# Estimation of Passenger Car Equivalents for Heterogeneous Traffic Stream

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***Abstract:*** ***Due to the rapid urbanization, urban arterials have witnessed increase in number of vehicles significantly all over the country as they cater maximum traffic in metropolitan cities. Traffic conditions are heterogeneous in all cities of the world, but the degree of heterogeneity is different in developed and developing countries. The traffic stream in India is purely heterogeneous with no lane discipline and vehicles of different static and dynamic characteristics sharing the same road space. The traffic stream comprises of vehicles like cars, light motorized vehicles, heavy commercial vehicles, three wheelers, motorized two wheelers, non-motorized vehicles, etc. Passenger car equivalents (PCEs) are used to express different vehicles in heterogeneous traffic stream to passenger cars in homogeneous traffic. PCEs play vital role in estimating highway capacity by converting heterogeneous mixed traffic flow in to equivalent homogeneous traffic, which consists of passenger cars only. Passenger car equivalents (PCE) are used in estimating the effect of different vehicles on the traffic stream compared to passenger cars. PCE values are crucial in traffic flow analysis and in capacity estimates. The present study has been concentrated on four and six lane divided urban arterials in Kolkata. The PCE of vehicles have been presented for both the urban roads and the values are more than the values given in IRC: 106-1990 for six lane divided urban arterials and lower for four lane divided urban arterials. It has also been observed that, PCE values of different types of vehicles have been found to be different at different ranges of volume and composition.***

***Index Terms*****: Urban arterials; heterogeneous traffic; capacity; Passenger Car Unit;**

## I. INTRODUCTION

Transportation by road is preferred over other means because of its ease in accessibility, reliability, flexibility in operations and door-to-door service. According to Ministry of Road, Transport and Highways (MoRTH), India has the second largest road network after USA with over 4.69 million km of road length including paved and unpaved roads [12]. The freight and passenger movement in India over the years have increasingly shifted towards roads in comparison to the other modes of transport. The functional characteristics, land use and roadway features widely vary from place to place. As per 2009-10 statistics, roads in India carried 85.2 per cent of the total passenger movement in the country and 62.9 percent of the freight. The annual traffic flow growth rate is considered as 6 to 8 percent and it is further expected to increase in near future. Government of India has declared the 10 year period from 2010-2020 as 'Decade of Innovation'. The all round development has taken place in transportation sector which is contributing almost 4.5 percent of Gross Domestic Product (GDP) of the nation. (Government of India website) [13]. The road density in our country is at 0.66 km of roads per square km of land very close to that in the US (0.65 km/km$^2$) and far ahead of China (0.16 km/ km$^2$) [12]. Being a populous country, India has less than 4 kilometres of roads per 1000 people, including paved and unpaved roads. This is one of the lowest road densities in terms of population in the world as compared to the United States which has 21 kilometres of roads per 1000 people, and France which has about 15 kilometres per 1000 people. Urban roads in India grew up by a compound annual growth rate of 4.5 percent from the year 1961 to 2011. In the last decade the volume of vehicles has increased approximately by 2.6 times. The total length of the urban roads in the country stood at 4,12,000 km in the year 2011[14]. In the recent past, the urban road network in the country changed significantly with an increase of 1,11,000 km between 2007 and 2011 as shown in Fig. 1[12]. Traffic prerequisites are heterogeneous in all cities of the world, which includes those in the Europe and the US, but the degree of heterogeneity is exclusive in developing and developed nations. While roads in developed nations have dominating site visitors of automobiles with very low (5 –10 percent) proportions of light/heavy industrial vehicles, the traffic circulation in creating nations like India has range of the motors like cars, light commercial vehicles, heavy commercial vehicles, motorized two-wheelers, three wheelers, non-motorized vehicles, etc. two All these motors share the equal avenue house without any segregation and occupy any lateral function on the road depending on the availability of the road house at given instantaneous of time barring any lane discipline. Fig. 2 and Fig. 3, show the non-lane based heterogeneous traffic condition as typically found on Indian urban roads. Traffic streams in India are generally heterogeneous consisting of wide variety of vehicles which varies in their physical and operating characteristics. Vehicles are not following lane discipline. There movements are highly depending on the available road space. This heterogeneous traffic consists of motorized vehicles (like heavy vehicle such as truck, mini truck, bus etc.; medium vehicle such as car, etc.; lighter vehicle such as two-wheeler, auto rickshaw etc.) and non-motorized vehicles (like cycle, cart, rickshaw, pedestrian, etc.). Further, the vehicles in Indian traffic streams do not follow lane discipline which makes the prevailing traffic stream behavior even more complex.

