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Estimation of Passenger Car Units for Different Category of Vehicles in Midblock

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Abstract—The mixed traffic flow magnifies the impact of one vehicle on another. The present study was carried out to estimate traffic stream speed to study the effect of increased flow volume of individual vehicle category to the speed. In order to achieve the desired objectives, Percentage composition of each vehicle category was prepared for each survey day and average stream speed with classified traffic volume was modelled using SPSS. The passenger car unit of individual vehicles has been estimated from the speed prediction model by taking the ratio of speed reduction coefficient of each vehicle category to that of standard vehicle. The effects of traffic volume and its composition on stream speed and dynamic passenger car unit in the context of urban mixed traffic has been analyzed. Based on the result obtained, passenger car unit of light vehicles increase with increase in road width for given composition, but it decreases with the road width for heavier vehicles. The result also indicated that passenger car unit of all vehicles category increases with increase in percentage composition of heavy vehicles except two wheelers and also the passenger car units of all vehicles category decrease with an increase in traffic stream speed for the given road width due to the fact that the impact of fast-moving vehicles to the nearby vehicle is high and hence the passenger car unit of that vehicle is higher than slow-moving one.

Keywords—mixed traffic flow, passenger car unit, reference vehicles, speed reduction coefficient

I. INTRODUCTION

The road traffic in Ethiopia is highly heterogeneous comprising vehicles like Mini buses, Buses, Mini trucks, Trucks, Truck with Trailers, Bicycles, Motor cycles, Cars and Auto Rickshaws etc. which comprise of wide-ranging static and dynamic characteristics. This heterogeneity magnifies the impact of one type of vehicle to the other due to the highly varying physical dimensions and speed characteristics. This also causes difficulties for vehicles to maintain traffic lanes and forces to occupy any convenient lateral positions over the road width based on the availability at any instant of time.

Passenger car equivalent (PCE) or passenger car unit (PCU) value is very important for any traffic flow studies of vehicles. Passenger car equivalents (PCE) are used as factors to convert a traffic stream composed of different vehicle category into an equivalent traffic stream composed exclusively of passenger cars (reference vehicles).

The travel characteristics, road way networks and local conditions are very different in the cities of developing countries than those of developed countries. It is therefore necessary to determine the different parameters of traffic movements which are suitable for local urban transport systems to characterize our real traffic flow patterns which is input for designing different urban transportation infrastructures.

Hawassa is one of the large cities in Ethiopia which comprises of large number of mixed traffic with traffic composition of pedestrian, bicycle, and motorized vehicles such as motor cycles, Bajaj, taxi, bus, heavy and medium trucks, etc. The city has several straight roadways with a number of different signalized and un-signalized intersections.

General Objectives

The primary objective of this study was to determine appropriate PCU values based on existing traffic flow and road way conditions and to analyse variation of PCU with traffic parameters and road way width.

Specific Objectives

(1). To investigate stream characteristics of traffic flow.
(2). To develop a model which correlate stream speed to the volume and composition.
(3). To calculate new PCU factor based on existing traffic flow characteristics.
(4). To analyze the variation of PCU values of vehicles with traffic stream speed and road way width.

II. RELATED WORK

The traffic in developing country is composited of motorized and non-motorized vehicles along same road space. The motorized vehicles include passenger cars, buses, trucks, truck trailers, Bajaj and motorcycles where as non-motorized vehicles include bicycles and animal drawn carts and because of this undulating speed, the capacity of the road is adversely affected and server congestion is resulted. One way to quantify the effect of different categories of vehicles on capacity is to convert all vehicles into equivalent number of a standard vehicle. Universally accepted such vehicle is passenger car and hence all vehicles in a traffic stream are converted into equivalent number of passenger cars by assigning this equivalency factors to all vehicles other than car. This factor is known as passenger car unit or PCU and capacity is expressed in terms of PCU per hour or per day [1].

The travel characteristics, geometry of roadway networks and local constraints such as traffic control and environmental conditions are very different in the cities of developing countries than those of developed countries. It is therefore necessary to determine different parameters of traffic movements which are suitable for local urban transport system characteristics before designing transport facilities. One of these important parameters is passenger car unit [2].

According to highway capacity manual [3] PCU is “the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions’’. PCU factors are used to convert heterogeneous traffic environment into homogenous in which it is assumed that only cars are travelling. PCU factors have an important significance in the subject of traffic engineering, as these factors are utilized in many traffic analysis methods and procedures which are developed considering homogeneity in traffic conditions such as capacity analysis, saturation flow rate determination and traffic flow models [4].

A passenger car unit is a measure of the impact that a mode of transport has on traffic variables (such as space headway, time headway, speed, density) compared to a single standard passenger car [5].

Various studies have been estimated and analysed homogenization factors for different vehicle types using many approaches. Some of them utilized traffic simulation models to find PCUs under a wide range of traffic and geometric conditions. Therefore, a short discussion of the previous literature has been made in this section.

Manual [3] recommended a single truck PCU value of 2.0 to account the impact of heavy truck to passenger car. Accordingly; a heavy vehicle is any vehicle which has more than four tires in contact with the driving surface. The PCU is implemented through a heavy-vehicle factor (fHV), which is used to adjust the base saturation flow rate. This heavy vehicle factor is one of several adjustment factors for the base saturation flow rate (S0). Equation (1) shows how the base saturation flow rate is adjusted by the adjustment factor as it is defined in [6].

$$S=S_0*f_{HV} \quad (1)$$

But, the form of equation for f_{HV} is

$$f_{HV} =1/(1+P_T*(E_T-1) +P_R*(E_R-1)) \quad (2)$$

Where: f_{HV} = Heavy vehicles adjustment factor, P_T and P_R = Percentage of truck or buses and Recreational vehicles in the traffic stream, E_T = Passenger car equivalency factor for trucks or buses, E_R = Passenger car equivalents for recreational vehicles

But in the case of Ethiopia, there is no recreational vehicles and the term P_{R*} (E_R-1) is not important in the equation (2). Keller and Saklas [7] developed a methodology to estimate PCU values for various vehicle types on an urban arterial network as a function of the level of service (LOS), using a macroscopic simulation model of traffic flow. The basic premise of their study was that the relative capacity reducing effect of larger vehicles is directly related to the additional delay caused by such vehicles when compared to that caused passenger car. Consequently, they hypothesized that the relative capacity reducing effect, measured as PCU of vehicle, could be estimated as the ratio of the total travel times of large vehicles to passenger cars when travelling through an urban network as shown in the following equation (3).

$$PCU^k= TT^k /TT^b \quad (3)$$

Where, PCU^k is PCU values of given vehicle k, TT^k is the total travel time of vehicle k over the networks in hour and TT^b is total travel time of reference vehicle over the network in hour.

