval(Vehicle/hr)					Volume interval(Vehicle/hr)			
Type of vehicles	180-230	231-280	281-330	330-380	180-230	231-280	281-330	330-380
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.25	1.31	1.29	1.21	1.375	1.255	1.23	1.19
Bus	2.715	2.68	2.67	2.645	2.88	2.8	2.715	2.56
Truck	3.175	3.155	3.13	2.9	2.95	2.88	2.82	2.745
3W	0.77	0.82	0.835	0.81	0.77	0.785	0.835	0.85

Table 18: Variation of Passenger Car Unit depending on Volume interval for Mennagesha-Holeta Road Section.

Type of vehicles	Mennagesha- Holeta Flow Direction(Chandra's method)				Holeta-Mennagesha Flow Direction(Chandra's method)		
	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)		
	150-200	201-250	251-300	301-350	150-200	201-250	251-300
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1
4WD	1.5	1.44	1.36	1.29	1.5	1.34	1.245
Bus	4.54	4.42	4.385	4.305	4.15	3.455	3.36
Truck	4.975	4.91	4.775	4.415	4.735	4.595	4.475
3W	0.64	0.65	0.685	0.68	0.625	0.645	0.685
Type of vehicles	Mennagesha- Holeta Flow Direction(Chandra's method)				Holeta-Mennagesha Flow Direction(Chandra's method)		
	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)		
	150-200	201-250	251-300	301-350	150-200	201-250	251-300
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1
4WD	1.34	1.31	1.285	1.225	1.335	1.195	1.12
Bus	2.975	2.94	2.925	2.82	2.82	2.4	2.365
Truck	3.5	3.475	3.25	3.215	3.2	3.11	3.055
3W	0.875	0.905	0.935	0.945	0.935	0.95	0.975

Note: S. Car = Standard Car, 3W = three wheeler, Max = Maximum, min = Minimum

Table 19: Variation of Passenger Car Unit depending on Volume interval for AA-Sululta Road Section.

PCU resulted in different volume interval by both methods								
Type of vehicles	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)			
	210-260	261-310	311-360	361-410	200-250	251-300	301-350	351-400
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.47	1.42	1.39	1.38	1.475	1.46	1.43	1.4
Bus	4.145	4.03	3.745	3.7	3.8	3.75	3.505	3.485
Truck	4.615	4.575	4.55	4.435	4.755	4.62	4.535	4.475
3W	0.63	0.735	0.79	0.86	0.555	0.57	0.59	0.61
Type of vehicles	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)			
	210-260	261-310	311-360	361-410	200-250	251-300	301-350	351-400
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.31	1.26	1.235	1.215	1.295	1.315	1.24	1.225
Bus	2.83	2.745	2.55	2.535	2.34	2.33	2.305	2.075
Truck	3.24	3.195	3.075	3	2.9	2.865	2.855	2.725
3W	0.79	0.83	0.87	0.935	0.875	0.865	0.905	0.95

Table 20: Variation of Passenger Car Unit depending on Volume interval for AA-Sebata Road Section.

PCU resulted in different volume interval by both methods								
	AA-Sebata Flow Direction (Chandra's method)				Sebata-AA Flow Direction (Chandra's method)			
	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)			
	300-400	401-500	501-600	601-700	360-460	461-560	561-660	661-760
Types of vehicles	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.56	1.525	1.505	1.41	1.395	1.42	1.43	1.52
Bus	4.215	4.14	4.095	3.86	3.65	3.98	3.66	3.85
Truck	4.61	4.605	4.305	4.39	4.705	4.625	4.535	4.92
3W	0.49	0.545	0.57	0.61	0.555	0.58	0.515	0.61
	AA-Sebata Flow Direction (Chandra's method)				Sebata-AA Flow Direction (Chandra's method)			
	Volume interval(Vehicle/hr)				Volume interval(Vehicle/hr)			
	300-400	401-500	501-600	601-700	360-460	461-560	561-660	661-760
Types of vehicles	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
S. car	1	1	1	1	1	1	1	1
4WD	1.4	1.35	1.345	1.25	1.325	1.315	1.22	1.155
Bus	2.86	2.815	2.735	2.65	2.745	2.71	2.485	2.46
Truck	3.155	3.11	2.91	2.9	3.19	3.115	3.065	3.03
3W	0.655	0.73	0.84	0.815	0.745	0.77	0.8	0.815

4.3. Comparison of PCU resulted by Chandra method and Homogenization coefficient method

As it was discussed by different researcher, the value of PCU are different depending on the method used and traffic condition exist during the study. Especially HCM (2000) mention the passenger car unit of truck by considering bus as truck under different flow rate; the value of PCU for truck is different under both level and rolling terrain. To compare the value resulted by two method under this study it is somewhat necessary to compare with the PCU value HCM (2010). As it was discussed by (Girum, 2016) the value of PCU for Bus and Truck depends on their percent and grade of the road section. As cited From HCM (2010) by Girum the PCU value for bus and truck on the level terrain are shown on table 19 with the percent composition of bus and truck. From table 20 the value of PCU of different vehicles are determined by both Chandra and Homogenization coefficient methods. Among the values of PCU listed for 4WD, bus and truck the value resulted by Chandra method are slightly greater than the value resulted by Homogenization coefficient methods reason that Chandra method consider in addition to speed, projected rectangular area of the different class of vehicles; while Homogenization coefficient methods considers speed and average length of different type of vehicles. The PCU resulted by both method is greater than the PCU stated on the HCM 2010 because the method used to calculate PCU is different.

Table 21: Passenger car unit developed by HCM 2010 when the grade of road less than four (HCM 2010 page 11-17)

Passenger car unit developed on highway capacity manual						
Vehicle type	S. Car	4WD	5% bus	10% bus	5% Truck	10% Truck
PCU	1	1	1.5	1.5	1.5	1.5

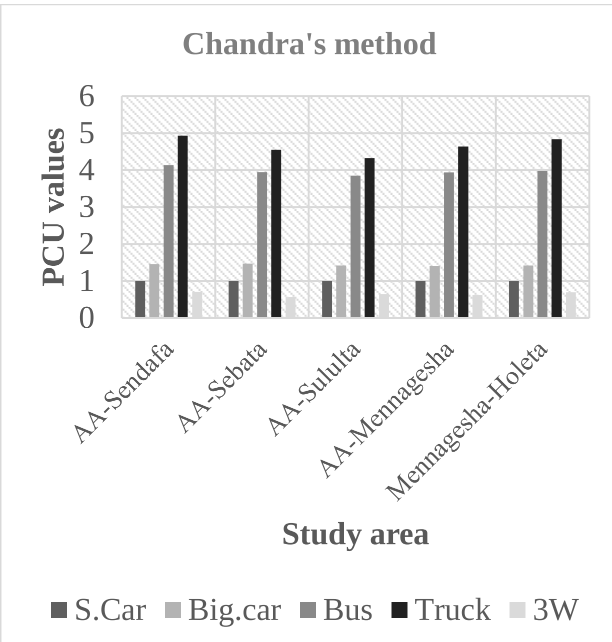
Table 22: Comparison of Passenger car unit for different type of vehicles for all the study road sections

PCU by Chandra method						PCU Homogenization Coefficient method				
Road section	Type of vehicles					Type of vehicles				
	S. car	4WD	Bus	Truck	3W	S .car	4WD	Bus	Truck	3W
AA-Sendafa	1.00	1.45	4.13	4.82	0.71	1.00	1.29	2.81	3.26	0.95
AA-Mennagesha	1.00	1.41	3.93	4.63	0.61	1.00	1.25	2.67	3.13	0.81
AA-Sululta	1.00	1.41	3.84	4.31	0.63	1.00	1.26	2.62	2.92	0.85
AA-Sebata	1.00	1.47	3.94	4.55	0.56	1.00	1.30	2.68	3.07	0.74
Mennagesha-Holeta	1.00	1.42	3.98	4.83	0.69	1.00	1.26	2.71	3.26	0.92
Mean	1.00	1.43	3.96	4.63	0.64	1.00	1.27	2.70	3.13	0.85

From above tables it is observed that the PCU value of Bus and Truck obtained by Chandra's method is higher than that of Homogenization Coefficient method value. The PCU values of other vehicles (4WD, & 3W) obtained by Chandra's method are nearer to that of Homogenization Coefficient method values. Results obtained from Chandra's method indicate that the method is far more reliable than other methods. Thus Chandra's method can be adopted for estimation of Passenger Car Units.

From the above table the Passenger Car Unit resulted by Chandra method is slightly large when compared with that resulted by Homogenization Coefficient method. These results indicate that the PCU can be affected by the factor that considered during study time.

Here by Chandra method; PCU is determined by space mean speed and projected rectangular area of vehicle. But by Homogenization Coefficient method the PCU was resulted by using the length & space speed of the vehicle.



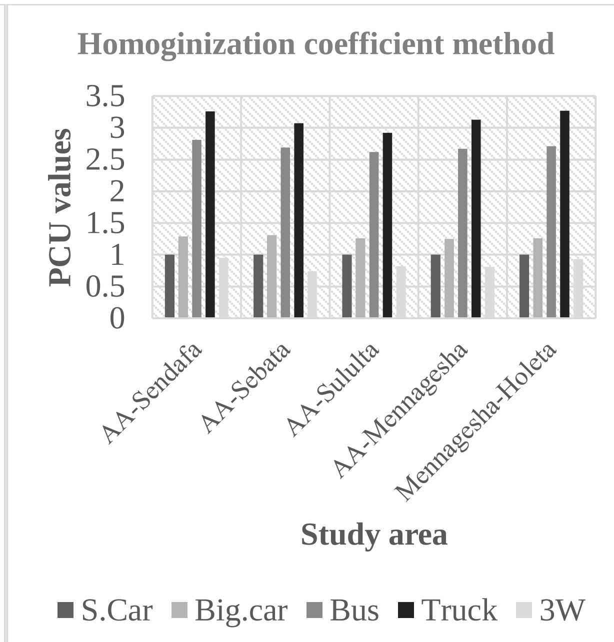


Figure 16: Graphical representation of passenger car unit resulted by Chandra's and Homogenization coefficient methods.