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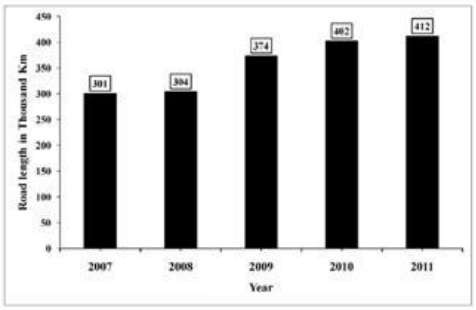


Fig. 1. Expansion of urban roads in India (Source: MoRTH 2012)

Fig. 2. EM Bypass road (Kolkata)

Fig. 3. VIP road (1) (Kolkata)

Passenger car equivalents (PCEs) are used to express different vehicles in heterogeneous traffic stream to passenger cars in homogeneous traffic. PCEs play vital role in estimating highway capacity by converting heterogeneous mixed traffic flow in to equivalent homogeneous traffic, which consists of passenger cars only. Passenger car equivalents (PCEs) are also known as Passenger car units (PCUs). PCEs are used in estimating the effect of different vehicles on the traffic stream compared to passenger cars. PCE values are crucial in traffic flow analysis and in capacity estimates. The estimation of PCE of different categories of vehicles is also necessary for design of different traffic facilities, operational analysis of roadway facilities, management of traffic regulation and control of traffic.

## II. OVERVIEW OF PREVIOUS LITERATURE

There are many studies available in literature to estimate the PCE of different categories of vehicles under heterogeneous traffic conditions in India and other countries. The first study on PCE was conducted in the year 1965, and it was introduced in HCM which is 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. This definition of PCE was valid for homogeneous traffic conditions (only bus, car and trucks) prevailing in developed countries [19]. HCM uses the PCE value as an intermediate value to find heavy vehicle adjustment factor, to account for the adverse effects of heavy vehicles and buses on traffic operations. In 1985 edition of HCM, PCE was defined as the number of passenger cars that would consume the same percent of the freeway's capacity as one truck, bus or recreational vehicle (RV) under prevailing roadway and traffic conditions [28]. In the HCM 1994 edition PCE is defined as the number of passenger cars that are displaced by a single vehicle of a particular type under prevailing roadway, traffic and control conditions [20]. In the HCM 1997 edition, PCE was defined as the number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic and control conditions [20]. HCM 2000 defines the term PCE as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic and control conditions [7]. In HCM 2010 edition the PCE is 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 [6]. Further various researchers have stated the different definitions of PCE are discussed below. Huber [26] has given the relationship between PCE and flow of passenger car only traffic stream and a mixed vehicle traffic stream. The effect of trucks is quantified by relating the traffic flows for an equal Level of Service (LOS). Any equivalent LOS or impedance could be chosen for the equality. Van Aerde and Yagar [17], assumed speed-flow relation as linear and defined PCEs based on relative rate of speed reduction. They defined the PCE for a vehicle type n, as the ratio of speed reduction coefficient for vehicle type n to the speed reduction coefficient for passenger cars. Turner et al., [16] stated that PCE captures the different characteristics of each vehicle type in the heterogeneous traffic by comparing the space of the road occupied by a vehicle to that of a passenger vehicle. Webster and Elefteriadou [18] found that PCEs increase with increasing traffic flow on freeway segments and decrease with increasing proportion of trucks and number of lanes. The authors concluded that the truck type defined by length and weight to power ratio, is critical for determination of PCEs. Al-Kaisy et al., [27] stated that PCE value can be obtained by dividing the number of cars removed to the number of introduced subjected vehicles, which have same effect as the introduced subjected vehicles, on the driver's perception of quality of the service provided by the facility. Rahman and Nakamura [23] defined PCE for non-motorized vehicle (Rickshaws) at mid-block sections based on speed reduction of passenger cars in the mixed flow as a unit value plus the ratio of the speed difference of passenger cars in basic flow and mixed flow to the speed of passenger cars in the base flow. Malliarjuna and Rao [9] used area occupancy in place of density, as equivalency criteria to estimate the PCE values for buses, trucks and motorized two-wheelers using a simulation model.

