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Determination of Passenger Car Unit for Urban Roads: A Case Study in Addis Ababa

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Abstract: In Ethiopia, specifically on Addis Ababa city roads operating, vehicles are mixed with varying static and dynamic traffic characteristics that are very challenging for the traffic analyst to come up with a sole solution to the traffic malady. Under heterogeneous traffic, each vehicle type cannot be compared with other vehicle types since it shows different effects on the road. It could be observed that the majority of the drivers in Addis Ababa road networks do not follow proper lane discipline to use any available space on the road sections. Currently, Ethiopia is using the passenger car unit values from other countries manual, which doesn't represent the local traffic and roadway conditions. This study was initiated to establish the PCU values that will cater the local settings. Hence, this study was focused on estimating the PCU values of multilane highways in Addis Ababa city and determining the influence of traffic volume and width of the road on the values of PCU. The PCUs were estimated for four vehicle types based on the variation of traffic volume and carriageway width. Dynamic PCU method was used to determine PCU values, and a linear regression analysis was performed for model development. The developed model is used to estimate PCU values having the same traffic conditions and roadway conditions found in other countries. The study results indicated that as the traffic volume and carriageway width increases, the passenger car unit value also increases. Also, it was found out that the results of PCU values in this study showed higher values than those provided in Highway Capacity Manual (HCM). Hence, the PCU values obtained are recommended to reflect the existing traffic condition in the locality.

Keywords: Passenger Car Unit, Dynamic PCU, Traffic Volume, Carriageway Width, Regression Analysis

1. Introduction

Traffic on multilane urban roads in developing countries is highly heterogeneous, composed of different vehicle characteristics [1]. Under mixed traffic conditions, each vehicle is unique and cannot be compared with other vehicle types as it demonstrates distinct effects on the behavior of traffic flow on varying composition. Small-sized vehicles penetrate the gaps between large-sized vehicles and make the operating conditions poorer [2].

Heavy vehicles in the traffic stream affect the movement of other small vehicles. As heavy vehicles are introduced into the traffic flow, the roadway's ability to carry vehicles is reduced because heavy vehicles are larger than passenger cars, so they occupy a lot of space, and their lower performance characteristics cause a delay [3]. Therefore, heavy vehicles cause disorder in traffic flow and affect the roads' capacity and level of service. The growth of urban traffic needs to improve transportation, so it is necessary to determine the road's capacity accurately to reduce congestion.

To account for the effects of each vehicle type on the quality of flow, a traffic stream composed of a mix of vehicle types is converted to an equivalent stream composed entirely of passenger cars using passenger car equivalent (PCE) values, Since Passenger Car Unit (PCU) is used to convert mixed traffic into equivalent homogeneous traffic conditions [4].

Passenger car unit is first introduced in1965 in highway

capacity manual and defined as “the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions [5].

The term passenger car unit (PCU) is used interchangeably with passenger car [6].

The more accurate calculation of passenger car units results in a more precise capacity analysis. The characteristic of traffic behavior is different from country to country. The reason is due to topography conditions, geometrical design, vehicle performance, driver behavior, facilities available, and rate of development in the transportation section [7].

Pavement width, percentage of slow-moving vehicles, grade and length of the road, surface characteristics, shoulder conditions, and directional split in two way traffic are some factors that affect the value of passenger car unit [8].

Ethiopian design Ethiopian design engineers use passenger car unit values from highway capacity manual (HCM), which is done based on the developed countries' traffic behavior. Thus it is inappropriate to use foreign traffic standards in Ethiopia since it doesn't fit the reality available in Ethiopia. So developing passenger car units based on the regional condition is necessary to estimate capacity correctly to reduce congestion along the highway.

This study's general goal is to determine passenger car units of urban roads in Addis Ababa for selected urban streets based on the local traffic and roadway condition.

2. Research Methodology

2.1. Description of the Study Area

In this research, there were two sections considered that are located in the Addis Ababa city, Ethiopia. The first study area is a roadway having six traffic lanes, and the second study area is a four-lane urban road. The study site was selected due to heterogeneous traffic movements in that area.