Al-Obaedi [1] compared ‘all passenger-car’ and ‘all other than passenger car types’ capacity of traffic lanes. It is relevant to traffic simulation models. The study used equal density method to estimate PCU based on speed difference between flow rates and lagging headway method to estimates the PCU as the ratio between lagging headway when the following vehicle is heavy goods vehicles to the lagging headway when the following vehicle is a small car based on equation (4).

$$PCU= h_t /h_c \quad (4)$$

Where: h_t = average lagging time head way when following vehicle is HGV and h_c = average lagging time head way when following vehicle is passenger car.

In Equation (4) PCU is estimated after estimating the lagging headway. Using equation (5) the study determined following headway based on speed of the following vehicle (SF) and length of the leading vehicle (LL). Equation (6) used to determine lagging headway using speed (SF) and length of the following vehicle (LF).

$$\text{Following headway} =h-(L_L/S_F) \quad (5)$$

$$\text{Lagging headway}=\text{Following headway} +-(L_F/S_F) \quad (6)$$

Webster and Elefteriadou [8] estimated passenger-car equivalents for heavy vehicles using simulation based on traffic density. Traffic density proves a good indicator of the driver's freedom to maneuver, an accurate measure of proximity to other vehicles, and consistent with the measures of effectiveness for freeways and multi-lane highways used in the highway capacity manual [3]. Homogeneous traffic in developed world less or never represents heterogeneous traffic in developing world such as traffic pattern in Ethiopia. Ethiopian highways carry non-homogeneous traffic, which often includes non-motorized traffic entities and ever pedestrians. Loose lane discipline prevails; lane driving and car following is not the norm. Therefore; methods based on homogeneous traffic concepts have limited applicability for this non-homogeneous traffic. [8] used the following equation (7) to calculate PCU of trucks in homogeneous traffic.

$$PCU= K_{tcar} /K_{truck} \quad (7)$$

Where: Kcar is density of car in pure homogeneous traffic (cars only traffic) and Ktruck is density of truck in pure trucks only traffic.
Field measurements were carried out to determine the density values of cars and trucks in addition to traffic flow simulation.
Obri-Yeboah et al. [9] used a headway to estimate PCU of different vehicle at signalized intersection in Ghana. They extracted Headway from the video recordings using the playback method on a computer screen and sorted out headway data for three categories of vehicles; Cars (C) (small cars, pickups, and taxis), medium vehicles (M) (small and medium buses) and trucks (T) (large buses, light, medium and heavy trucks and trailers). Accordingly; estimation of the PCU values for a given vehicle category i was based on the headway ratio method given by the expression:

$$PCU_i= H_i /H_b \quad (7)$$

Where; PCUi is the passenger car unit of vehicle category I, H_i is the average headway of vehicle category i under prevailing conditions, and Hb is the average headway of passenger cars under the same conditions.
Rahman and Nakamura [10] established traffic stream speed-based methods on the aspect in which it is quantified. Accordingly, the effect of certain type of vehicle in changing the traffic stream speed was compared to that of passenger cars. Most common method in this regard is known as speed reduction method which has been utilized mostly for determination of PCU factors which are slower in speed than the passenger cars based on the following expressions.

$$PCU_{nmv}= 1 + (S_b - S_{m)} /S_b \quad (8)$$

Where: PCEnmv = Passenger car unit of non-motorized vehicles, Sb = Average speed of passenger car in the basic flow (km/hr.) and Sm = Average speed of passenger car in the mixed flow (km/hr.).
Girum [11] conducted research to evaluate passenger car equivalents for trucks and buses for basic freeway segments on Addis Abeba-Adama expressway by considering by considering truck proportion, grade percentage and length of grade using equal flow density method. Accordingly, passenger care equivalents values decrease non-linearly as truck proportion increases in less than or equal two percent (2%), greater than two up to three percent (>2-3%), greater than three up to four percent (>3-4%), and greater than four up to five percent (>4-5%) on upgrades. It is less than four percent (4%) and from four up to five percent (4-5%) on downgrades. It was also stated that passenger car equivalents increase non-linearly as the length of grade increases both upgrades and downgrades. In generally, the study concluded that grade length has significant effect on passenger car units in steeper upgrades than gentle upgrades, and the percentage of grade has significant effect on passenger car equivalents in higher grades than lower grades.

III. METHODOLOGY

Description of Study Area

Hawassa is a one of largest city in Ethiopia. It is located 273 km south of Addis Ababa. The city has a latitude and longitude of 7°3′N 38°28′E or 7.050°N 38.467°E coordinates and an elevation of 1708 meters above sea level which is one of rapidly growing secondary cities of Ethiopia. In line with the establishment of the city with master plan, the city has good progress and city administration has been taking measures in response to rising demands for basic infrastructure. The quality of roads, coverage and accessibility are among the factors that contributed for the growth and development of the city as a model in Ethiopia. Even though the city is model in the road sector growth; there is common problems related to traffic flow as the other Ethiopian city.

Site Selection Criteria and Description

This study aimed at estimating passenger car unit (PCU) factor at different midblock which are exposed to excessive amount of traffic volume especially heavy vehicles. Those study areas are listed in the Table 2 and described in the succeeding section. In order to encompass a good image about the site and the flow condition, repeated visual visits were done at major roads of the city. Some information was also gathered from traffic polices and different road users in order to support the result obtained through site reconnaissance. From these repeated visual visits and interviews, a decision on highly congested midblock and peak flow and off-peak flow period for those midblock was arrived.

Based on the observation done in the study area, four midblock were selected for further study. Among criteria to select these sites for data collection, the main one includes high traffic volumes or high level of traffic congestion and good mix of different vehicles category.
In order to reduce the impact of additional factors that could affect speed of vehicle, high consideration was given to the following points during data collection. The selected midblock should free from frequent parking of city taxies,

disturbance from bus stops and bus stations, disturbance from pedestrian crossings and far enough from intersection to minimize the impact of intersection on speed. Based on this, four the most congested midblock were selected.

Table 1 Selected midblock in the study area

Name of midblock	Road width (m)	Study Length (m)	Number of Lanes	Grade (%)	Terrain Type
Logita-Sefereselam	7.20	257	2	+0.8	Flat
Wanza-menharia	10.80	275	3	+0.75	Flat
Mobil-Arebsefer	11.60	350	3	+1.25	Flat
Gabriel-Piazza	10.80	250	3	-1.30	Flat

Field Data Collection Technique

Secondary data was collected from Hawassa city department of transportation for comparing present traffic flow parameters, i.e. traffic speed and volume with that of past time which was used to design traffic lights at different intersections but there was no organized data in the city department of transportation. Therefore, this study depends only on primary data. Spot speed, traffic volume with composition and road width were collected data which are required for this work.

Vehicle Classification

A fully comprehensive classified count may identify up to 20 different vehicle types, but it is rare that such detail will be required. According to overseas road note in order to minimize survey difficulties, five groups will often be sufficient based upon the sub-groups. The group or category number is based on the number of tires on the vehicle. Sub-divisions should be chosen to include groups of common interest. For example, in a transport planning study, divisions may be according to vehicle occupancy; for a road damage study, they may be by vehicle weight; and for traffic signals studies they may be according to their passenger car unit values [12].