The estimated PCE values, for all the considered vehicle categories are found to decrease with increase in their respective proportions. Robert [22] defined it as the ratio of number of cars removed to number of vehicles added. The impedance caused by vehicles for a chosen volume level was calculated by replacing a certain percentage of cars with respective types of vehicles. Chandra and Kumar [3] studied the effect of lane width on PCE values and also on the capacity of a two-lane road under mixed traffic conditions. PCUs were estimated at ten road sections for nine categories of vehicles. They found that the PCE for a vehicle type increases linearly with the width of carriageway. Al-Kaisy et al., [2] worked on developing passenger car equivalency factor for heavy vehicles during congestion. A set of PCE factors for oversaturated traffic conditions was developed for use in traffic analyses. Arkatkar [21] estimated the PCE values by studying the influence of roadway and traffic characteristics such as variation in traffic volume, road width and magnitude of upgrade and its length . Manraj et al., [24] used speed as performance measure and estimated PCE values for Indian expressways using simulation technique. They studied the effect of vehicle composition on PCE values and evaluated capacity of expressways and found that PCE decreases with increase in volume capacity ratio irrespective of vehicle category. They concluded that PCE values decreases for all categories, when their proportion increases in the traffic stream. It is found that due to the complex nature of interaction between vehicles under the heterogeneous traffic condition, the PCE estimates made through simulation for different types of vehicles of heterogeneous traffic, significantly changes with change in traffic volume level. Arpan et al., [29] analyzed traffic flow data on four-lane and six-lane divided highways under mixed traffic conditions and determined capacity and speed distribution parameters. They estimated PCEs based on speed, using Chandra method and VISSIM for simulation to determine PCE at different LOS for capacity analysis of multilane highways in India. Dhamaniya and Chandra [5] worked on the concept of stream equivalency factors for heterogeneous traffic on urban arterial roads. In this study, they converted heterogeneous traffic volume in vehicle per hour to homogeneous PCU per hour without determining PCU factors for each and every individual vehicles type by making use of stream equivalency factors (SEF). Paul and Sarkar [10] determined dynamic PCU of different types of vehicles on urban roads. The effect of proportion of Non-Motorised Traffic (NMT) and heavy vehicles on PCU of different categories of vehicles were studied and the effect of stream speed on PCU was presented in form of mathematical equations. They found that PCU of two wheelers increased with increase in proportion of heavy vehicles and decreased with proportion of NMT whereas PCU of bus deceased with increase in heavy vehicle percentage and increases with NMT percentage. There was no significant change in PCU of three wheelers with proportion of NMT and heavy vehicles. Khode et al. [8] studied on impact of lane width of road on passenger car unit capacity under mix traffic condition in cities on congested highways. This study shown the variation in PCU for different types of vehicles with lane width. It was found that the PCU for a vehicle type increases with increasing lane width. Muhammad Adnan [1] studied on passenger car equivalent factors in heterogeneous traffic environment-are we using the right numbers ? Four different methods were used to estimate the PCU of vehicles. They found that method that incorporate vehicles speed along with projected area of vehicles were provide appropriate estimate of PCE values. Dhamaniya and Chandra [4] worked on midblock capacity of urban arterial roads in India. They considered the speed and size of the vehicle as the prime variables for determination of PCU.