Study area one: from gelan condominium to lebu mebrat hail. this road has 11m width in one direction and connects southern parts of Addis Ababa with northern part.

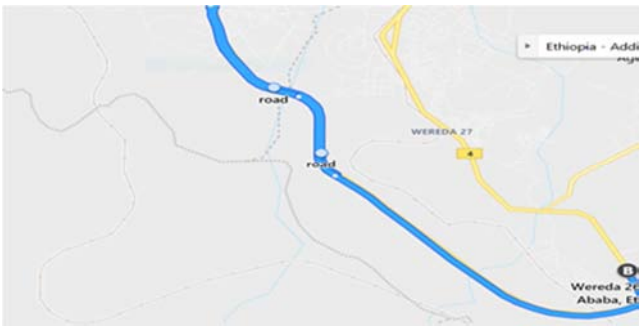

Figure 1. *Road Section Study Area One.*

Study area two: this connects ayat square to legetafo square and has four lane roads. The width of the road in one direction is 7m. This road section is found in the eastern Addis Ababa region.

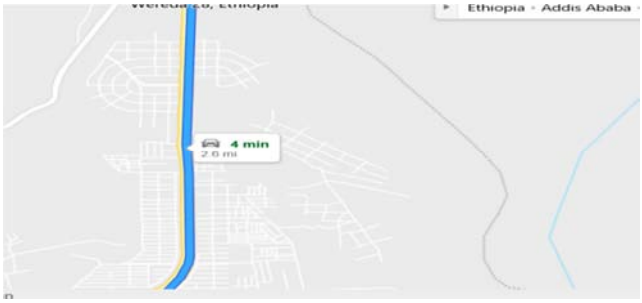

Figure 2. *Road Section of Study Area Two.*

2.1.1. Data Collection

The data for this study were collected under sunny conditions from 10:00 am-4:00 pm. large vehicles allowed to move from 10:00 am-4:00 pm in Addis Ababa city, so to get heterogeneous traffic conditions and peak hours, the filming was done for six hours in Wednesday December 18, 2019 and Thursday, December 19, 2019 for six lane and four lane roads respectively.

The video has recorded the movement of vehicular traffic in one direction of travel by considering a trap length of 100m for six-lane road, and the electric pole was used as a reference for trap length determination. Each Electric pole is 50m apart with each other, so two electric poles are used as a reference. For the four-lane road, a 60m trap length was used to take the filming since the electric pole here is 20m apart from each.

The selection of the study area was based on the following criteria:

1. Good mix of traffics during peak hours.
2. No parking in the area
3. Level terrain, is free from rising and fall.
4. Both sides are separated by a median

2.1.2. Data Extraction

Recorded data from the video was extracted using a video playback method on the computer. From the video, travel time data and traffic volume were extracted. Travel time of each vehicle was measured from the video by calculating the difference between entry of trap length and end of trap length. Then using this travel time, the speed of each vehicle can be determined. The speed of the vehicle and the physical dimension of the vehicle can be used to estimate the passenger car unit.

$$s=d/t \quad (1)$$

Where s=speed of the vehicle, km/hr.

d=distance traversed, km.

t= time to traverse the distance, hr.

Traffic volume is measured by counting the number of vehicles that pass a predetermined line. Rates of flow can be computed for any period of time, and researchers often use rates of flow for periods of one to five minutes, rates of flow for shorter periods of time has consistent mathematical representation [9]. For this study rates of flow can be calculated for five minute periods.

$$q = \sum Vi * 12 \quad (2)$$

Where, q=rates of flow, per hour per direction, (veh/hr/dr)

Vi=number of vehicles that pass the study section with a specified time interval

2.2. Determination of Passenger Car Unit and Data Analysis

This study adopted a dynamic PCU method for PCU estimation. The reason for using dynamic PCU method is due to the non-lane based traffic movement of vehicles and due to higher heterogeneity of traffics in Ethiopia, specifically in Addis Ababa. In the conditions where vehicles do not follow lanes strictly, the occupancy is better reflected by area [14].