4.4. Estimation of capacity

This study has considered on the Green shield's and Greenberg model for estimation of capacity by considering the average PCU value of individual vehicle type on the selected two lane highway. Therefore, the speed – density model which follows the parabolic relationship, developed by using regression technique has been considered. A scatter diagram has been developed by plotting the speed (u) and density (k) of the given road section was discussed on the following graph for each section of road respectively where R^2 gives a high value represents less variability of the actual data points with the Green shield's model. It has been observed that the speed – density curve fits nicely with the observed data, indicating the validity of the field data for highly heterogeneous traffic flow. The capacity of AA-Sendafa, Sebata, under heterogeneous traffic conditions are estimated as shown on the figure below respectively.

4.5.1. Density -Speed model

Typical traffic speed-density relation models can be divided into two categories: single-regime and multi-regime models. In this study, single regime speed density models were used to analyze and verify field data. The most well-known single regime speed flow model is shown in the following table.

Table 23: model used in analysis of data obtained during the study period.

Number	Name	Function	Transformation	Parameters
1	Green shields Model	$\mathbf{U = Uf(1 - \frac{k}{kj})}$	$\mathbf{U = Uf - Uf\frac{k}{kj})}$	Uf, kj
2	Greenberg Model	**U = $U_O$ln(kj/k)**	**U = $U_o$lnkj – $U_o$lnk**	$U_{o,}$ kj

4.5.2. Curve fitting: speed- density relationship

This procedure has been carried out with the use of regression analysis. In this study, the speed-density curve was used for describing the available data. This curve was selected since it is easy to handle mathematically and once it is established. The other curves namely flow-density and speed-flow curves can be derived easily by applying the steady-state by equation

Q = Us*K

Where Q = Flow (Veh/hr.)

Us = macroscopic speed (km/hr.)

K = density (veh/km)

In search of the model which best predicts speed-density relationships based on available data, the known parameters were mentioned and unknown parameters were obtained through regression.

4.5.3. Regression models for 15 minute interval

With reference to the methodology developed in the (HCM, 2010) indicating that analysis of two-lane highways is done by considering only one direction. In the same way, in this study both direction was investigated separately and analysis is based on 15 minute time intervals.

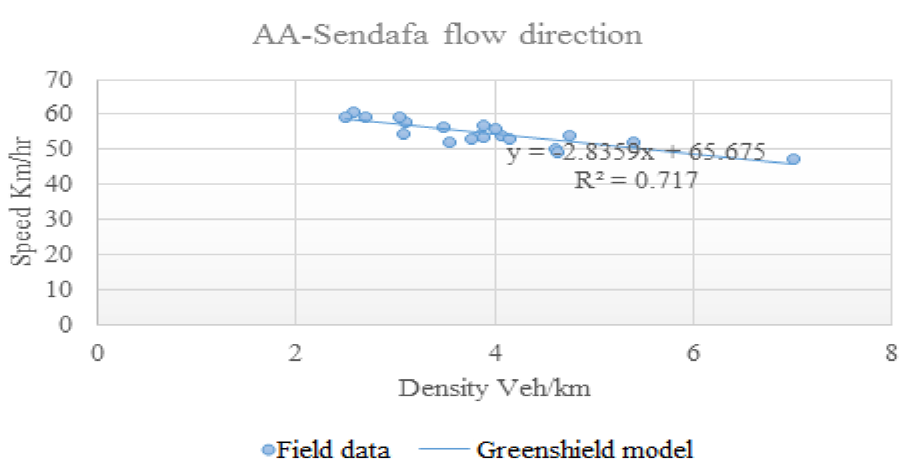
Green shield model: The linear model proposed by Green shields was represented by the following equation.

$$\mathbf{U} = \boldsymbol{Uf}(\mathbf{1} - \frac{\boldsymbol{k}}{\boldsymbol{kj}})$$

Where: U=space mean speed; U_f=free flow speed (km/hr.); k_j=jam density (veh/km); K= density (Veh/km).

For this Model, while free-flow speed, U_f and jam density, K_j, are identified as unknown Parameters. Figure below illustrates the Green shields curve fitted to the data taken on Addis Ababa to Sendafa, Sebata, The regression analysis performed on the AA-Sendafa give the following values:

Speed-Density relation by graph



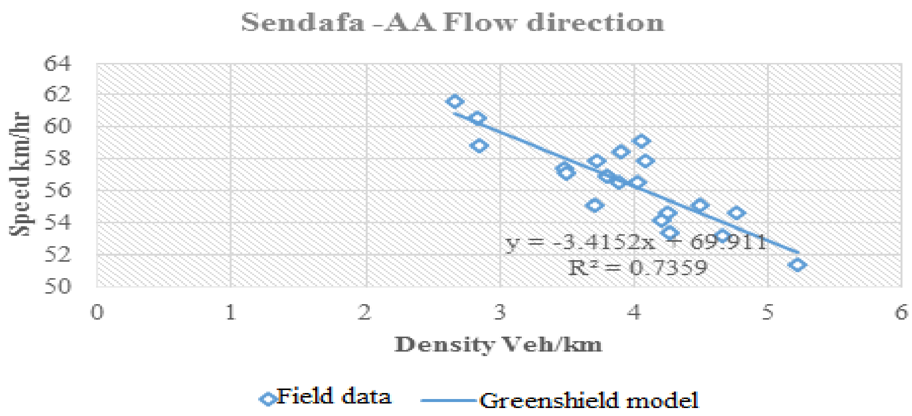


Figure 17: Speed – density relationship for both direction of both direction flow of Sendafa road.

Table 24: By using regression analysis the Speed- density relation is shown according to the following description for AA-Sendafa flow direction

Regression Statistics	
Multiple R	0.85
R Square	0.72
Adjusted R Square	0.70
Standard Error	1.94
Observations	20

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	65.67	1.69	38.76	8.5E-19	62.11	69.23	62.11	69.23
X Variable 1	-2.84	0.42	-6.75	2.5E-06	-3.72	-1.95	-3.72	-1.95

Sendafa-AA flow direction

Regression Statistics	
Multiple R	0.85
R Square	0.73
Adjusted R Square	0.72
Standard Error	1.36
Observation	20

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	69.91	1.91	36.51	2.47E-18	65.88	73.934	65.89	73.93
X Variable 1	-3.41	0.48	-7.08	1.33E-06	-4.43	-2.40	-4.42	-2.40

Depending on the statistical value obtained on the above table the following values are obtained

For AA-Sendafa U_f = 65.67 Km/hr., K_j= 65.67/2.83 =23.15 ~ 24Veh/Km and R^2=72

For Sendafa-AA U_f = 69.91 Km/hr., K_j= 69.91/3.41 =20.47 ~ 21Veh/Km and R^2=73

Q max = $\frac{\mathbf{65.67*24}}{\mathbf{4}}$ = 381 veh/hr./direction for AA- Sendafa flow direction.

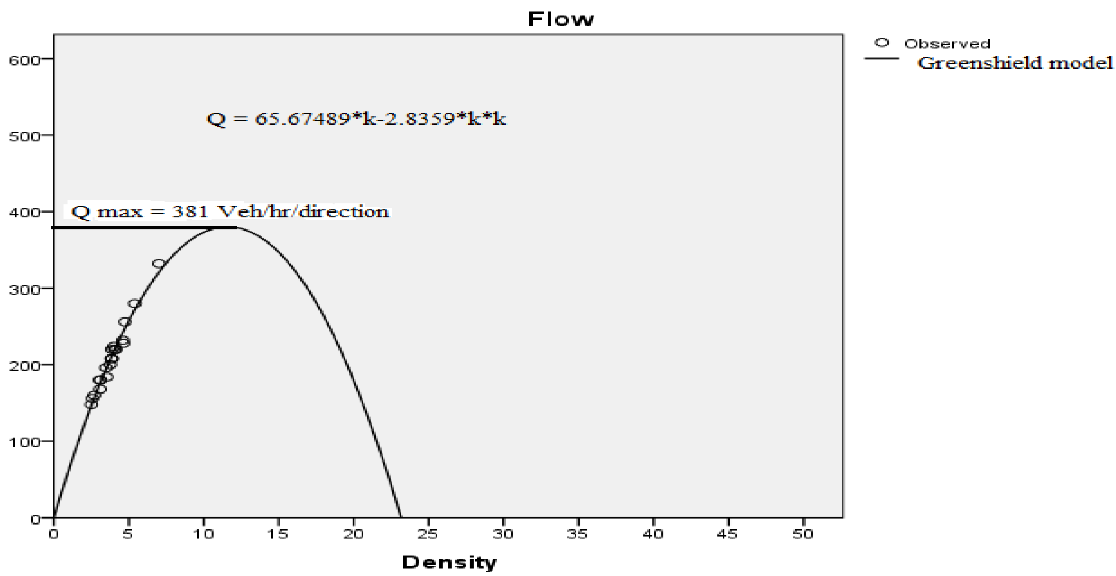
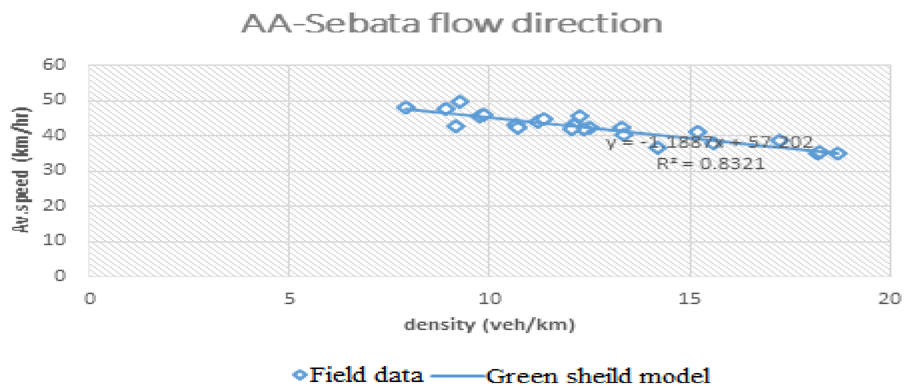