According to Ethiopian road authority manual [13] more detailed classification of vehicles shown in the Table 3. Each class must be distinguished from the others by a unique characteristic which can be seen easily in a moving traffic stream on a busy street. For example, methods which involve the counting of the number of tires are more reliable than those which require estimation of length or weight. For clarification, a sketch or photograph of vehicle types should always be given to survey staff which was done in this study.

Table 2 Vehicle classification [13]

Class	Type	Description
1	Car	Passenger car and taxis
2	Pick-up/4-wheel drive	Pick-up, minibus, land rovers, land cruisers
3	Small bus	≤ 27 seats
4	Bus/coach	> 27 seats
5	Small truck	≤ 3.5 tones
6	Medium truck	3.5 – 7.5 tones
7	Large 2-axled truck	> 7.5 tones
8	3-axled truck	>7.5 tones
9	4-axled truck	>7.5 tones
10	5-axled truck	>7.5 tones
11	6-axled truck	>7.5 tones
12	2-axled trailer	>7.5 tones
13	3-axled trailer	>7.5 tones

Table 3: Simplified vehicle classification [13]

Vehicle class	Abbreviation	Description
Two wheelers	TW	Motorized two wheelers
Bajaj/three wheelers	3W	Motorized three wheelers
Passenger car	PC	Passenger car and taxis
Pick-up/4-wheel drive	PU	Pick-up, land rovers, land cruisers
Small bus, small truck and medium truck	MV	Bus (<27 seat), small truck (<3.5 tone) and medium truck (3.5-7.5 tones)
Large buses and large truck	LV	Large buses and single unit large trucks (>7.5 tones)
Articulated truck	TT	Trucks with trailers

PCU Values as Recommended by Ethiopian Roads Authority

Authority, [13] recommend PCU values which were produced by east African transport facilitation strategy (EATFS) for countries in the east Africa. The manual provides PCU for both motorized and non-motorized vehicle classes as shown in the Tables 5 and 6.

Table 4: PCU of non-motorized and mortised small vehicles [13]

Vehicle class	PCU values
All based on Passenger Car	1.00
Pedestrian	0.15
Bicycle	0.20
Motor cycle	0.35
Bicycle with trailer	0.35
Motor cycle taxi	0.40
Motor cycle with trailer	0.45
Small animal drawn cart	0.70
Bullock cart	2.00

Table 5: PCU values of normal motorized vehicles as per [13]

Vehicle Types	Terrain type		
	Level	Rolling	Mountainous
Passenger cars	1.0	1.0	1.5
Light goods vehicles	1.0	1.5	3.0
Medium goods vehicles	2.5	5.0	10.0
Heavy goods vehicles	3.5	8.0	20.0
Buses	2.0	4.0	6.0
Motor cycles, scooters	1.0	1.0	1.5
Pedal cycles	0.5	0.5	Not available

Traffic Volume and Classification Survey

Since traffic volume and its composition is important parameters to achieve the objective of this thesis, it was found necessary to collect volume data using video camera installed at appropriate location and speed data manually using stop watch method at the same time of recording. Reference line was drawn at the appropriate location in the midblock and high-quality video camera was installed at focusing to the reference line. Later on, video was played in the computer and every consecutive 15 minutes traffic volume with composition can be obtained. Video recording and speed data collection was done simultaneously.

Traffic Speed Data Collection

Spot speed study was conducted on the approximate midpoint of the selected midblock at the same time (simultaneously) with volume study. This study was conducted by using stop watch techniques (short-base method) and skilled persons trained for this particular work. A short-base length is created, over which vehicles can be timed. The length has been depending on average speed of vehicle. Finally, after data organization; speed was calculated and presented for each midblock separately.

Field Data Organization

The analysis area and study segments are selected by considering the problem that is being addressed by the project and information that is required to fully assess the problem and propose appropriate solutions. To simplify the analysis, average of respective 15-minute speed data for one selected road segment was used as dependent variable which can be obtained from equation (9).

$$U_{st} = (U_{15tw} + U_{15bjj} + U_{15pc} + U_{15pu} + U_{15mv} + U_{15lv} + U_{15tt}) / 7 \quad (9)$$

Where, U_{st} = overall average stream speed of a day in km/hr., U_{15tw} = 15 minutes average speed of Two wheelers in km/hr., U_{15bjj} = 15 minutes average speed of Bajaj in km/hr., U_{15pc} = 15 minutes average speed of Passenger cars in km/hr. , U_{15pu} = 15 minutes average speed of Pickups and in km/hr. , U_{15mv} = 15 minutes average speed of Medium vehicles (Mini buses, mini and medium trucks) in km/hr. , U_{15lv} = 15 minutes average speed of Large Vehicles (Large buses and Single unit Large trucks in km/hr., U_{15tt} = 15 minutes average speed of articulated trucks or trucks with trailers in km/hr.

Development of the Multivariate Models for Speed Prediction

The speed analysis using multiple regression model has been developed based on the following basic principle. When one vehicle is added to traffic stream, this cause reduction in stream speed for volume V, and also the amount of reduction in the speed depends on the type and size (i.e. ease of maneuverability) of the vehicle. At any traffic state (defined by traffic volume and its composition), increase in traffic volume separately by each vehicle type cause different reductions in stream speed. Therefore, multiple regression model correlates stream speed as a function of dynamic control variables like traffic volume and its composition or different road sections. The reduction in stream speed caused by an increase in traffic volume by each vehicle type is compared with the reduction that is caused by passenger car. For developing multiple regression model, basic principle used is that considering the impact of increased flow volume which tends to decrease speed. It is known that if stream volume is very low, then vehicle can travel at the desired speed without being affected by other drivers. The only thing that can affect the speed of vehicle is roadway and vehicle constraints. We can designate this speed as free flow speed U_f, since vehicle is free to move at desired speed. As the volume of each category of vehicles increases, speed decreases with the respective reduction coefficient. This relation can be depicted by multiple linear regression formula as indicated in equation (12).

$$U_{st} = U_f + C_1X_1 + C_2X_2 + C_3X_3 + \dots C_nX_n \quad (10)$$

Where, U_{st} is mean stream speed at volume V, C_1 to Cn are speed reduction coefficients due to the addition of each vehicle type and X_1 to X n are composition for ith vehicle category from total volume V.

IV. Results and Discussion

This section describes the reduction and analysis of the field data, as well as the development of a model to estimate average stream speed from volume and composition obtained from field data. From the model developed, coefficients for speed reduction are used to estimate PCU of different category vehicle. Then after, dynamic nature of PCU was considered different models was developed to correlate PCU values of individual vehicles to composition, stream speed and road width. Based on these models, different analysis was done and finally in this chapter, the research findings are analysed and discussed analytically, statistically, graphically, in tabular form and qualitatively.