$$PCU=((Vc/Vi))/((Ac/Ai)) \quad (3)$$

Where;

Vc=mean speed of a car and Vi=mean speed of vehicle type i Ac=projected area of the car and Ai=projected area of vehicle type i

Ethiopian Road Authority [12] classifies vehicles into thirteen, among those types of vehicles; four types of vehicles were selected for this study due to the good mix of these types of vehicles on the road, These is cars, big cars, minibus, bus and truck. Table 1 shows the rectangular plan area of vehicles

Table 1. *Rectangular Plan Area of Vehicles.*

Vehicle type	Average dimension		Rectangular plan area m^2
	Length (m)	Width (m)	
Standard car	3.7	1.6	5.92
Big car	4.7	1.8	8.46
minibus	4.75	1.8	8.55
bus	9.05	2.35	21.27
Heavy vehicle	9.84	2.37	23.28
2 wheelers	1.87	0.64	1.2

Finally, Regression analysis is used to model passenger car unit. MS excel 2013 was used for regression analaysis.

3. Analysis, Result and Discussion

3.1. Traffic Flow Rate and Traffic Composition

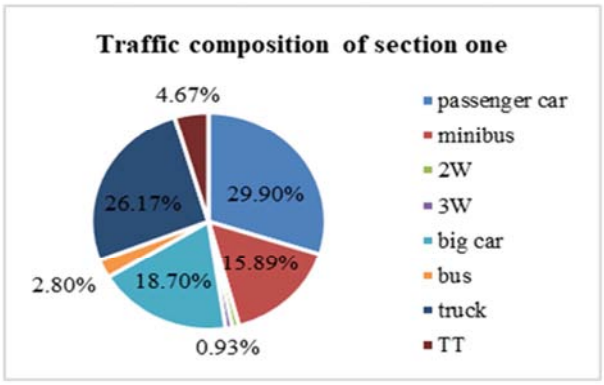

Figure 3. *Traffic Composition for Study Area One.*

Traffic composition and flow rates of each section were taken only from one direction, which has a larger flow during study time. The traffic composition was done by using a peak of 15 minutes during the study.