## III. OBJECTIVE AND STUDY AREA

This study has been concentrated on finding the values of PCE for different categories of vehicles under heterogeneous traffic conditions on mid-block section in urban arterials of Kolkata and also to analyse the variation of PCE values with respect to different traffic stream parameters. The coordinates of Kolkata city are 22.82° North and 88.20° east. It is the principal business hub of the Eastern and Northeast India and lies on the eastern riverbanks of the Hooghly River. The metropolitan region of the city covers an area of 1,886.67 km2. It is the 7th most populated city in India according to the census 2011. Data has been collected from two road sections, VIP Road (Kazi Nazrul Islam Sarani) six lane divided urban arterial and E.M. Bypass (Eastern Metropolitan Bypass) four lane divided urban arterial. Sections were selected based on various criterion such as, the section should have wide variation in proportion of different categories of vehicles, should be free from the effects of road side friction, access point like intersection, parking facilities, bus stop, curvature, gradient and median opening. A straight mid–block section of the selected urban roads has been selected for the data collection purpose. Out of twenty seven hours of data collected, Four hours data from E.M. Bypass, Seven hours data from VIP Road (1) is used in this study and details of section are shown in Table 1.

Table 1: Details of study sections

| Study sections | Carriageway Width (m) | Road Geometry | Time of data collection (Hrs) |
|---|---|---|---|
| E. M. Bypass Near Appolo Hospital | 6.6 | Four lane divided C/W | 9.31-10.31;10.35-11.37; 11.39-12.40;12.40-1.41; 1.41-2.41;2.41-3.42; 3.46-4.48. (7 Hrs) |
| VIP Road (1) Sreebhumi Footbridge Near Gokul Banquet hall, | 10.5 | Six lane divided C/W | 9.00-10.00;10.03-11.04;11.05-12.06;12.07-1.06; 1.09-2.12; 2.13-3.14; 3.15-4.15 (7 Hrs) |

## IV. RESEARCH METHODOLOGY

In the present study Chandra's method [3] has been adopted to evaluate PCE values of vehicles. In a heterogeneous traffic stream, speed of the vehicles is mostly affected among the other traffic stream parameters. In Chandra's method speed is considered as the basic parameter for determination of PCE. Hence, Chandra's method has been adopted as proposed methodology. In this study Standard Car (LMV) is considered as the standard design vehicle.

According to Chandra's method PCE of any vehicle type can be obtained by using the following relationship.

$$PCE_i = \frac{V_c/V_i}{A_c/A_i} \qquad (1)$$

where $PCE_i$ = Passenger Car Equivalent of vehicle i
$V_c$ = Average speed of passenger car in traffic stream (km/hr)
$V_i$ = Average speed of vehicle i in traffic stream (km/hr)
$A_c$ = Projected rectangular area of passenger car ($m^2$)
$A_i$ = Projected rectangular area of vehicle i ($m^2$)

The numerator in the above equation is the function of composition of traffic stream as the speed of any vehicle type depends upon its category, own proportion and proportion 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 pavement occupancy with respect to standard car. The physical size of different types of vehicles are presented in Table 2.

Table 2: Vehicle categories and their average dimensions

| Category | Average Dimensions | | Projected rectangular area on ground |
|---|---|---|---|
| | Length (m) | Width (m) | Area ($m^2$) |
| LMV | 3.72 | 1.44 | 5.36 |
| Two Wheeler | 1.87 | 0.64 | 1.2 |
| 3 Wheeler (Auto) | 3.2 | 1.40 | 4.48 |
| HMV | 10 | 2.45 | 24.5 |

## V. FIELD DATA COLLECTION AND EXTRACTION

Field data have been collected on a typical weekday at four urban arterials in Kolkata to determine the traffic volume, speed of different types of vehicles and composition of traffic stream. Video photography technique has been used to record the movements of vehicular traffic in one direction of travel. A trap length of 30 m has been selected which would eventually act as the reference lines for the measurement of speed and traffic volume. In this study, data have been gathered the usage of video image processing software, TRAZER. Video videos have been accrued using the cameras focused over the mid block sections of divided multilane roads, with uninterrupted flow, at unique urban areas in Kolkata. Traffic flow facts had been collected in height and off peak hours, so as to look at the conduct in congested as well as in free drift conditions. Data had been also accrued on roads with distinct widths ranging from 6.60 m to 12.80 m. Image processing software program TRAZER classifies all the automobiles into 4 categories, namely, Light motorized automobiles (LMV), Motorized-two-wheeler (TW), Motorized-three-wheeler (AUTO), and Heavy motorized automobile (HMV). Mallikarjuna [14] has listed a range of problems and the corresponding corrections in element for heterogeneous site visitors prerequisites using TRAZER. After making use of corrections to TRAZER output, velocity and go with the flow are calculated at a section where the software program detection accuracy is high and density is calculated the usage of fundamental equation of traffic flow. All automobiles in the visitors circulation have been grouped and divided into 4 categories as mentioned above. The classified vehicle count has been calculated at every 1 minute interval and it has been converted into hourly traffic volume. The composition of traffic observed at various sections are presented in percentages in Fig. 4 and Fig. 5 and the hourly variation of traffic volume on the roads in Fig. 6 and Fig. 7, respectively.