Figure 18: Green Shields model fitted to field data to AA-Sendafa flow direction

The regression analysis performed on the AA-Sebata road section gave the following values:

U_f=68.481 Km/hr., K_j= 40.25 Veh/hr. R^2 = 73.42%



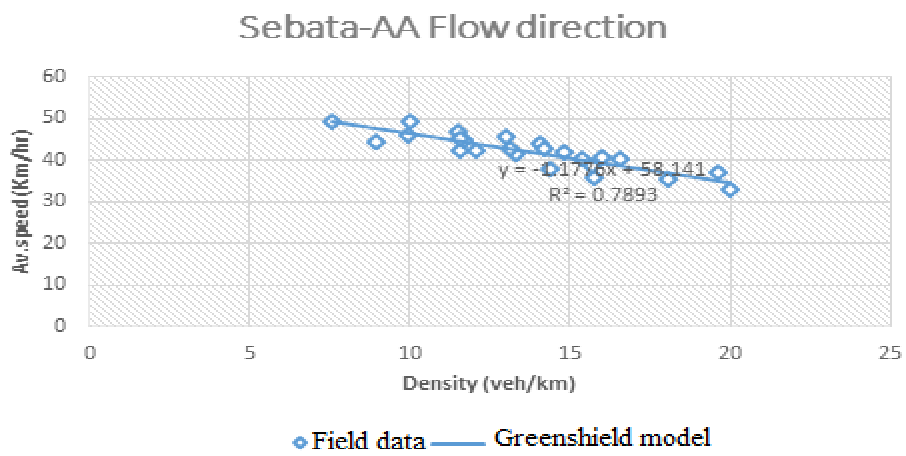


Figure 19: Green Shields model fitted to field data to AA- Sebata road for both direction

Table 25: Regression analysis for AA-Sululta road Section for one direction by Speed – Density relation to find capacity of Addis – Sululta road Section.

Regression Statistics								
Multiple R	0.83							
R Square	0.68							
Adjusted R Square	0.67							
Standard Error	1.81							
Observations	32							
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	60.4	1.42	42.58	2.17E-28	57.48	63.27	57.48	63.27
X Variable 1	-1.88	0.23	-8.05	5.44E-09	-2.35	-1.402	-2.35	-1.4

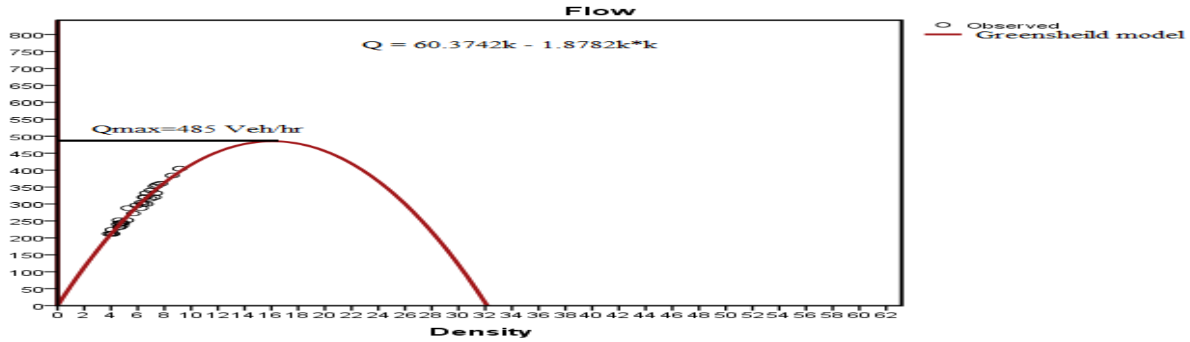


Figure 20: Capacity developed by using 15 minute intervals on this study for AA- Sululta Flow direction.

Table 26: Regression analysis for AA-Sebata road Section for one direction by Flow – Density relation to find capacity of Addis – Sebata direction flow.

Regression Statistics								
Multiple R	0.9							
R Square	0.81							
Adjusted R Square	0.8							
Standard Error	1.71							
Observations	24							
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	55.2	1.52	36.4	3.74E-21	52.03	58.32	52.03	58.32
X Variable 1	-1.09	0.11	-9.55	2.79E-09	-1.322	-0.85	-1.322	-0.85

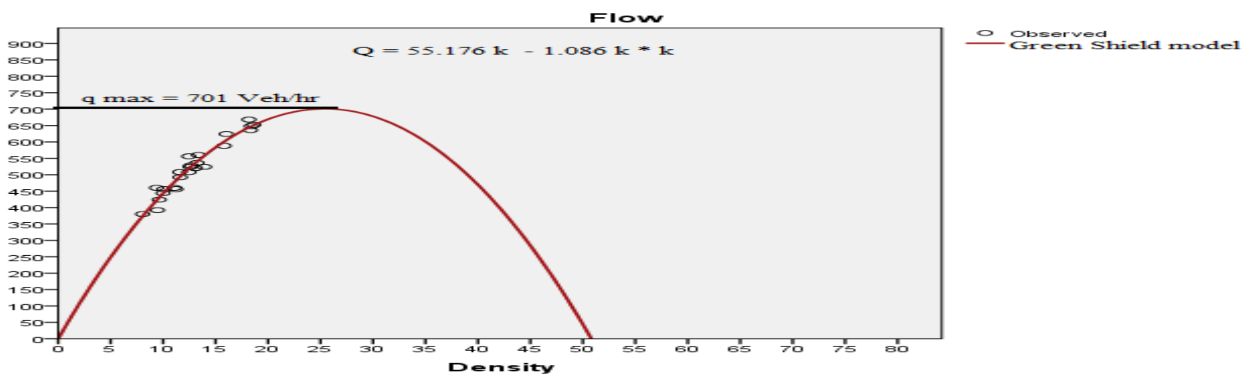


Figure 21: Capacity developed by using 15 minute intervals on this study for AA- Sebata Flow direction.

The Greenberg Model

The logarithmic model proposed by Greenberg is represented by the following equation

$$U = Uo * Ln. \frac{Kj}{K}$$

Where: Uo (speed at maximum flow, km per hour), k=traffic density (veh/km)

The unknown parameters are optimum speed, Uo, and jam density Kj. These parameters as well as the Coefficients of determination (**R**^{2}) relevant to each data set were generated by regression analysis. The regression analysis performed using data of each road section and gave the following values of the capacity of each road section in table 27.

Table 27: Ideal Capacities of Different road section which are selected for this study are listed as the following table

No.	Study Sections	Capacity(veh/hr./drn)	Capacity(veh/hr./drn)
		Green shied	Greenberg
1	AA-Sendafa	381	839
2	Sendafa – AA	358	384
3	AA-Sululta	485	422
4	Sululta – AA	410	310
5	AA-Sebata	701	831
6	Sebata – AA	712	800
7	AA – Mennagesha	426	746
8	Mennagesha-AA	348	432
9	Mennagesha – Holeta	350	467
10	Holeta – Mennagesha	309	421

4.5. Capacity determination using passenger unit factor

As it was introduced by different researcher in chapter two in heterogeneous traffic condition there is a variation of speed and size of different vehicles. For these reason it is important to convert mixed traffic to homogeneous traffic by using PCU to obtain Flow-Density relationship and capacity by PCU/hr./direction. To determine this capacity passenger car unit was determined by using Chandra's method, Homogenization coefficient method and the result stated on the highway capacity manual and the comparison is done by both obtained values and the values written on the

(HCM, 2010).By using PCU resulted by both methods above the capacity of the road section selected for the study is expressed as the following table.

Table 28: Ideal Capacity on the study section by using PCU resulted by both Chandra's & Homogenization coefficient methods.

Study Section	Capacity(PCU/hr./direction)					
	Capacity using PCU of Chandra		Capacity using PCU of Homogenization coeff. Method		Capacity by using (HCM)	
	Green shield	Green berg	Green shield	Greenberg	Green shield	Greenberg
AA-Sendafa	926	928	627	782	436	470
Sendafa-AA	947	1738	642	1187	431	451
AA-Sebata	1304	1236	1045	1053	667	680
Sebata –AA	1300	1195	1060	1004	695	703
AA-Sululta	926	1199	694	846	442	509
Sululta –AA	762	816	584	672	388	411
AA – Mennagesha	1177	2215	876	1558	537	560
Mennagesha –AA	759	1035	583	786	387	403
Mennagesha-Holeta	997	1800	712	1209	389	453
Holeta – Mennagesha	752	826	571	655	344	362

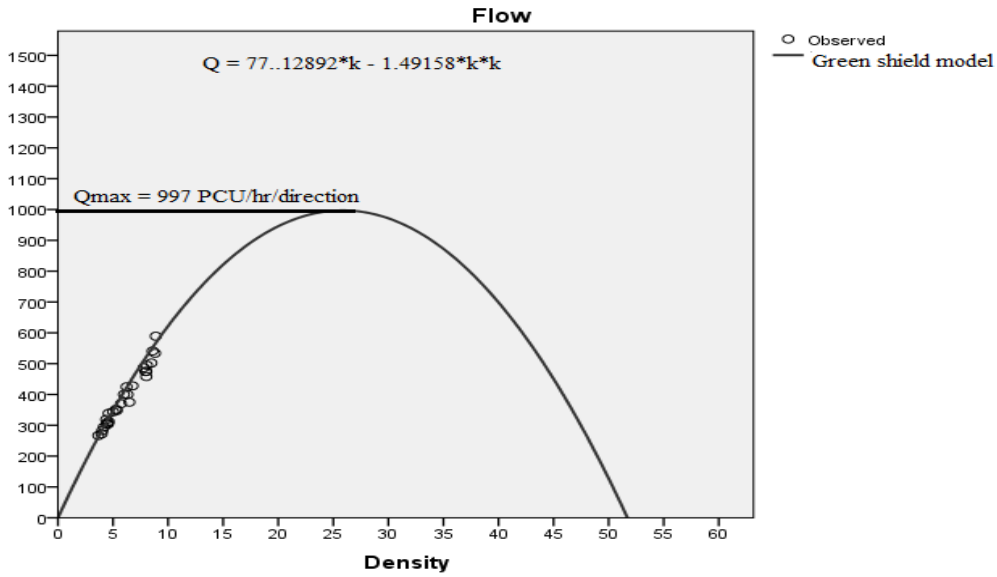


Figure 22: Capacity developed by using 15 minute intervals using PCU resulted by Chandra's methods on this study for Mennagesha to Holeta Flow direction.