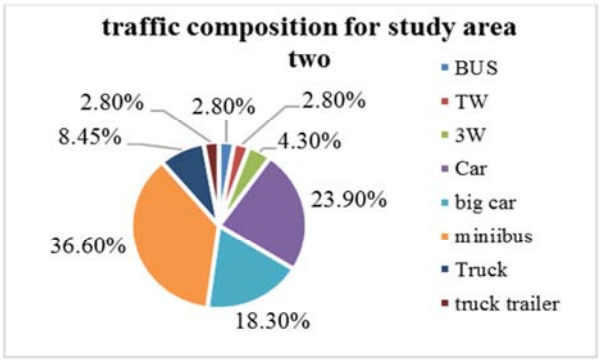

Figure 4. *Traffic Composition for Study Area One.*

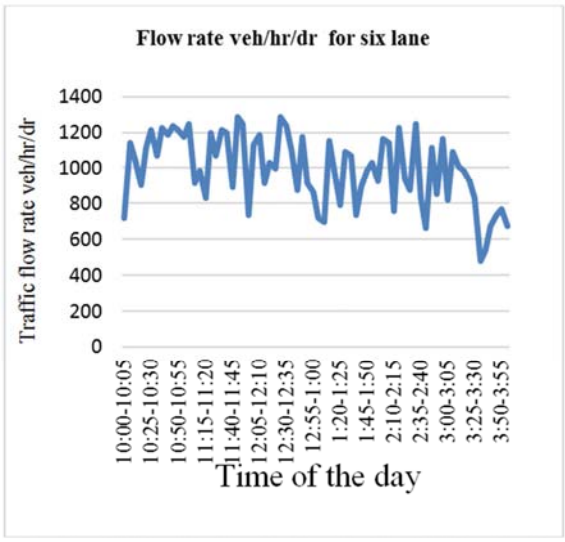

Figure 5. *Traffic Flow Rate for Study Area One.*

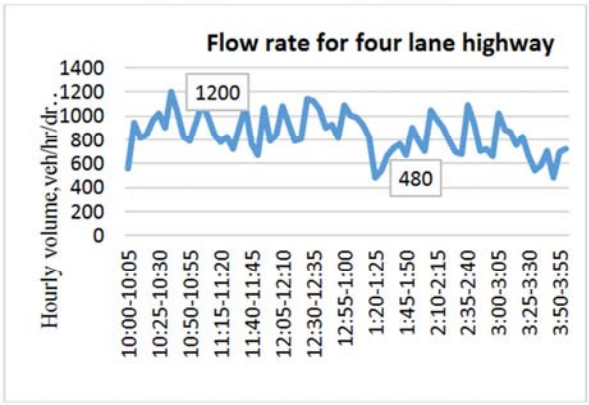

Figure 6. *Traffic Flow rate for study area two.*

3.2. Variation of Speed with Traffic Volume

The average speed of a vehicle can be measured using vehicles traveled time over 100m and 60m distance for six lane road four lane road respectively. Space mean speed was collected for each one-minute intervals.

The speed of individual types of vehicles is different due to that some vehicles move faster than the other, and also, the traffic volume affects the speed of the same types of vehicles. The variation of the speed of each vehicle has been determined by studying the speed of individual vehicle types at different volume levels.

Table 2. *Variation of Speed as Traffic Volume Varies for Six Lane Road.*

vehicle type	`Traffic volume in veh/hr.				
	0-500	500-700	700-900	900-1100	1100-1300
Car	90	88	86	82	70.34
big car	91	88.6	84	80	52.4
Minibus	88	83	78	74	63
Truck	75	72	69.8	65.89	56
TT	62	59	53.6	50.2	49.35

Table 3. *Variation of Speed as Traffic Volume Varies for four Lane Road.*

Vehicle type	Traffic volume in veh/hr and speed of each vehicle type in km/hr.				
	0-500	500-700	700-900	900-1100	1100-1300
Car	48.54	47.2	40	32.03	29.39
Big car	52	49.86	41.54	32.1	29.3
Minibus	47.9	45.5	38.5	30.2	26.6
Truck	44.6	41.2	34	26.7	24.18

3.3. Determination of Passenger Car Unit

Dynamic PCU method is used in this study and to predict PCU regression analysis was carried out.

Table 4. *Variation of PCU with change in traffic volume for six lane road.*

Veh. Type	Traffic volume in veh/hr (six lane)				
	0-500	500-700	700-900	900-1100	1100-1300
Car	1	1	1	1	1
Big car	1.42	1.45	1.46	1.48	1.51
Minibus	1.477	1.53	1.59	1.6	1.63
Truck	4.71	4.80	4.84	4.89	4.93

Table 5. *Variation of PCU with change in traffic volume for four lane road.*

Veh. Type	Traffic volume in veh/hr (four lane)				
	0-500	500-700	700-900	900-1100	1100-1300
Car	1	1	1	1	1
Big car	1.33	1.35	1.376	1.42	1.431
Minibus	1.46	1.493	1.50	1.57	1.59
Truck	4.23	4.50	4.63	4.71	4.77