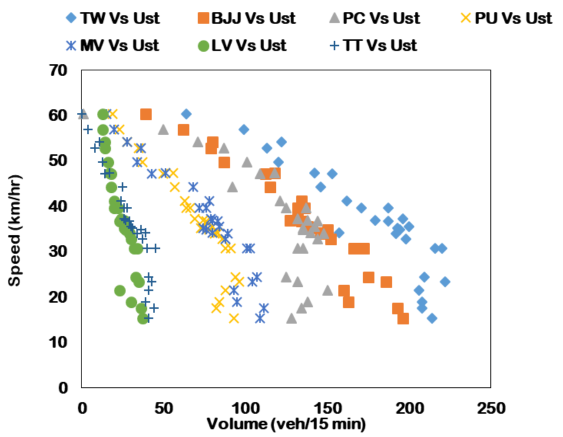
Factors which affect the speed of vehicles include weather conditions, road way geometry, surface conditions, pedestrian's characteristics and etc. But, in this study definite, quantifiable and fundamental relationship has been discovered between speed and volume of vehicles on the road.

According to [3] for freeways and multilane highways, specific range of flow rates exists over which speed is relatively not affected to the flow rate this flow rate may extends to fairly high flow rates. Then, as the flow increases speed decreases. For two-lane highways, over the entire range of flow rates between zero and capacity, speed decreases linearly with increasing flow rate.

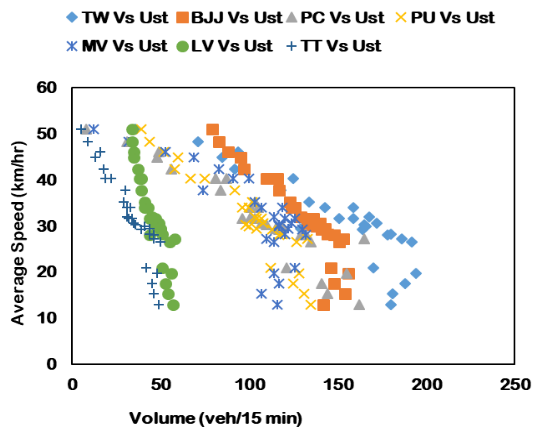
Based on the premises above, model was developed which correlates the average stream speed with volume. From this developed model, passenger car unit (PCU) of different category of vehicles has been calculated.

Speed Volume Relationship

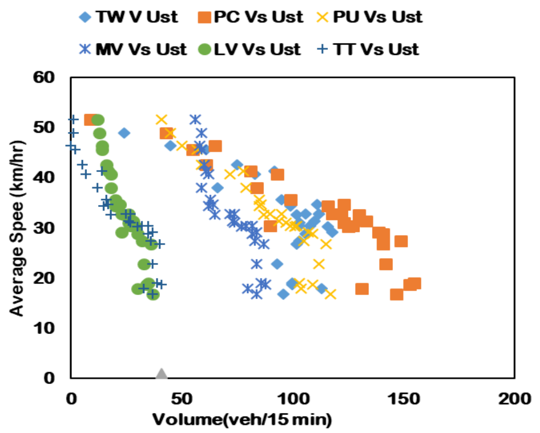
According to [5] free-flow speed is the theoretical speed when the density and flow rate on the study segment are both zero. Accordingly, free-flow speed is expected to prevail at flow rates between 0 and 1,000 passenger cars per hour per lane (pc/h/ln). In this broad range of flows, speed is insensitive to flow rates. This happens when there are small numbers of cars on the road and there are multiple lanes for overtaking. When traffic is more congested, a vehicle cannot maintain desired speed. So that, it needs to reduce their speed to that of slower vehicle. This kind of traffic flow is called partly constrained traffic. When it is not possible for drivers to carry out their desired overtaking maneuvers, this traffic can become completely constrained.



a) Logita-tirrufat midblock



b) Wanza-Menharia midblock



c) Mobil-Arebsefer midblock

Figure 1. Variation of traffic volume and stream speed

Where

TW Vs Ust = Two wheelers versus Stream speed, MV Vs Ust =Medium vehicles versus Stream speed,LV Vs Ust =Large vehicles versus Stream speed,TT Vs Ust = Truck Trailers versus Stream speed, PC Vs Ust =Passenger cars versus Stream speed, BJJ Vs Ust =Bajaj versus Stream speed, PU Vs Ust =Pickups versus stream speed

Figure 1 shows the variation of average stream speed with volume for selected midblock. As shown in the figure, average stream speed decreases linearly with volume of each category of vehicles.

When choosing technique to make regression analysis using multiple linear regression, part of the process involves checking to make sure that the data to be analyzed can actually analyzed using multiple linear regression method. All the independent variables are statistically checked and found to be significant as shown in the following sections. In addition to this the relation between dependent and each of the independent variables has been checked. It was shown in the chapter three that nonlinear (poison and negative binomial) regression method do not appropriately predict the model. It is also important to do this because it is only appropriate to use multiple linear regression analysis if the data passes the following basic assumptions that are required for multiple linear regression method to get a valid and meaningful result. These basic assumptions are explained as follows.

First, we need to check whether there is a linear relationship between the dependent variables and each of the independent variable and dependent variable and independent variables collectively. To do this, we can use scatter plots between variables. Figure 1 indicates the variation of traffic volume and stream speed for Logita-Tirrufat Midblock depicts consolidated scatter plots indicating that there is good linear relationship between the dependent variable (Traffic Stream Speed) and each of independent variables for Logita Tirufat midblock and that for the other three midblock has been shown in Figure 1.
The second point which has to be checked during multiple linear regression analysis is that there should be two or more independent variables and the dependent variable should be measured on a continuous scale (i.e., it is either an interval or ratio variable). In this study, there is one dependent variable (traffic stream speed) which can be measured on continuous scale and seven independent variables (volume of each category of vehicles) which are interval variable.

The third thing that has been checked is homoscedasticity, which is where the variance along the line of best fit remain similar as someone moves along the line. It is also called as homogeneity of variance.

Finally, the residual/error terms are normally distributed with zero mean and constant variance. Errors in the model implies the difference between observed value and predicted value from the model.

Multivariate Model for Speed Prediction

Separate stream speed prediction model was developed for all midblock from the variables listed and stream speed reduction coefficient from the developed model is further used for calculating the respective passenger car unit (PCU) of all vehicle types under study. In this case, the dependent variable for modeling is traffic stream speed (Ust) and independent variables are volume composition of each vehicle category as described in the above section.

After compiling and analyzing the collected data from the study area, SPSS software was used to generate stream speed prediction model and the result is presented separately for each midblock as follow with a detail discussion, figurative and tabular illustrations. After completing the process of building multiple regression model, let us move onto a very crucial steps before making any predictions and further analysis using model. From the developed models below, different statistical interpretations for different parameters were drawn. Some statistical assumptions that need to be taken care of before confirming the model were discussed below.