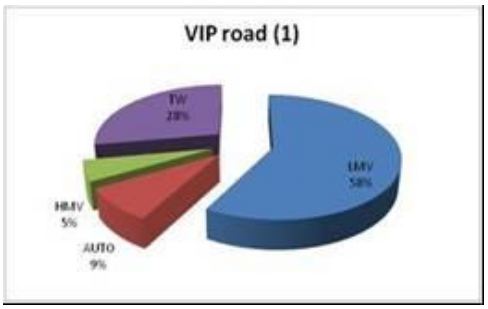


Fig. 4. % of vehicles on VIP Road (1)Units

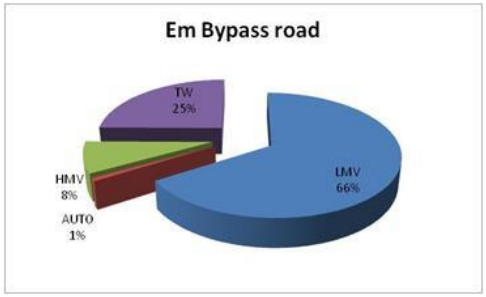


Fig. 5. % of vehicles on Em Bypass Road

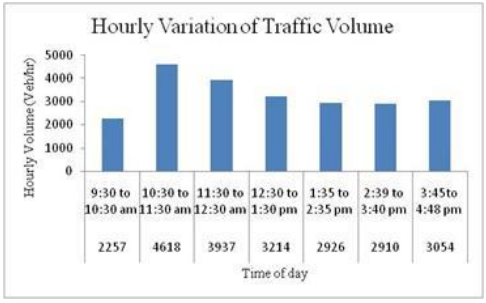


Fig. 6. Hourly variation of traffic volume on VIP Road (1)

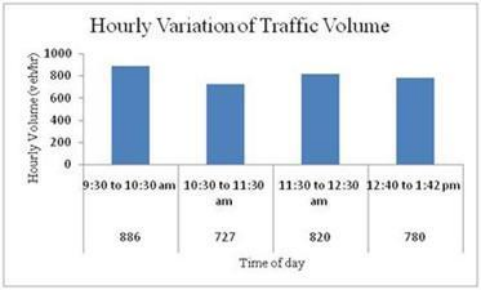


Fig. 7. Hourly variation of traffic volume on EM Bypass Road

*Estimation of PCE values*

In order to develop a proper speed – flow equation to estimate capacity and design of traffic facilities for heterogeneous traffic, it is necessary to convert the heterogeneous traffic into homogeneous by using a common unit, which is termed as Passenger Car Equivalent. Chandra's model has been used to determine the PCE of different vehicle categories. It has been observed that speed of the individual vehicle class is different at different volume levels. So, a range of PCE values of different categories of vehicles have been determined for limited range of traffic volume for both urban roads and presented in the Table 3 and Table 4.

Table 3. PCE of different categories of vehicles on EM bypass road

| Type of Vehicle | Traffic volume (veh/hr) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | > 0-500 | | 500-1000 | | 1000-1500 | | 1500-2000 | |
| | Min | Max | Min | Max | Min | Max | Min | Max |
| TW | .230 | .265 | .223 | .278 | .217 | .266 | .209 | .249 |
| AUTO | 1.30 | 1.35 | 1.21 | 1.25 | 1.05 | 1.18 | 1.03 | 1.07 |
| HMV | 4.74 | 4.85 | 4.82 | 4.91 | 4.86 | 4.94 | 4.95 | 5.02 |