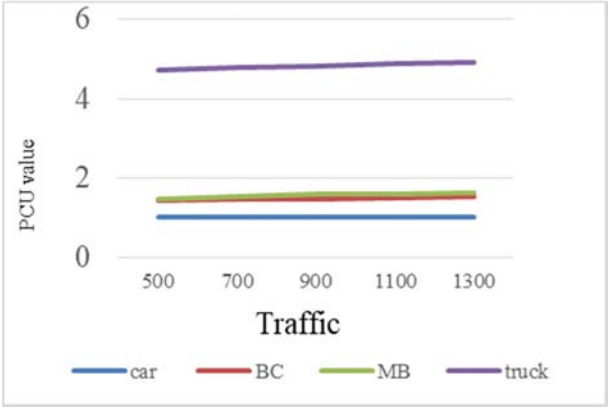

Figure 7. *Variation of PCU with Traffic Volume for Six Lane.*

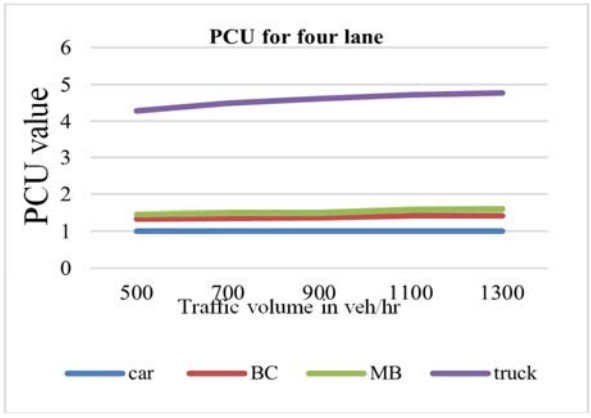

Figure 8. *Variation of PCU with Traffic Volume for Four Lane.*

From the above table and graph it can be concluded that, as traffic volume increases, the passenger car unit increases for each type of vehicle. As traffic volume increases the speeds of large vehicles decreases, but the speed of passenger car and a big car is not affected, so the difference in speed between a passenger car and other vehicles increases this increases passenger car unit. According to [10], in road sections, as the volume of traffic increases, density will increase; this makes the vehicles move at a slower speed. But for smaller vehicles, the speeds will not be affected since they can move by using any lateral positions. So, it makes the variation of speed between large vehicles and passenger car unit higher, due to this difference passenger car unit for larger vehicles increases as traffic volume increases.

In this study, two types of urban roads are considered four-lane road and six-lane road. The pavement width of these roads is different. For six lanes width of one lane is 3.5m, which is 10.5m in one direction and for four lanes width of one lane is 3.5m, which is 7m in one direction. Based on this, the value of passenger car unit estimated.

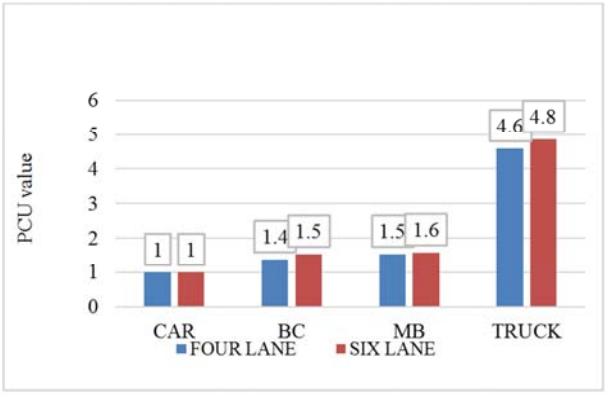

Figure 9. *Variation of PCU with Variation in Carriageway Width.*

The increase in carriageway width or the wider the carriageway, the more would be the driver's confidence to increase their speeds [11]. In the case of wider carriageways, both the driver of a large vehicle and passenger car travels at their normal speed. This results in an increase in the difference in speed for larger vehicles and passenger cars, which provides an increase in passenger car unit values.