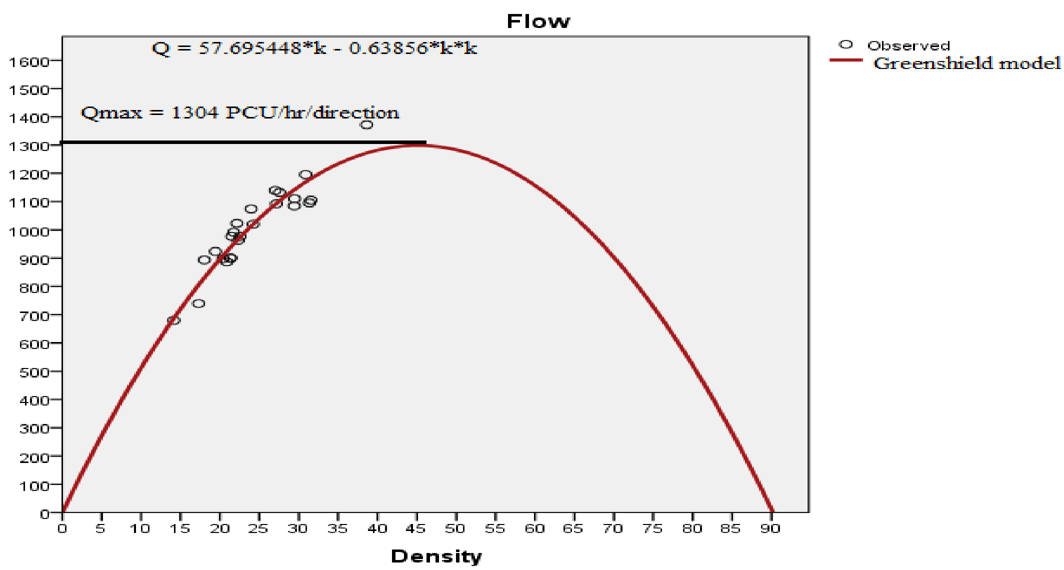


Figure 23: Capacity developed by using 15 minute intervals using PCU resulted by Chandra's methods on this study for AA-Sebata Flow direction.

4.6. Simulation Model Validation and Applications

4.6.1. VISSIM Validation

Validation is the process of checking the result obtained from calibrated model in terms of simulated model against field measurement. For this study VISSIM parameter validation was done by comparing simulated volume and average speed with field obtained data. Average speed and volume of field and simulated data comparison is done and shown on Figure 35, Table 29, Figure 36 and Table 30

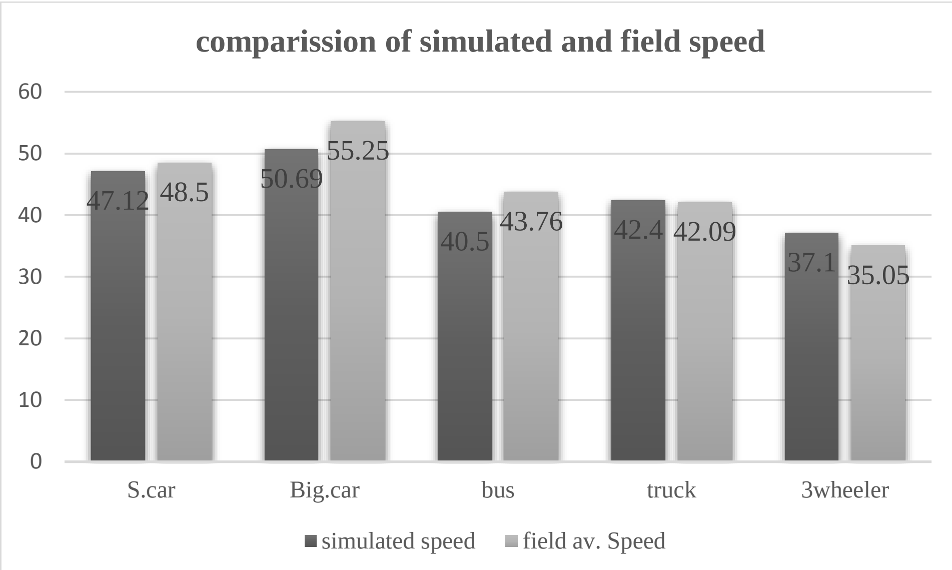


Figure 24: Comparison of calculated and simulated speed

Table 29: Comparison of field and simulated speed

Av.Speed	Simulated Speed	Field Av. Speed	Difference	Squired Of Difference
S. car	47.12	48.50	-1.38	1.91
4WD	50.69	55.25	-4.56	20.79
Bus	40.50	43.76	-3.26	10.63
Truck	42.40	42.09	0.31	0.10
Three wheeler	37.10	35.05	2.05	4.20
d_{mean}			-1.40	37.62

d_{mean} = mean observed speed = $\frac{\mathbf{-1.38-4.56}-3.26+0.31+2.05}{5}$ = -1.40

t – Statics, $t_o = \frac{d\ mean}{Sd\sqrt{n}}$

$Sd^2 = \frac{\sum n(d^2)-(\sum d)^2}{n(n-1)}$, $Sd^2 = \frac{5*37.62-46.79}{5*4}$ = 7.06

S d = 2.66

$t_o = \frac{1.40}{2.66\sqrt{5}}$ = 1.40/5.96 = <u>0.23</u>

The critical value of t-distribution table for 95% level of confidence and 4 degrees of freedom is

2.78. t=test yields the calculated value t-static 0.230 value of t-static (to) calculated is less than Value obtained from t-distribution table. This implies that simulated speed considerably represent the field speed.

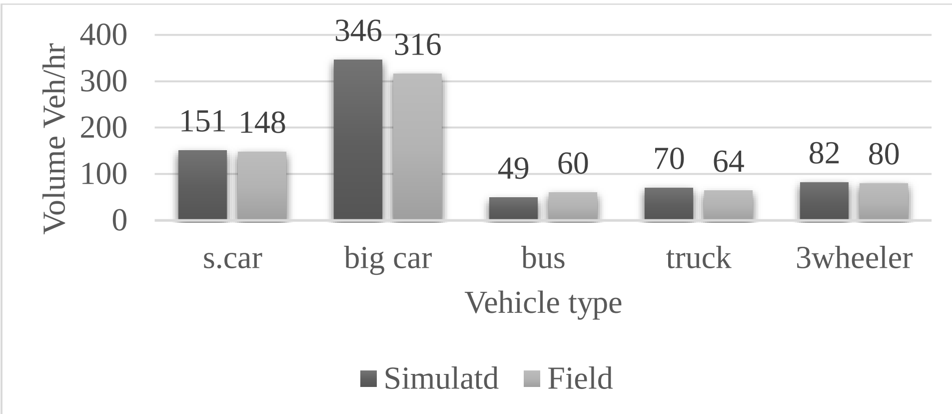


Figure 25: Compression of Simulated and observed traffic volume

Table 30: Comparison of Field and Simulated Volume

Vehicle Type	Simulated volume	Field	Difference	Squired Difference
S. Car	151	148	3	9
4WD	346	316	30	900
Bus	49	60	-11	121
Truck	70	64	6	36
3W	82	80	2	4

S. Car = Standard car, 3W three wheeler

d_{mean} = mean observed speed = $\frac{3+30-11+6+2}{5}$ = 6

t – Statics, $t_o = \frac{d\ mean}{Sd\sqrt{n}}$

$Sd^2 = \frac{\sum n(d^2)-(\sum d)^2}{n(n-1)}$ = $Sd^2 = \frac{5*1070-900}{5*4}$ = 222.5

S d = 14.92

$t_o = \frac{6}{14.92\sqrt{5}}$ = 6/33.42 = <u>0.18</u>

The critical value of t-distribution table for 95% level of confidence and 4 degrees of freedom is 2.78. t=test yields the calculated value t-static 0.18. Value of t-static (to) calculated is less than value obtained from t-distribution table. This implies that simulated volume considerably represent the field volume.

4.3.1. Capacity Estimations Using VISSIM Output Data

Table 31: Capacity of Addis Ababa-Sebata road section by using PCU of HCM, and PCU developed in this study by (Chandra model and Homogenization Coefficient Method)

No	Capacity (using PCU of HCM)	Capacity (using PCU of Homogenization Coefficient method)	Capacity (using PCU of Chandra method)
1	742	1162	1498

In this study capacity obtained in simulation is 742 PCU/hr./Direction using PCU of (HCM, 2000) and 1162 PCU/hr./Direction using PCU of (Homogenization Coefficient method) and 1498 PCU/hr./direction using PCU of Chandra method. The capacity obtained after simulation is greater than field capacity. This may due to aggressive driving behaviors, absence of lane discipline and roughness of roads in Ethiopia. This show that traditional method under estimate or overestimate capacity, thus using the value obtained from simulation model is more realistic since it consider every movement of each vehicle in the stretch.