Table 4. PCE of different categories of vehicles on VIP road (1)

| Type of Vehicle | Traffic volume (veh/hr) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | >0-500 | | 500-1000 | | 1000-1500 | | 1500-2000 | |
| | Min | Max | Min | Max | Min | Max | Min | Max |
| TW | .256 | .261 | .235 | .2554 | .223 | .241 | .21 | .228 |
| AUTO | 1.17 | 1.24 | 1.03 | 1.15 | 0.97 | 1.05 | 0.88 | 0.92 |
| HMV | 4.99 | 5.15 | 5.05 | 5.29 | 5.33 | 5.41 | 5.47 | 5.60 |

*Estimation of Capacity*

This study has been adopted the Greenshield's model [15] for estimation of capacity for four lane and six lane divided urban arterials. Therefore, the speed – flow model which follows the parabolic relationship, developed by using regression technique has been considered. Therefore a scatter diagram has been developed by plotting the speed and flow of the urban arterials shown in Fig. 8 and Fig. 9 respectively.

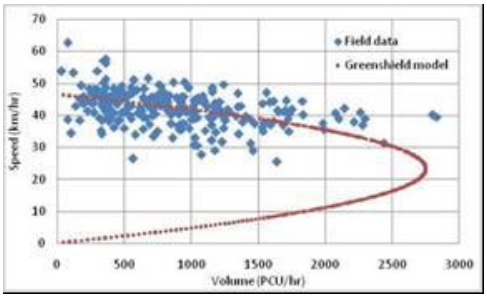


Fig. 8. Speed-flow relationship for four lane divided urban arterial

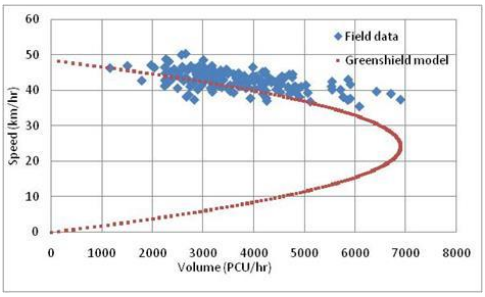


Fig. 9. Speed-flow relationship for four lane divided urban arterial

It has been observed that the speed – flow curve fits nicely with the observed data, indicating the validity of the field data for highly heterogeneous traffic flow. The capacity of four lane and six lane divided urban arterial, under heterogeneous traffic conditions is estimated as about 2752 PCU/hour and 6907 PCU/hour respectively.

## VI. CONCLUSIONS

In the present study the dynamic PCE values on four lane and six lane divided urban arterial have been determined. This study has been considered speed and size of the vehicle as prime variables for estimation of PCU factors. The calculated PCE of different categories of vehicles are larger than the values given in IRC: 106-1990. A range of PCE values have been estimated for each category of vehicles for limited range of traffic volume for both the urban roads. Capacity of four lane and six lane divided urban arterials have been found to be 2752 PCU/hr and 6907 PCU/hr by using the Greenshield's model. IRC 106:1990 suggests the capacity of four lane and six lane divided urban road as 3600 PCU/hr and 5400 PCU/hr [25]. This variation may be obtained because of higher PCE values of vehicles. It has also been found that per lane capacity decreases as the number of lane increases. The PCE value of HMV (Bus and Truck) increases linearly with the increase in traffic volume, but for Two Wheeler and Motorized Three Wheeler it decreases linearly with increase in traffic volume.

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## REFERENCES

1. M. Adnan, "Passenger car equivalent factors in heterogeneous traffic environment-are we using the right numbers?," Procedia Engineering 77, Fourth International Symposium on Infrastructure Engineering in Developing Countries, IEDC 2013, pp. 106 – 113, (2014)
2. Al. Kaisy, A. F., Jung, Y. and Rakha, H. "Developing Passenger Car Equivalency Factors for Heavy Vehicles during Congestion,". Journal of Transportation Engineering, ASCE, Vol. 131, No. 7, pp. 514-523, 2005.
3. Chandra, S. and Kumar, U., "Effect of Lane Width on Capacity under Mixed Traffic Conditions in India," Journal of Transportation Engineering, ASCE, Vol. 129, No. 2, pp. 155-160, 2003.