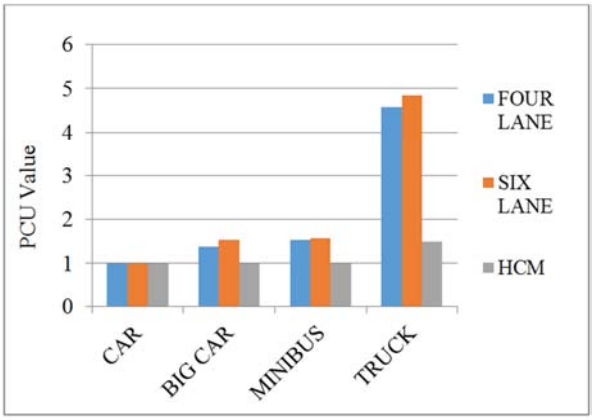

Figure 10. *Variation of Executed PCU with HCM PCU.*

In HCM 2010, manual passenger car values are provided only for trucks, buses, and recreational vehicles. For level terrain, PCU was 1.5 for bus and truck, while 1.2 for a recreational vehicle [14]. In this study, the value of the passenger car was higher than that provided in the HCM manual. For trucks, passenger car unit value was 4.9 and 4.6 for six and four-lane respectively for this study, while in HCM for trucks and buses, it was 1.5, which is very low compared to this study.

3.4. Interpretation of Regression Analysis

For this study, linear regressions are used to develop models for passenger car unit estimation. The input variable is traffic volume, while the output variable is the passenger car unit. Since all vehicles are not affected in the same way by traffic volume, a separate relationship is developed for each vehicle category.

From the statistical analysis, the variable that has a result of $P<0.05$ is a statistically significant variable that shows the variation in the dependent variable's value in this study passenger car unit. The variable in this study was traffic volume, and the statistical significance of this variable was cross-checked.

After regression analysis, the following linear equation model was developed.

$$PCU = a + b(10^{(-x)})Q \quad (4)$$

Where, PCU=passenger car unit
a=constant, y intercept
b=coefficient,
Q=traffic volume in veh/hr

The values of the constants and coefficients for each category of vehicles are presented in the table 6.

Table 6. *Values of Constants Obtained From Regression Analysis.*

Types of vehicle	Four lane				Six lane			
	a	b	x	Ad.R^2	a	b	x	Ad.R^2
Big car	1.26	1.36	4	0.94	1.36	1.15	4	0.95
minibus	1.37	1.73	4	0.89	1.39	1.88	4	0.91
Truck	4.3	6.06	4	0.92	4.6	2.64	4	0.97

3.5. Model Validation

The validation is necessary to show how well the developed model predicts future values in the same city or other countries or cities with the same problems. In this research, the external validation was carried out for each developed model to validate the predicted model. It was found that the adjusted R2 value is 0.95 for big car, 0.91 for minibus and 0.97 for truck an six lane while, 0.94 for big car, 0.9 for minibus and 0.92 for truck on four lane and all the values of R2 above 0.9, which shows a confirmed prediction, as indicated in the graph below. As previously mentioned, since all vehicles are not affected in the same way by traffic volume, there is a separate relationship for each category of vehicles. Therefore, the validation is also carried out for each category of vehicles.