One of the basic studies in traffic flow research is to examine the relationship between speed and volume of traffic. The capacity of the facility under different roadway and traffic condition can be estimated from this relationship. In this study, flow-density relationship was developed using validated simulation model for heterogeneous flow with vehicle composition and roadway conditions same as that observed in the field. The value of capacity obtained from the simulation for the observed flow and simulated mixed vehicle type flows on Addis Ababa to Sebata Road is given on Figure 37 and Table 31 below.

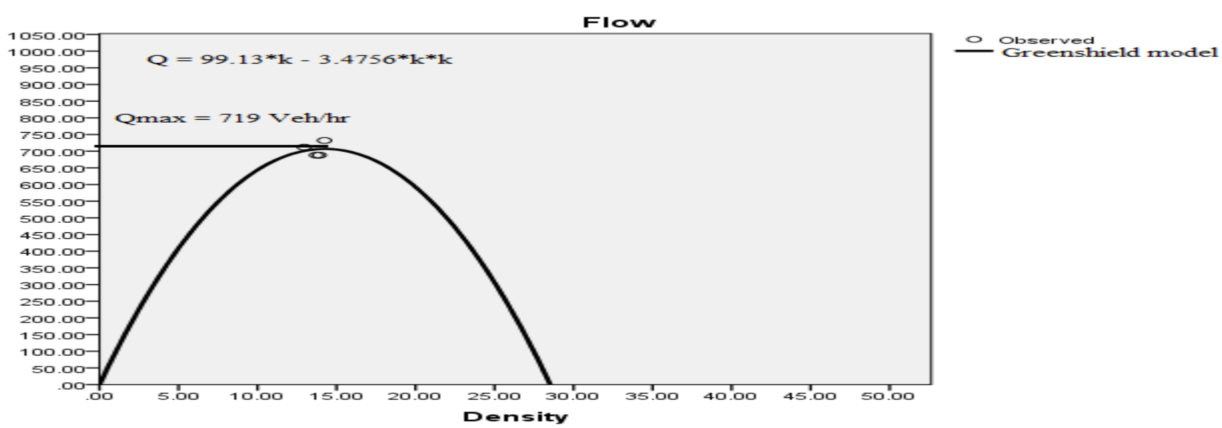


Figure 26: Flow – density relationship showing the Capacity for Simulated data

4.3.2. Passenger car unit estimation by Using VISSIM Output

As explained in literature review, capacity of highway facility with heterogeneous traffic flow with vehicles varying static and dynamic characteristics is best expressed in terms of passenger car unit. To consider dynamic nature of vehicles estimation of PCU was done using equation 2-13. PCU value of different categories of vehicles under heterogeneous traffic conditions at eight different volume-capacity (V/C) ratios, 0.125, 0.25, 0.375, 0.5, 0.625, 0.750, 0.875 and 1 were estimated using simulation. The capacity value for the calculation of V/C ratio obtained from Flow-density graphs. For the purpose of simulations eight traffic volume levels corresponding V/C ratio with the same compositions as observed in the field were considered.

Example at Volume to Capacity ratio (V/C) = 0.875

V/719 = 0.875

V = 630 Veh/hr./direction, similarly for all V/C ratio simulation runs are carried out for one hour durations. The table below explains the obtained result from output speed

Table 32: PCU resulted from Simulated Speed depending on the volume ratio

V/C ratio	PCU				
	Standard car	4WD	Bus	Truck	Three wheeler
0.125	1	1.58	4.32	4.61	0.51
0.25	1	1.54	4.28	4.58	0.59
0.375	1	1.49	4.26	4.57	0.61
0.5	1	1.48	4.22	4.54	0.62
0.625	1	1.38	4.20	4.51	0.63
0.75	1	1.35	4.19	4.50	0.65
0.875	1	1.34	4.18	4.49	0.66
1	1	1.33	4.16	4.44	0.67
Average	1	1.44	4.23	4.53	0.62

As it can be observed from table above, truck and buses have higher value followed by 4WD. This implies that, the heavier the vehicle, the lesser movement ability. In addition to this from the table above PCU value of Buses and Truck decrease as volume increase the reason is that, as volume increase, headway decrease, vehicle become closer, over passing opportunity decrease. This situation results decrease in speed of standard vehicle and PCU. Another finding is that HCM assume at flat terrain PCU is constant, but PCUi value varies with volume to capacity ratio.

In addition, the values of PCU obtained by PTV VISSIM software in table 32 is slightly greater for all vehicle types except for 3wheelers; which is lesser when compared with values obtained by Chandra’s and Homogenization coefficient methods in table 22, served from the table 22, the values obtained by Chandra’s. This is more probably for PTV VISSIM software, the head way and spacing are considered which govern the traffic flow conditions and directly concerned with the aggressiveness of driver’s behaviour unlike the results obtained by the others two methods using directly collected field data.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

From the results of the current study, which done on the flat terrain of selected road sections, the PCU resulted by Chandra's method and homogenization coefficient methods for field data for all categories of vehicles (4WD, Bus, Truck and three wheeler) were done. For all categories of vehicles in all the study road sections, the PCU values resulted by Chandra's method are significantly greater than the homogenization coefficient method, except for three wheelers (lower values). The PCU values obtained by Chandra method for simulated data is greater than the PCU obtained by Chandra methods for data collected directly from the field. The mean PCU values for different vehicles was done for simulated data by Chandra method and for field data by Chandra method and Homogenization coefficient method.

For 4WD, bus, and truck in all of the study road sections, value of PCU is increasing as volume of the road sections decreases, except for three wheelers; in which its PCU values increase with volume interval.

The ideal road capacity was done by using Green shield model and Green berg model. Among these two model Green shield model was found to be presented more consistent with less variation. The ideal capacity done by Green shield model of each road sections resulted from PCU values obtained from both Chandra and homogenization coefficient methods are low as compared to the maximum value stated on the highway capacity manual of 2010. Accordingly, the values of ideal road capacity resulted by Chandra's method are (926, 947), (1304, 1300), (926, 762), (1177, 759), and (997, 752PCU/hr./direction) for AA-Sendafa, AA-Sebeta, AA-Sululta, AA-Mennagesha and Mennagesha-Holeta, respectively with vice versa of flow directions. Similarly, the values of ideal road capacity resulted by Homogenization's coefficient method are (627,642), (1045, 1060), (694,584), (876,583), and (712, 571), for AA-Sendafa, AA-Sebeta, AA-Sululta, AA-Mennagesha and Mennagesha-Holeta, respectively with vice versa of flow directions. The validation result of the VISSIM simulation model for mixed traffic flow done using speed and volume shows microscopic simulation developed for this study have a capability of replicating heterogeneous traffic flow for two way two lane road.

Under mixed traffic condition under constant roadway condition and traffic compositions, Passenger car unit value heavy vehicles decrease with increase in volume to capacity ratio. Thus, it is better to use dynamic PCU values instead of fixed value for different types of vehicles.

5.2.RECOMMENDATIONS

Based on observation and finding from research, recommendation have made and possible areas of extension for this research have been summarized below as per the research objectives:

- The passenger car unit and the capacity of two lane highway found from this study by field data are different from the value suggested in the highway capacity manual 2010. Based on this, the proposed capacity and PCU may be important for Ethiopian Traffic Engineers who plan, design, operate and maintain two lane highway corresponding to local traffic conditions.
- The passenger car unit for this study was determined by using Chandra's method and homogenization coefficient method for field data and by Chandra's method for simulated data. But future researchers can study the passenger car unit of two lane by other methods and compare with the value resulted in these study.
- This study was conducted on the flat terrain of the road segment and further researchers may consider the geometric effect of the two way road section.
- The traffic flow on the study section is heterogeneous traffic which has effect during the design of highway volume count but it is better to make it homogeneous by separating heavy vehicles from standard vehicles.
- Even though the current road capacity of the study sections are not saturated, depending on the future expectation of number of car increments, government may need to plan for further road options like multi-lane roads and additional route options.
- Separation of time flow for heavy vehicles from the small and medium depending on their performance and daily duty.
- For determination of PCU in heterogeneous traffic flow for two way two lane road, as the result of PCU obtained by PTV VISSIM simulation model is greater, it is better to be used than the other two methods.

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Appendix A

AA-Sendafa road section data traffic data

Fundamental parameters of AA-Se road							Fundamental parameters of Sebata-AA road		
Time	No. of vehicle	Flow	Speed	Density	speed		Av.Speed	flow	Density
3:00-3:15	55	220	54.2901	4.052304	54.2901		56.91953	216	3.794831
3:15-3:30	55	220	52.96381	4.15378	52.96381		60.59024	172	2.838741
3:30-3:45	64	256	54.81793	4.670004	54.81793		57.44918	200	3.481338
3:45-4:00	39	156	53.3816	2.922355	53.3816		57.90966	216	3.729948
4:00-4:15	58	232	46.99201	4.937009	46.99201		58.88162	168	2.853183
4:15-4:30	45	180	57.33499	3.139444	57.33499		61.57615	164	2.663369
4:30-4:45	83	332	55.17774	6.016919	55.17774		54.59738	260	4.762133
4:45-5:00	70	280	52.61623	5.321552	52.61623		55.11759	248	4.499471
5:00-5:15	46	184	49.9575	3.683131	49.9575		54.58634	232	4.250148
5:15-5:30	56	224	54.51325	4.109093	54.51325		51.4042	268	5.213582
5:30-5:45	52	208	51.90614	4.007233	51.90614		54.14477	228	4.210933
5:45-6:00	57	228	48.89268	4.663274	48.89268		57.11116	200	3.501943
6:00-6:15	52	208	50.76156	4.097589	50.76156		53.43009	228	4.267259
6:15-6:30	49	196	47.51685	4.124853	47.51685		56.5126	220	3.892937
6:30-6:45	55	220	52.73474	4.171823	52.73474		59.08144	240	4.062189
6:45-7:00	50	200	52.24428	3.82817	52.24428		57.86263	236	4.078625
7:00-7:15	45	180	54.99681	3.272917	54.99681		56.571	228	4.030333
7:15-7:30	40	160	56.46068	2.833831	56.46068		58.4164	228	3.903013
7:30-7:45	37	148	54.67682	2.706815	54.67682		53.19551	248	4.662048
7:45-8:00	42	168	52.18642	3.219228	52.18642		55.12914	204	3.700402