In the Tables 8 through 9, coefficient of determination (R-square) is shown which is statistical measure of how close the data are to the fitted regression line. In this modeling, it was shown in the table that the model explains 99.5% variability of response data around its mean for Logita-Tirrufat midblock; 99.3% variability of response data around its mean for Wanza-Menharia midblock; 98.7% and 99.4% variability of response data around its mean for Gabriel-Piazza and Mobil-Arebsefer midblock respectively. These value of R-square indicate that the model's best fits data. The statistical significance for each of the independent variables can also be tested with the help of P-value. Significance of variables is indicated by the P-values of the estimated coefficients which should be less than or equal to 0.05 for 95% confidence. This result indicates that overall regression model statistically significantly predicts the outcome variable except Bajaj at Wanza-menharia midblock. The reason for this was that the number of Bajaj category was less in two midblock; Wanza-menharia and Gebriel-piazza.

Table 6 Final result of general multivariate stream speed prediction model for Logita-Tirrufat mid-block

Variables	**Constant**	**Coefficients**	**Standard Error**	**P-Value**	**R^2**	**Remark**
TW	58.795	-0.020	0.016	0.021	0.995	Accepted
BJJ		-0.024	0.010	0.022		Accepted
PC		-0.048	0.012	0.001		Accepted
PU		-0.068	0.033	0.051		Accepted
MV		-0.081	0.028	0.009		Accepted
LV		-0.159	0.059	0.013		Accepted
TT		-0.233	0.045	0.000		Accepted

$$Ust=58.795-0.02*TW-0.024*BJJ-0.048*PC-0.068*PU-0.081*MV-0.159*LV-0.233*TT \quad (11)$$

Table 7 Final result of general multivariate stream speed prediction model for Wanza-Menharia Mid-block

Variables	**Constant**	**Coefficients**	**Standard Error**	**P-Value**	**R^2**	Remark
TW	62.679	-0.027	0.011	0.026	0.993	Accepted
BJJ		-0.030	0.033	0.370		Rejected
PC		-0.037	0.015	0.025		Accepted
PU		-0.056	0.023	0.023		Accepted
MV		-0.058	0.011	0.000		Accepted
LV		-0.161	0.053	0.006		Accepted
TT		-0.216	0.046	0.000		Accepted

$$Ust=62.679-0.027*TW-0.037*PC-0.056*PU-0.058*MV-0.161*LV-0.216*TT \quad (12)$$

Table 8 Final result of general multivariate stream speed prediction model for Gabriel-Piazza Mid-block

Variables	**Constant**	**Coefficients**	**Standard Error**	**P-value**	**R^2**	**Remark**
TW	51.003	-0.038	0.017	0.033	0.987	Accepted
PC		-0.050	0.015	0.004		Accepted
PU		-0.071	0.051	0.018		Accepted
MV		-0.141	0.102	0.028		Accepted
LV		-0.168	0.090	0.077		Accepted
TT		-0.242	0.118	0.053		Accepted

$$Ust=51.003-0.038*TW-0.05*PC-0.071*PU-0.141*MV-0.168*LV-0.242*TT \quad (13)$$

Table 9 Final result of general multivariate stream speed prediction model for Mobil-Arebsefer Mid-block

Variables	**Constant**	**Coefficients**	**Standard Error**	**P-Value**	**R^2**	**Remark**
TW	65.97	-0.031	0.015	0.0516	0.994	Accepted
BJJ		-0.051	0.020	0.0182		Accepted
PC		-0.056	0.012	0.0001		Accepted
PU		-0.063	0.042	0.0146		Accepted
MV		-0.071	0.030	0.0289		Accepted
LV		-0.198	0.070	0.0105		Accepted
TT		-0.248	0.060	0.0005		Accepted

$$Ust=65.97-0.031*TW-0.051*BJJ-0.056*PC-0.063*PU-0.071*MV-0.198*LV-0.248*TT \quad (14)$$

Passenger Car Unit Estimation

The analysis of the ratio between the regression coefficient for a specific vehicle type and that for passenger car produced final PCU values as illustrated in equation 15. Using those speed reduction coefficients, PCU values for different category of vehicles can be calculated and tabulated as shown in the Table 10.

$$PCU= C_i / C_1 \quad (15)$$

Where Ci is speed reduction coefficient for vehicle type i and C1 is speed reduction coefficient for reference vehicle (passenger car).

Table 10: PCU values for observed volumes and composition using the procedure explained above

Vehicle category	**Wanza-Menharia**	**Mobil-Arebsefer**	**Logita-Tirrufat**	**Gabriel-Piazza**	**Average PCU values**
TW	0.73	0.55	0.41	0.76	0.60
BJJ	0.00	0.91	0.50	0.00	0.70
PC	1.00	1.00	1.00	1.00	1.00
PU	1.51	1.12	1.40	1.41	1.36
MV	1.57	1.26	1.67	2.81	1.82
HV	4.35	3.53	3.29	3.37	3.63
TT	5.84	4.41	4.81	4.84	4.97

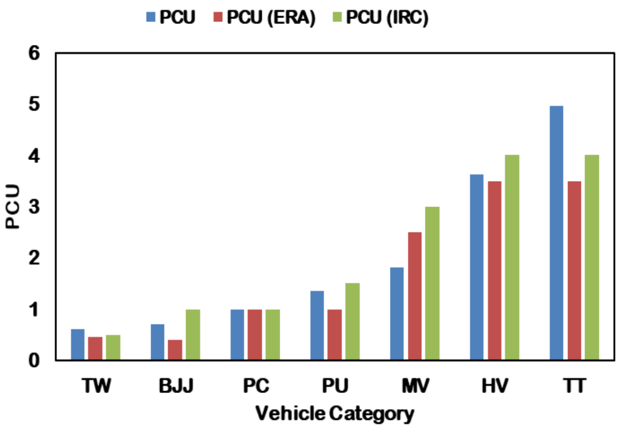


Figure 2. Comparison of obtained PCU values with PCU of different manuals

Figure 2 compares PCU values for studied vehicles type in Indian Roads Congress (IRC), Ethiopian Roads Authority (ERA) and this study. PCU values in this work is slightly different from that in ERA manual and IRC guide line. The reason might be the method applied to calculate this equivalence factor. Different scholars use different methods as explained in review parts of this thesis. Some used headway method, others used density method, travel time method, Multiple linear regression method, simulation method, delay method etc. Since these methods are measuring different things such as headway, delay, density, speed and volume; then it seems fair to suppose that PCU values that they produce are different. In addition to this, ERA manual doesn't provide separate PCU values for urban congested traffic flow.