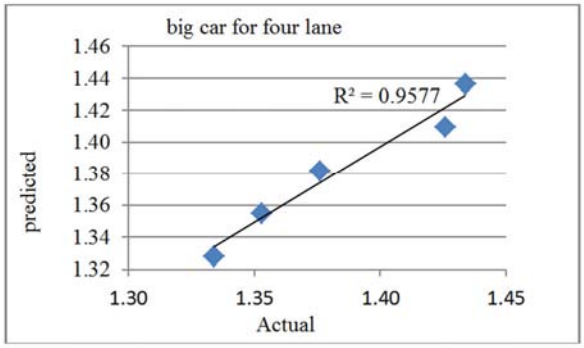

Figure 11. *Values of R^2 for Big Car on Four Lane.*

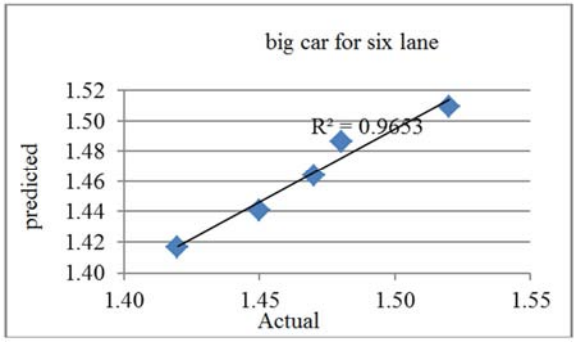

Figure 12. *Values of R^2 for Big Car on six Lane.*

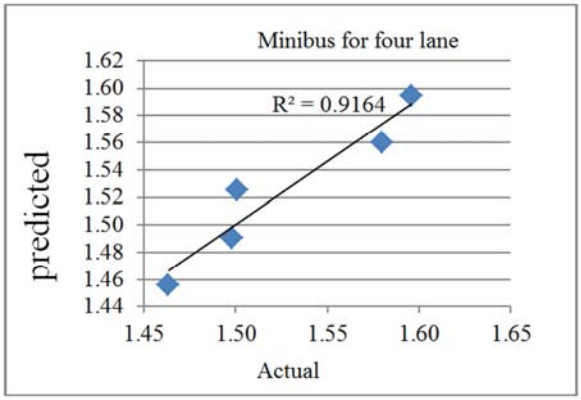

Figure 13. *Values of R^2 for Minibus on Four Lane.*

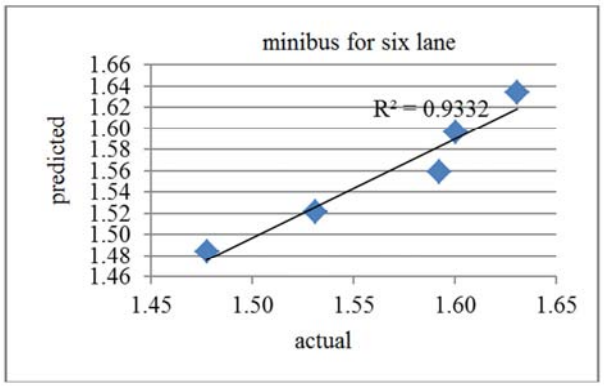

Figure 14. *Values of R^2 for Minibus on Six Lane.*

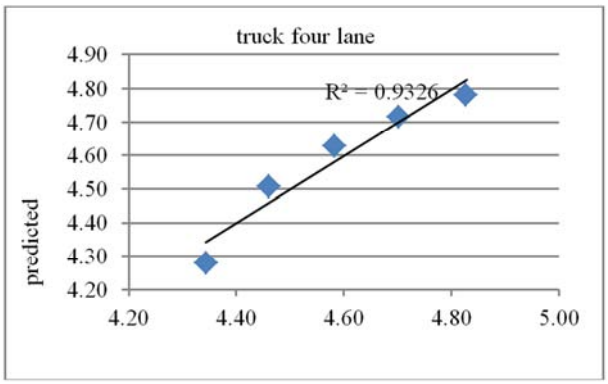

Figure 15. *Values of R^2 for truck on Four Lane.*

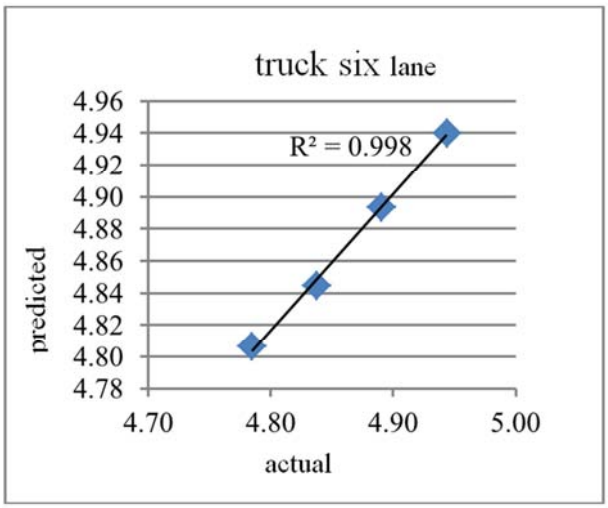

Figure 16. *Values of R^2 for truck on Six Lane.*

4. Conclusion

Passenger car unit values increases as traffic volume increase. This was due to the traffic volume increased. The speed of larger vehicles decreases, but the speeds of smaller vehicles are not affected. This makes the speed difference between passenger cars and other vehicles higher, which results in an increase in passenger car unit values as traffic volume increases. From this point of view, it can be concluded that as traffic volume increases, the passenger car unit also increases. It means the passenger car unit value can be affected by traffic volume levels at a specific period of the day.