Appendix B

Addis Ababa –Sululta traffic data

For AA-Sululta direction							For Sululta-AA direction				
Time	N. Veh	q V/hr	V km/hr	K veh/km	av. V km/hr		N.Veh	Flow V/hr	av.V km/hr	k veh/km	Av.Speed
2:00-2:15	58	232	45.22	5.13	45.22		86	344	48.45	7.1	48.45
2:15-2:30	101	404	40.68	9.93	40.68		91	364	38.46	9.46	41.61
2:30-2:45	83	332	42.53	7.806	42.53		72	288	41.07	7.01	41.07
2:45-3:00	61	244	50.06	4.874	50.06		92	368	46.24	7.96	46.24
3:00-3:15	59	236	47.57	4.961	47.57		88	352	46.4	7.59	46.4
3:15-3:30	90	360	42.71	8.428	42.71		61	244	45.55	5.36	45.55
3:30-3:45	68	272	43.58	6.241	43.58		73	292	47.64	6.13	47.64
3:45-4:00	72	288	42.4	6.792	42.4		66	264	46.23	5.71	46.23
4:00-4:15	53	212	53.91	3.933	53.91		78	312	47.58	6.56	47.58
4:15-4:30	63	252	48.88	5.155	48.88		75	300	45.76	6.56	45.76
4:30-4:45	79	316	43.8	7.215	43.8		66	264	43.79	6.03	43.79
4:45-5:00	80	320	47.85	6.688	47.85		68	272	43.98	6.18	43.98
5:00-5:15	80	320	50.41	6.348	50.41		65	260	43.24	6.01	43.24
5:15-5:30	58	232	47.85	4.849	47.85		81	324	40.98	7.91	40.98
5:30-5:45	75	300	44.99	6.668	44.99		74	296	48.53	6.1	48.53
5:45-6:00	61	244	48.15	5.067	48.15		66	264	46.82	5.64	46.82
6:00-6:15	76	304	47.12	6.452	47.12		72	288	45.71	6.3	45.71
6:15-6:30	53	212	43.31	4.895	43.31		70	280	43.83	6.39	43.83
6:30-6:45	72	288	52.16	5.522	52.16		68	272	49.31	5.52	49.31
6:45-7:00	80	320	42.86	7.467	42.86		73	292	45.08	6.48	45.08
7:00-7:15	83	332	47.6	6.974	47.6		86	344	46.09	7.46	46.09
7:15-7:30	63	252	53.77	4.686	53.77		73	292	53.98	5.41	53.98
7:30-7:45	56	224	51.31	4.366	51.31		69	276	50.97	5.42	50.97
7:45-8:00	96	384	45.03	8.527	45.03		68	272	43.94	6.19	43.94
8:00-8:15	75	300	39.41	7.612	39.41		57	228	50.37	4.53	46.91
8:15-8:30	60	240	50.43	4.759	50.43		88	352	46.41	7.58	46.41
8:30-8:45	88	352	45.24	7.78	45.24		72	288	43.06	6.69	43.06
8:45-9:00	53	212	46.92	4.519	46.92		87	348	46.08	7.55	46.08
9:00-9:15	61	244	49.77	4.902	49.77		78	312	47.2	6.61	47.2
9:15-9:30	74	296	47.85	6.186	47.85		73	292	49.57	5.89	49.57
9:30-9:45	85	340	47.12	7.216	47.12		74	296	43.75	6.77	43.75
9:45-10:00	89	356	52.24	6.815	52.24		64	256	47.62	5.38	47.62

Appendix C

Addis Ababa to Sebata traffic data

AA- Sebata flow						Sebata-Addis Ababa			
Time	No.vehicle	Flow	Density	av.speed		No.vehi	Flow	Density	av.speed
2:00-2:15	147	588	15.6	37.68		142	568	15.767	36.02
2:15-2:30	163	652	18.68	34.91		152	608	15.659	38.83
2:30-2:45	159	636	18.17	35.01		166	664	20.021	33.16
2:45-3:00	167	668	17.26	38.71		128	512	12.084	42.37
3:00-3:15	139	556	12.24	45.44		134	536	11.485	46.67
3:15-3:30	156	624	15.2	41.07		123	492	11.597	42.42
3:30-3:45	131	524	12.1	43.32		155	620	15.393	40.28
3:45-4:00	132	528	12.52	42.16		138	552	13.314	41.46
4:00-4:15	140	560	13.28	42.18		141	564	13.145	42.91
4:15-4:30	98	392	9.172	42.74		163	652	16.013	40.72
4:30-4:45	134	536	13.33	40.2		136	544	14.369	37.86
4:45-5:00	162	648	18.24	35.52		160	640	18.08	35.4
5:00-5:15	130	520	12.35	42.11		155	620	14.79	41.92
5:15-5:30	123	492	11.18	44.02		155	620	14.05	44.13
5:30-5:45	127	508	12.07	42.09		151	604	14.191	42.56
5:45-6:00	131	524	14.22	36.85		181	724	19.634	36.87
6:00-6:15	115	460	10.67	43.12		166	664	16.536	40.15
6:15-6:30	114	456	10.73	42.51		131	524	11.701	44.78
6:30-6:45	106	424	8.916	47.55		131	524	11.599	45.18
6:45-7:00	111	444	9.738	45.6		115	460	9.9681	46.15
7:00-7:15	127	508	11.33	44.85		99	396	8.9517	44.24
7:15-7:30	114	456	9.874	46.18		93	372	7.559	49.21
7:30-7:45	95	380	7.91	48.04		148	592	12.994	45.56
7:45-8:00	115	460	9.272	49.61		123	492	9.9928	49.24

Appendix D

Addis Ababa to Mennagesha Traffic data

AA- Mennagesha Flow direction						Mennagesha-AA			
Time interval	av.speed	No.Veh	Flow	Density		av.speed	No.Veh	Flow	Density
3:00-3:15	67.78	66	264	3.89		61.53	55	220	3.58
3:15-3:30	74.19	47	188	2.53		55.31	65	260	4.7
3:30-3:45	73.49	60	240	3.27		59.35	65	260	4.38
3:45-4:00	68.42	79	316	4.62		55.92	71	284	5.08
4:00-4:15	75.23	65	260	3.46		65.27	53	212	3.25
4:15-4:30	71.07	65	260	3.66		71.74	49	196	2.73
4:30-4:45	70.55	76	304	4.31		62.17	66	264	4.25
4:45-5:00	66.25	79	316	4.77		58.47	75	300	5.13
5:00-5:15	73.57	66	264	3.59		65.25	61	244	3.74
5:15-5:30	65.65	80	320	4.87		61.35	83	332	5.41
5:30-5:45	75.88	56	224	2.95		69.12	66	264	3.82
5:45-6:00	70.88	72	288	4.06		73	61	244	3.34
6:00-6:15	69.33	65	260	3.75		55.08	89	356	6.46
6:15-6:30	67.95	81	324	4.77		66.24	62	248	3.74
6:30-6:45	67.99	80	320	4.71		61.3	74	296	4.83
6:45-7:00	72.84	68	272	3.73		58.25	72	288	4.94
7:00-7:15	73.82	67	268	3.63		69.32	55	220	3.17
7:15-7:30	75.86	68	272	3.59		65.17	66	264	4.05
7:30-7:45	69.28	82	328	4.73		71.12	54	216	3.04
7:45-8:00	74.04	74	296	4		66.82	62	248	3.71
8:00-8:15	70.77	59	236	3.33		71.51	60	240	3.36
8:15-8:30	62.91	96	384	6.1		66.36	65	260	3.92
8:30-8:45	72.73	65	260	3.57		58.35	77	308	5.28
8:45-9:00	78.25	53	212	2.71		59.96	74	296	4.94

Appendix E

Mennagesha – Holeta road segment

Mennagesha-Holeta						Holeta-Mennagesha			
Time interval	Av.Speed	No.Vehicle	Flow	Density		Av.Speed	No.vehicle	Flow	Density
2:00-2:15	72.87	44	176	2.42		62.28	74	296	4.75
2:15-2:30	68.34	66	264	3.86		67.71	55	220	3.25
2:30-2:45	59.26	85	340	5.74		74.32	47	188	2.53
2:45-3:00	66.76	56	224	3.36		73.57	44	176	2.39
3:00-3:15	72.85	49	196	2.69		61.98	56	224	3.61
3:15-3:30	68.81	45	180	2.62		64.43	63	252	3.91
3:30-3:45	67.41	53	212	3.14		68.64	52	208	3.03
3:45-4:00	68.18	50	200	2.93		69.79	46	184	2.64
4:00-4:15	65.33	50	200	3.06		67.05	58	232	3.46
4:15-4:30	70.3	47	188	2.67		57.73	67	268	4.64
4:30-4:45	63.26	64	256	4.05		63.13	55	220	3.48
4:45-5:00	63.55	64	256	4.03		64.25	54	216	3.36
5:00-5:15	68.85	50	200	2.9		56.09	64	256	4.56
5:15-5:30	57.08	68	272	4.76		61.73	67	268	4.34
5:30-5:45	64.84	59	236	3.64		64.19	66	264	4.11
5:45-6:00	70.7	50	200	2.83		68.94	48	192	2.79
6:00-6:15	68.11	47	188	2.76		64.33	60	240	3.73
6:15-6:30	68.23	52	208	3.05		68.02	57	228	3.35
6:30-6:45	66.96	55	220	3.29		67.6	45	180	2.66
6:45-7:00	60.63	64	256	4.22		69.37	47	188	2.71
7:00-7:15	62.66	59	236	3.77		59.54	51	204	3.43
7:15-7:30	66.34	61	244	3.68		76.04	40	160	2.1
7:30-7:45	59.63	60	240	4.03		63.78	48	192	3.01
7:45-8:00	57.89	51	204	3.52		68.47	51	204	2.98
8:00-8:15	63.02	73	292	4.63		62.36	70	280	4.49
8:15-8:30	59.31	68	272	4.59		66.34	42	168	2.53
8:30-8:45	73.7	43	172	2.33		63.99	59	236	3.69
8:45-9:00	61.37	62	248	4.04		66.72	53	212	3.18