Analysis on Dynamic PCU Values in a Mixed Traffic Stream

a) Multiple Linear Regression Model for PCU Estimation

Using the data obtained from the study area, speed reduction model was developed for different midblock and corresponding PCU values were calculated using equation (15) as shown in the preceding sections. It was also noted in the literature review section that passenger car unit is dynamic rather than fixed values. It varies with road way geometry, degree of heterogeneity of traffic stream and traffic flow parameters. In this section, models estimating PCU in mixed traffic were developed with PCU of vehicle category as dependent variable and the percentage composition of each vehicle category, road width and average stream speed as independent variables. Percentage composition of different vehicles was calculated from collected traffic volume data and used here as input.

All independent variables are the same for other vehicle categories, except dependent variable i.e. PCU values. Therefore, separate model was developed for each vehicle class by only changing PCU values for respective vehicle category.

Multiple linear regression was used once again to develop a model, which correlate PCU of two wheelers with composition of each vehicle category for different road width. Model was the following equations (equation 16-21).

The model of passenger car unit for TW is as follows with standard error of regression 0.0262and R square 0.96.

$$PCU_{TW} = 0.8149-0.0087TW-0.009BJJ-0.0025PC - 0.0033PU + 0.0072MV + 0.0206LV - 0.0087TT- 0.00021Ust + 0.0136RW \quad (16)$$

The model of passenger car unit for BJJ is as follows with standard error of regression 0.0042 and R square 0.98.

$$PCU_{BJJ} = - 0.2642 + 0.0009TW + 0.0015BJJ + 0.0029PC + 0.0005PU - 0.0011MV - 0.0023LV + 0.0018TT - 0.0002Ust + 0.097RW \quad (17)$$

The model of passenger car unit for PU is as follows with standard error of regression 0.0425 and R square 0.94.

$$PCU_{PU} = 2.8768 - 0.012TW - 0.0138BJJ - 0.0056PC - 0.0058PU + 0.0129MV + 0.0354LV - 0.0146TT - 0.0016Ust - 0.097RW \quad (18)$$

The model of passenger car unit for MV is as follows with standard error of regression 0.0295 and R square 0.97.

$$PCU_{MV}= 3.0482 - 0.0083TW - 0.0096BJJJ - 0.0038PC - 0.0041PU + 0.009MV + 0.0246LV- 0.0102TT - 0.001Ust - 0.1144RW \quad (19)$$

The model of passenger car unit for LV is as follows with standard error of regression 0.1084 and R square 0.95.

$$PCU_{LV} = 5.4917- 0.0306TW - 0.0352BJJ - 0.0141PC - 0.0148PU + 0.0329MV + 0.0902LV - 0.0373TT - 0.0037Ust - 0.0232RW \quad (20)$$

The model of passenger car unit for TT is as follows with standard error of regression 0.1703 and R square 0.93.

$$PCU_{TT} = 9.5419 - 0.048TW - 0.0554BJJ - 0.0222PC - 0.0233PU + 0.0517MV + 0.1418LV - 0.0586TT - 0.0058Ust - 0.213RW \quad (21)$$

Where, TW=two wheelers, BJJ= Bajaj, PC=Passenger car, PU=Pickups MV=Medium vehicles, LV= Large vehicles, TT= Truck trailers

b) Validation of Developed Models

The results of multiple linear regression models relating the PCU of different vehicle classes to traffic stream speed, traffic composition and road width corresponding to the goodness of fit. Indicating that the value of determination coefficient (R^2) is high and the models are statistically significant. Validity of the models developed to correlate dynamic PCU with influencing parameters was checked with the data left for validity test in Table 11. Figure 10 shows the validation indicating a good match between the observed PCU and predicted PCU values for each vehicle category.

c) Analysis of PCU Variation with Traffic Parameters

In order to study the variation of PCU values with the proportion of different classes of vehicles under mixed traffic conditions, the validated multiple linear regression model was developed to study the effect of road width and stream speed on PCU values for varying traffic composition and carriageway width.

From the developed PCU models, it is observed that the dynamic PCU values for all categories of vehicles have got a negative correlation with the stream speed showing that PCU of each vehicle in mixed traffic flow decreases with increase in stream speed.

Naturally when traffic volume decreases, the drivers get more comfort of driving and the impact of one vehicle on the other decreases due to fewer interactions. This cause the speed of the entire vehicle category to increases, which will cause lesser PCU values for the vehicles, when stream speed increases.

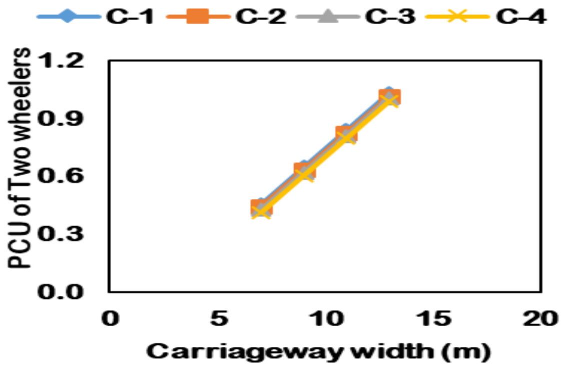
It also observed from the model that PCU values got negative correlation with carriageway width for heavier vehicles category and positive correlation for light vehicle categories like Two wheelers and Bajaj. This is because of the fact that light vehicles utilize small gap between two larger vehicles during saturated flow. They do not follow traffic lanes and occupy any lateral position on the road space the wider roads making flow complex and maneuverability difficult. Though the road width is narrow, the smaller vehicles like two-wheeler and three-wheeler utilized the narrow gaps and due to this the heavier vehicles have less freedom to move freely, which will cause a high-speed differential between the vehicles. The increase in width of roadway invariably provides relatively higher maneuverability for all vehicle types on wider roads which in turn make PCU of heavy vehicles to be decreased.

The relation between dynamic PCU values and percentage composition of each vehicle category has been predicted from the models developed. In this case, what we observe from the model is that PCU of vehicles got negative correlation with the percentage compositions of Two wheelers, Auto rickshaw, Passenger car and Pickups where as it got positive correlations with percentage compositions of heavy vehicles categories like Medium and Large Buses, Medium and Large Trucks and Articulated Trucks (Truck trailers). In this section, detailed explanation with the help of illustrative figures is presented for variation of dynamic PCU values with traffic flow parameters for different combination of percentage composition.