As the carriageway width increases passenger car unit also increases. This is due to that in case of wider carriageways; all vehicles travel within normal or maximum speed since the road is wider. And the speed difference increases, which results in a higher value of the passenger car unit. From this study, it can be concluded that as the width of the carriageway increases, the value of the passenger car unit also increases.

References

[1] Praveen, Prema Somanathan, and Venkatachalam Thamizh Arasan. "influence of traffic mix on pcu value of vehicles under heterogeneous traffic conditions." *International Journal for Traffic and Transport Engineering* 3, no. 3 (2013): 302-330.

[2] Mehar, A., S. Chandra, and S. Velmurugan. "Passenger Car Units at Different Levels of Service for Capacity Analysis of Multilane Interurban Highways in India." *Journal of Transportation Engineering*, January 2014: 81-88.

[3] West, James E., and Glens Thurgood. "Developing Passenger-Car Equivalents for left-turning trucks at a compressed diamond interchange." *transportation research record 1484*, n.d.: 90-97.

[4] M. Rahman and F. Nakamura. "Measuring passenger car equivalent for no-motorized vehicles (rickshaws) at mid-block sections." *journal of the eastern Asia society for transportation studies, Vol, 6*, 2005: 119-126.

[5] Sarraj, Yahya. "Passenger Car Equivalents at Signalized Intersections for Heavy and Medium Trucks and Animal Driven Carts in Gaza, Palestine." *International Journal of Emerging Technology and Advanced Engineering*, 2014: 80-88.

[6] Gani, Fadly Arirja, Toshio Yoshii, and Shinya Kurauchi. "Estimation of Dynamic Value of Passenger Car Unit in the Mixed Traffic." *Journal of the Eastern Asia Society for Transportation Studies* 12 (2017): 1666-1675.

[7] Olwan, Fatema Khames. *Passenger Car Equivalent for Motorcycles and Three-wheelers at Signalized intersection in Gaza City, Palestine.* 2017.

[8] Aggarwal, Praveen. "Passenger Car Unit Value for Trucks using Fuzzy model." *Proceedings of the World Congress on Engineering* 2 (2011).

[9] P. Roess, Roger, Elena S. Prassa, and William R. Mcshane. *Traffic engineering.* Third edition. Upper Saddle River, New Jersey 07458: Pearson Education, Inc, 2004.

[10] Mondal, Satyajit, Sandip Chakraborty, Sudip Kumar Roy, and Ankit Gupta. "capacity and dynamic passenger car unit estimation for heterogeneous traffic stream of urban arterials: a case study of indian metropolis." *Semantics Scholar.* 2016. https://pdfs.semanticscholar.org/a2bb/c48dd6b13e1603dae24594d6f791c51a94d6.pdf (accessed 1 13, 2020).

[11] N, M. Mardani, S. Chandra, and I. Ghosh. "Passenger Car Unit of Vehicles on Undivided Intercity Roads in India." *Procedia Computer Science*, 2015: 926-936.

[12] Ethiopian road authority ERA. "pavement design manual." Vol. Volume I. 2013.

[13] Tadesse, Firehun. *Analysis of capacity and traffic flow characteristics of mixed traffic on addis ababa ring road.* Addis ababa, march, 2019.

[14] Chandra, S., and P. K. Sikdar. "Factors affecting PCU in mixed traffic situations on urban roads." *Road & Transport Research* 9, no. 3 (2000): 40-50.

[15] Highway Capacity Manual. *uninterupted flow.* washington: TRANSPORTATION RESEARCH BOARD, 2010.