Appendix F

Regression analysis by using Green shields model

Example for Mennagesha - Holeta road section

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.78
R Square	0.61
Adjusted R Square	0.59
Standard Error	2.99
Observations	28

ANOVA

	df	SS	MS	F	Significance F
Regression	1	356.7634061	356.7634061	39.76184523	1.12429E-06
Residual	26	233.2851633	8.972506281		
Total	27	590.0485694			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	77.13	1.92	40.24	6.01E-25	73.19	81.07	73.19	81.07
X Variable 1	-1.49	0.24	-6.30	1.12E-06	-1.98	-1.01	-1.98	-1.01

$$u = u_f \left(1 - \frac{k}{k_j}\right)$$

Y= U, K= X, a = uf, b=-uf/kj

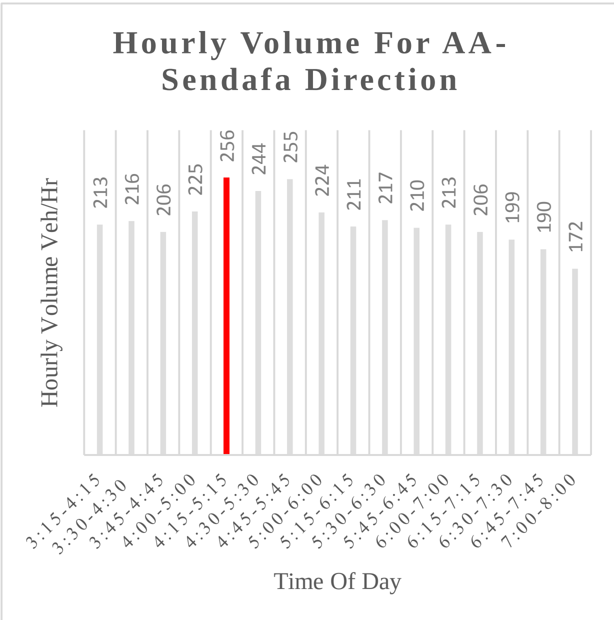
Y = a+ bx

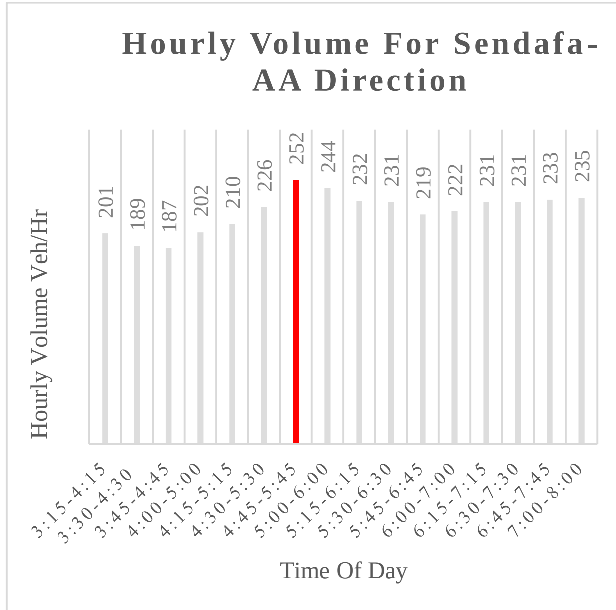
Kj=52 veh/km

a=uf=77.13 km/h b= -uf/kj = -1.49

Appendix- G

1. Traffic volume of Sendafa road section from collected video on May, 11/2019 is shown on the figure blow.

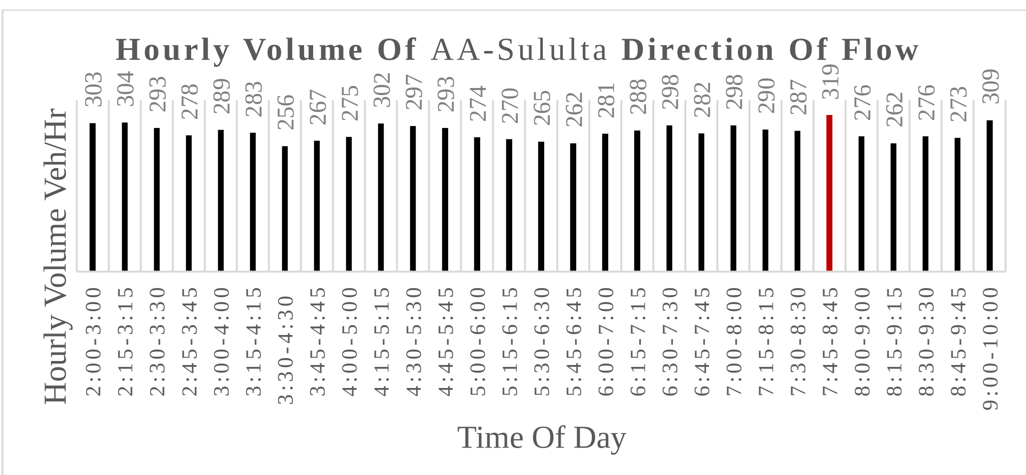


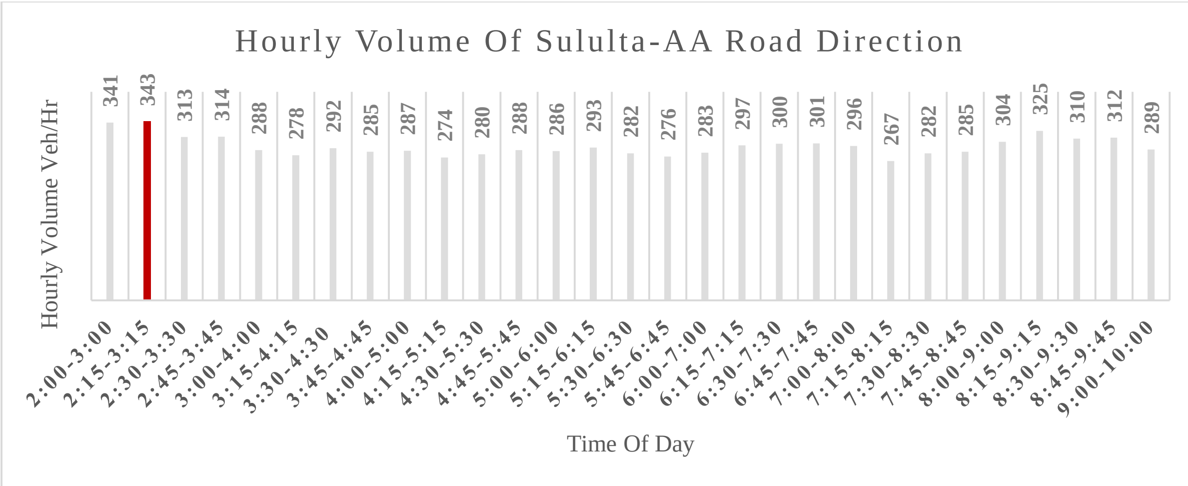


2. **Vehicle composition of Sendafa road from collected video on May, 11/2019 is shown on the figure blow.**

3. **Vehicle composition of Sululta road from collected video on May, 13/2019 is shown on the figure blow**

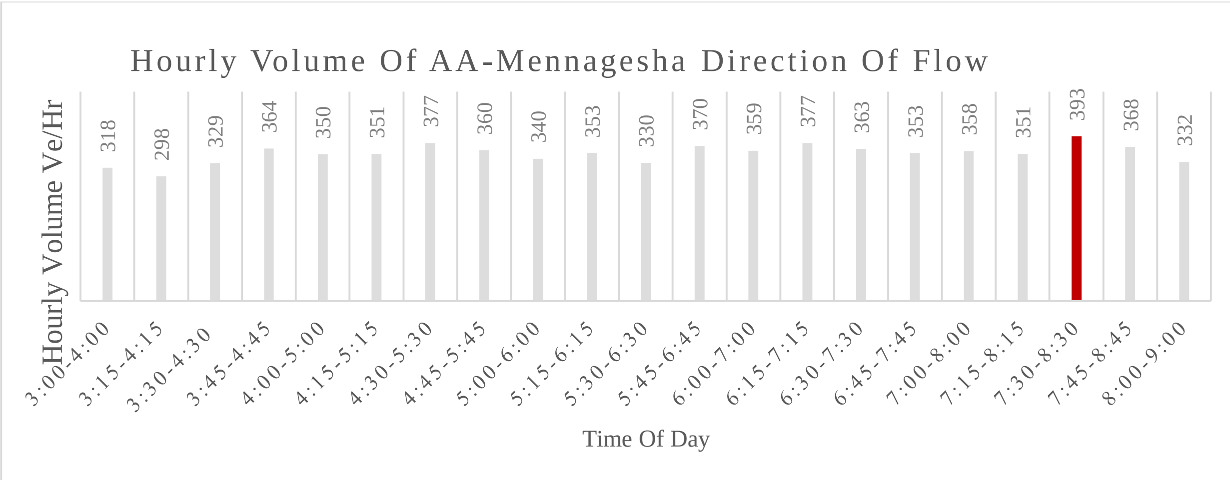
4. Hourly volume of Sululta road from collected video on May, 13/2019 is shown on the figure blow