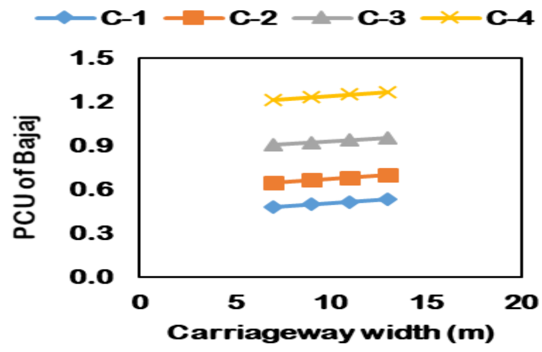
1) Variation of PCU values with carriageway width

It was clearly discussed in the above sections that traffic flow parameters were influenced by the composition of traffic stream. The variation of traffic condition affects movement of one vehicles on adjacent vehicles in the traffic stream. To analyze the effect of carriageway width on PCU values of different category vehicle under study, the dynamic PCU models given in Tables 8 through 11 were used. The effect of following four composition on PCU values were studied for varying road width using sensitivity analysis:

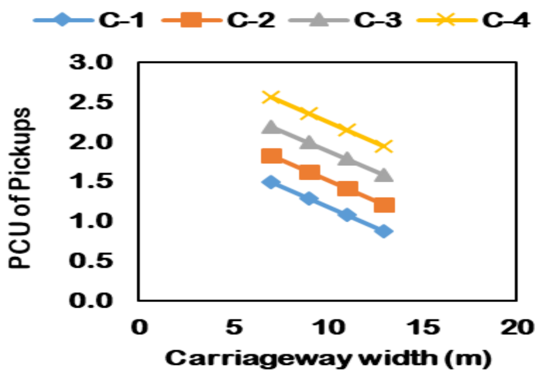
- Composition (C-1): - 20% Two wheelers (TW), 30% Bajaj (BJJ), 15% Passenger cars (PC), 20% Pickups (PU), 10% Medium vehicles (MV), 5% Large vehicles (LV) and 0% Truck trailers (TT).
- Composition (C-2): - 20% Two wheelers (TW), 25% Bajaj (BJJ), 10% Passenger cars (PC), 15% Pickups (PU), 15% Medium vehicles (MV), 10% Large vehicles (LV) and 5% Truck trailers (TT)
- Composition (C-3): - 15% Two wheelers (TW), 20% Bajaj (BJJ), 10% Passenger cars (PC), 10% Pickups (PU), 20% Medium vehicles (MV), 15% Large vehicles (LV) and 10% Truck trailers (TT)
- Composition (C-4): - 10% Two wheelers (TW), 15% Bajaj (BJJ), 5% Passenger cars (PC), 10% Pickups (PU), 25% Medium vehicles (MV), 20% Large vehicles (LV) and 15% Truck trailers (TT).



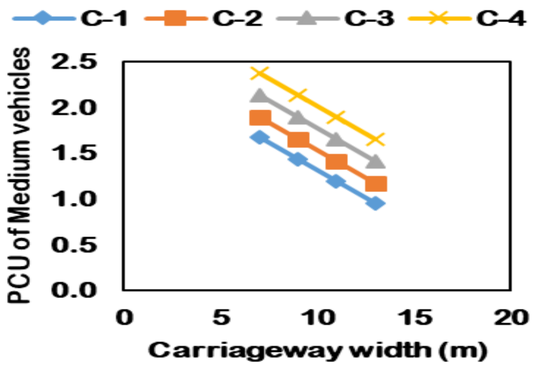
a) Two wheelers



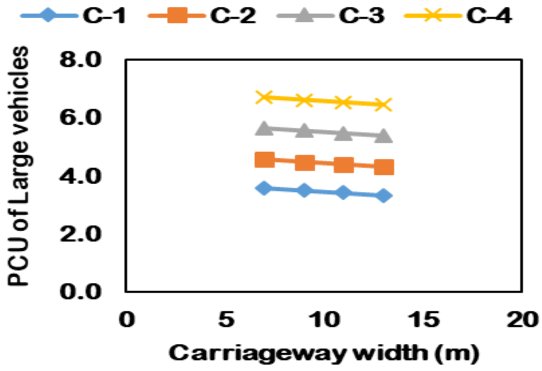
b) Bajajs



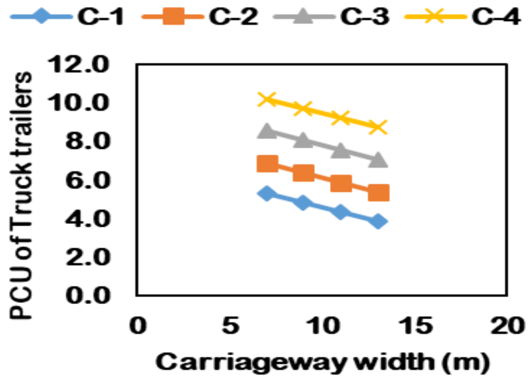
c) Pickups



d) Medium Vehicles



e) Large Vehicles



f) Truck Trailer

Figure 3. Variation of PCU values for different carriageway width under different compositions

Figure 3 shows the variation of PCU with road width for different percentage composition. It is clearly depicted from the figure that the impact of highway carriageway width on the PCU is apparently linear. From Fig. 3, it can be seen that for a given composition, as width of the road increases, the PCU value decreases except for light vehicles. This may be due to the freedom of light vehicles to choose the speed, as the width increases. In the urban traffic flow, light vehicles violate stream speed by utilizing even small gaps between other vehicles which cannot be used by heavier vehicles. Light vehicles in the traffic flow also do not follow traffic lanes and occupy any lateral position on the available road space. Even though the maneuvering process becomes relatively easier on wider roads, this facilitate faster movement of vehicles in turn creating larger gaps that is why their equivalency factor increase with width of the road. It can also be concluded from the figure that PCU of heavy vehicles decrease with an increase in carriage way width. As the road width increases, the hindrance of heavy vehicles to other vehicles decreases and hence, PCU decreases.

By comparing the different compositions, it can be said that at higher compositions of heavy vehicles, the PCU values for all vehicle's category get increased for all road width except Two wheelers. From the results obtained in this thesis, Fig.3 shows the influence of the traffic composition on PCU. The amount of this influence varies with vehicle category. That means PCU of two-wheelers slightly decreases with the increase in the percentage composition of heavy vehicles and it increases for all other vehicle category. The reason to this is that the resistance of other vehicles category on Two-wheelers is lower compared to others due to their smaller size and easy operating. On the contrary to this; bajaj, pickups, medium vehicles, large vehicles and truck trailers experience more resistance with the increased proportion of heavy vehicles in the flow.

- In general, for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), PCU of two wheelers is 0.6 for carriageway width of 9m.
- PCU of bajaj is 0.74 for composition (C-2) i.e. 20% two wheelers (TW), 25% bajaj (BJJ), 10% passenger cars (PC), 15% pickups (PU), 15% medium vehicles (MV), 10% large vehicles (LV) and 5% truck trailers (TT) at the road width of 11.6m.
- PCU of pickups is 1.36 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m
- PCU of medium vehicles is 1.82 for composition (C-2) i.e. 20% two wheelers (TW), 25% bajaj (BJJ), 10% passenger cars (PC), 15% pickups (PU), 15% medium vehicles (MV), 10% large vehicles (LV) and 5% lruck trailers (TT) at the road width of 7.2m.
- PCU of large vehicles is 3.63 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m
- PCU of truck trailers is 4.97 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m

2) Variation of PCU values with stream speed

The PCU values of different categories of vehicles were estimated by modeling dynamic PCU with different percentage compositions and different carriageway widths. To study the effect of stream speed on PCU values, models developed for each vehicle category were made use of. For a particular proportion of Two-wheeler, Bajaj, Passenger car, Pickups, Medium vehicles, Large vehicles and Truck trailers and also for a particular carriageway width, the variation in the obtained PCU values was studied. Similar chart of figure 3 has been drawn for the variation of PCU with traffic stream speed for varying carriageway widths. For the analysis, the observed the percentage composition chosen were 20% Two wheelers, 30% Bajaj, 10% passenger car, 15% Pickups, 15% Medium vehicles, 7% Large vehicles and 3% Truck trailers. Minimum road width measured in the study area was 7.2m and maximum was 11.6m. Based on this, analysis was done for variation of dynamic PCU values for different road width. The result shows that for a given road width, PCU values of all vehicles category decrease with increase in stream speed. This is due to the fact that as vehicles move fast, the impact to the nearby vehicle is high and drivers of nearby vehicles give more attention to it.