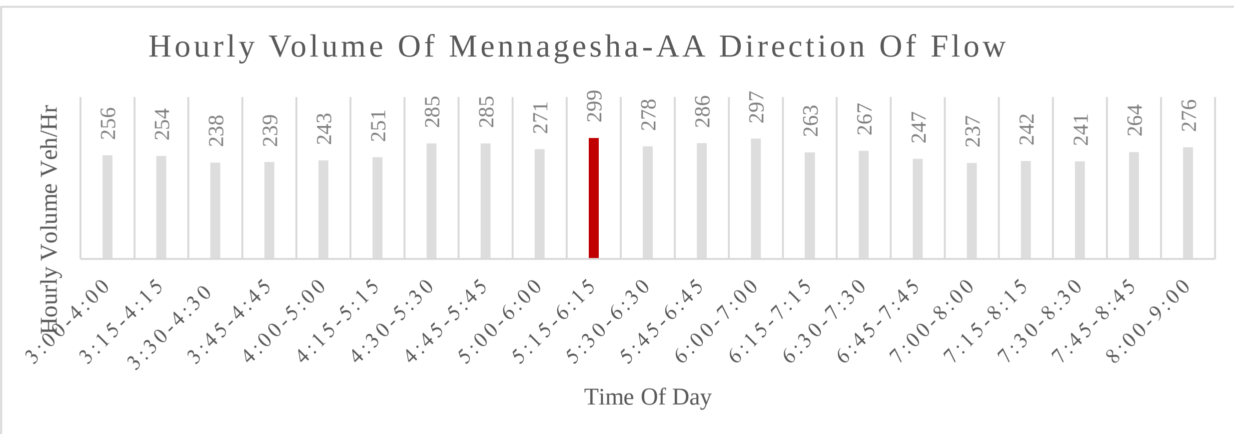




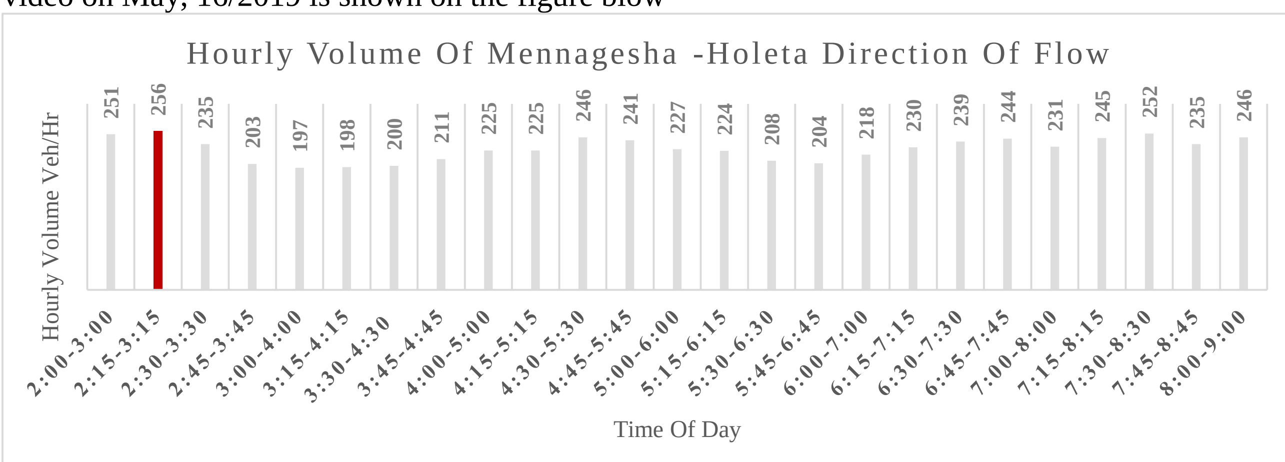
5. Vehicle composition of AA-Mennagesha & Mennagesha –AA flow direction from collected video on May, 21/2019 is shown on the figure blow

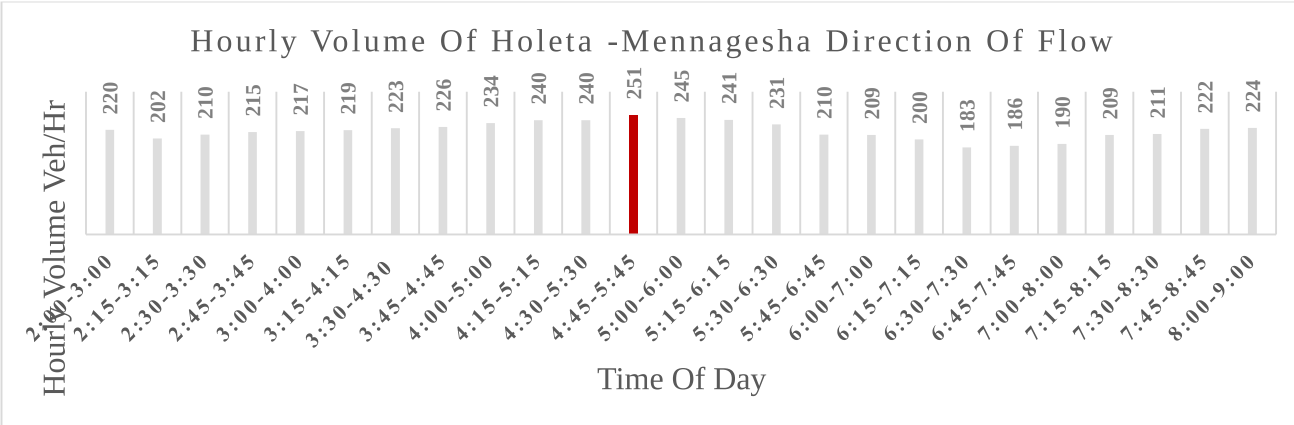
6. Hourly volume of AA-Mennagesha & Mennagesha –AA flow direction from collected video on May, 21/2019 is shown on the figure blow





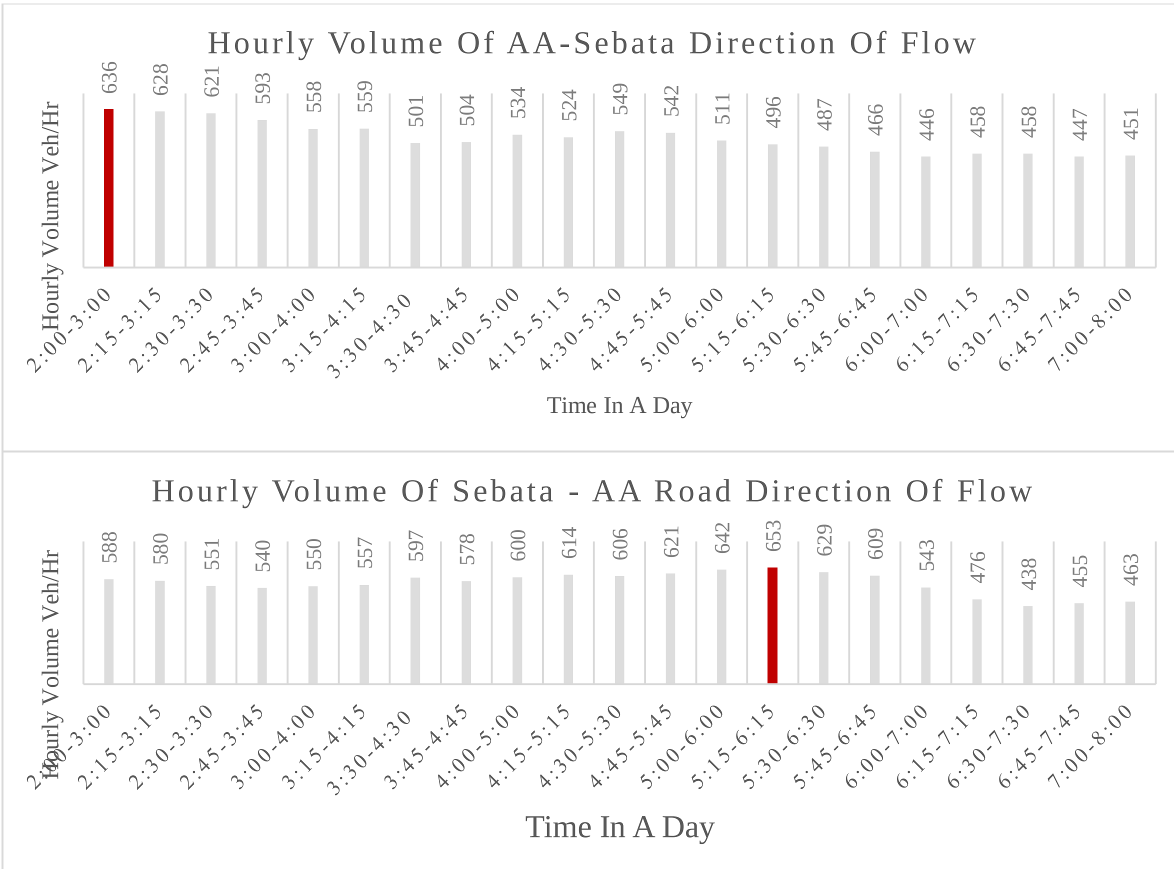
7. Hourly volume of Mennagesha –Holeta & Holeta –Mennagesha Flow direction from collected video on May, 16/2019 is shown on the figure blow





8. Vehicle composition of Mennagesha –Holeta & Holeta –Mennagesha flow direction from collected video on May, 16/2019 is shown on the figure blow

9. Hourly Volume of Sebata road from collected video on May, 17/2019 is shown on the figure blow



10. Vehicle composition of Sebata road from collected video on May, 17/2019 is shown on the figure blow.