V. CONCLUSION AND FUTURE SCOPE

Speed prediction model was developed based on Speed-volume approach under mixed traffic condition. The model developed is based on the presumption that stream speed decreases as volume increases from the least congested (off-peak hour flow) to the most congested (peak hour flow) conditions. The developed speed model was used to determine PCU factor for individual vehicle category by taking the ratio of stream speed reduction coefficients.
This paper clearly explained the significance of PCU values, and has been proved that PCU values are dynamic rather than assigning single static value. Hence, dynamic PCU is highly sensitive to the given traffic and geometric condition such as carriageway width, traffic composition as well as traffic stream speed. The models developed for dynamic PCU value show us that dynamic PCU values for all categories of vehicles has got a negative correlation with the stream speed which indicates that PCU values of all category of vehicles under study decreases with increase in stream speed. It was also observed from the developed model that PCU of all vehicle's category decreases with increase in stream speed except for light vehicles (Two wheelers and Bajaj). The reason for exception is that light vehicles utilize even small gap between larger vehicles by occupying any lateral position on the available road space. This makes flow more complicated and maneuvering difficult for heavier vehicles. To performance of developed PCU model for each vehicle category has been a comparatively assessed to validate the model. This validation indicates that PCU have a good agreement with the observed ones.

In general, major findings in this research can be summarized below.

- Increase in the traffic volume has a significant influence which varies with vehicle category on the stream speed. Heavy vehicles with poor operating characteristics have higher speed reduction rate compared with small car and light vehicles which have lower speed reduction rate.
- Traffic composition affects speed and dynamic PCU for each vehicle categories. The increment in the proportion of larger-sized vehicles in the traffic stream occupies more space on the road. Due to this, vehicles tend to move at low speed. The amount of this speed reduction depends on each vehicle category and compared to that due to standard car which numerical represented as PCU.

This study suggests further detailed investigations are necessary to examine behavior of different types of vehicles which may lead to appropriate values of PCU factors. The main question to be answered in this regard is "Are we using the right number in traffic studies of Ethiopia when it comes to PCU values?" Therefore, what this study recommends for PCU values based on different composition and road width is here below.

- For composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% Pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), PCU of two wheelers is 0.6 for carriageway width of 9m.
- PCU of bajaj is 0.74 for composition (C-2) i.e. 20% two wheelers (TW), 25% bajaj (BJJ), 10% passenger cars (PC), 15% pickups (PU), 15% medium vehicles (MV), 10% large vehicles (LV) and 5% truck trailers (TT) at the road width of 11.6m.
- PCU of Pickups is 1.36 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m
- PCU of medium vehicles is 1.82 for composition (C-2) i.e. 20% two wheelers (TW), 25% bajaj (BJJ), 10% passenger cars (PC), 15% pickups (PU), 15% medium vehicles (MV), 10% large vehicles (LV) and 5% truck trailers (TT) at the road width of 7.2m.
- PCU of large vehicles is 3.63 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m
- PCU of truck trailers is 4.97 for composition (C-1) i.e. 20% two wheelers (TW), 30% bajaj (BJJ), 15% passenger cars (PC), 20% pickups (PU), 10% medium vehicles (MV), 5% large vehicles (LV) and 0% truck trailers (TT), at the road width of 7.2m

It was observed that PCU values are dynamic in nature. Therefore, using fixed values from standard manuals for designing and capacity studies of every urban infrastructure is not good practice. The current problems associated with transportation sector such as congestion, high rate of fatal and injury accident and low level of service (LOS) may be associated with PCU value under estimation and also lack of research in this area. The government authority and concerned body has to give due concern to this field of study.

REFERENCES

[1] J. T. S. Al-Obaedi "Estimation of passenger car equivalents for basic freeway sections at different traffic conditions," World Journal of Engineering and Technology, no. 4, pp. 153-159, 2016.

[2] C. O. Cruz-Casas, "Development of passenger car equivalency values for trucks at signalized intersections," University of Florida, 2007.

[3] H. C. Manual, "Transportation Besearch Board," National Research, Washington DC, 2010.

[4] G. Tiwari, J. Fazio and S. Gaurav, "Traffic planning for non-homogeneous traffic," Sadhana, vol. 32, no. 4, p. 309–328, 2007.

[5] K. Shalini and B. Kumar, "Estimation of the passenger car equivalent," International Journal of Emerging Technology and Advanced Engineering, vol. 4, no. 6, pp. 97-102, 2014.

[6] H. C. Manual, "Highway Capacity Manual," TRB, Washington DC, 2000.

[7] E. L. Keller and J. G. Saklas, "Passenger car equivalents from network simulation," Journal of Transportation Engineering, vol. 110, no. 4, pp. 397-411, 1984.

[8] N. Webster and L. Elefteriadou, "A simulation study of truck passenger car equivalents (PCE) on basic freeway sections," Transportation Research Part B: Methodological, vol. 33, no. 5, pp. 315-385, 1999.

[9] A. A. Obri-Yeboah, Y. A. Tuffour and M. Salif, "Passenger car equivalents for vehicles at signalized intersections within the Kumasi Metropolis in Ghana," International organization of Scientific Research (IOSR) Journal of Engineering, vol. 04, no. 04, pp. 24-29, 2014.

[10] M. Rahman and F. Nakamura, "Measuring passenger car equivalents for non-motorized vehicle (rickshaws) at mid-block sections," Journal of the Eastern Asia Society for Transportation Studies, vol. 6, pp. 119-126, 2005.

[11] G. Tamene. "Passenger car equivalents for basic freeway segments on Addis Abeba- Adam Expressway," Addis Abeba Universiti, Addis Abeba, 2016.

[12] N. W. Marler, F. Montgomery, A. D. May and P. Bonsall, "Urban road traffic survey," Oversea Road Note 11, Crowthorn and Berkshire, 1993.

[13] E. R. Authority, "Route selection manual," Ethiopian Roads Authority, Addis Abeba, 2013.