4. Dhamaniya, A. and Chandra, S., "Midblock capacity of urban arterial roads in India," Indian Highways, Vol. – 42, No. – 7, pp. 39-51, July 2014.
5. Dhamaniya, A., and Chandra, S., "Concept of Stream Equivalency Factor for Heterogeneous Traffic on Urban Arterial Roads,". Journal of Transportation Engineering, ASCE, Vol.139, pp. 1117-1123, 2013.
6. Highway Capacity Manual, TRB, National Research Council, Washington D.C., 2010.
7. Highway Capacity Manual, Washington, D.C. Transportation Research Board, National Research Council, 2000.
8. Khanorkar, A. R., Ghodmare, S.D. and. Khode, B.V. "Impact of Lane Width of Road on Passenger Car Unit Capacity under Mix Traffic Condition in Cities on Congested Highways," International Journal of Engineering Research and Applications. ISSN: 2248-9622, Vol. 4, Issue 5(Version 2), , pp. 180-184, May 2014.
9. Mallikarjuna C and K Ramachandrarao "Area Occupancy Characteristics of Heterogeneous Traffic," In Transportmetrica. 2( 3), , Pages 223- 236, 2006.
10. Paul, P. and Sarkar, P. "Determination of Dynamic PCUs of Different Types of Passenger Vehicles on Urban Roads: A Case Study, Delhi Urban Area." Indian Highways, 41(4), Indian Roads Congress, New Delhi., 2013.
11. Ministry of Road Transport and Highways (MORTH) *Basic Road Statistics of India* 2011, Transportation Research Wing, New Delhi, India.
12. Ministry of Road Transport and Highways (MORTH) *Manual of Road Accidents in India* 2012, Government of India, New Delhi, India.
13. Ministry of Home Affairs, Government of India. *Population Enumeration Data*, New Delhi, India. http://www.censusindia.gov.in/2011 census/population enumeration Accessed March 15, 2013.
14. Mallikarjuna, C. "Analysis and modeling of heterogeneous traffic". PhD Thesis, Indian Institute of Technology Delhi, New Delhi, India, 2007.
15. Greenshields, B.D.,"A study of traffic capacity," Highway Research Board Proceeding 14, 10, pp. 448-477, 1935.
16. Turner J, and Harahap G., "Simplified saturation flow data collection methods," CODATU VI Conference on the Development and Planning of Urban Transport, Tunis, Feb. 1993.
17. Van A.M, and Yagar S., "Capacity, speed, and platooning vehicle equivalents for two-lane rural highways," Transportation Research Record 971. TRB, National Research Council, Washington, DC., pp. 58-67, 1984.
18. Webster N, and Elefteriadou L., "A simulation study of truck passenger car equivalents (PCE) on basic freeway sections," Transportation Research, 33B, pp. 323-336, 1999.
19. Special Report 87: Highway Capacity Manual, 2nd ed. Highway Research Board, Washington, DC., 1965
20. Special Report 209: Highway Capacity Manual, 3rd ed.(1994,1997 updates), Transportation Research Board, National Research Council, Washington, DC., 1985.
21. Shriniwas S. A., "Effect of intercity road geometry on capacity under heterogeneous traffic conditions using microscopic simulation technique," International Journal of Earth Sciences and Engineering. ISSN 0974-5904, 4(6),375-380, 2011
22. Robert M.B., "Influence of roadway width and volume to capacity ratio on PCU values," Transport Problems,5(2), 2010
23. Rahman M. M, and Nakamura F., "Measuring passenger car equivalents for non-motorized vehicle (Rickshaws) at mid-block sections," Journal of the Eastern Asia Society for Transport Studies. 6:119-126, 2005
24. Manraj S.B, Balaji P, Shriniwas S.A., "Modeling of traffic flow on Indian expressways using simulation technique," Procedia - Social and Behavioral Sciences. 43:475 – 493, 2012
25. Indian Road Congress ,Tentative Guide lines in Rural Areas IRC : 64 – 1990.
26. Huber M., "Estimation of passenger car equivalents of trucks in traffic stream," Transportation Research Record 869. TRB, National Research Council, Washington, DC.,pp. 60-70, 1982
27. Al-Kaisy A, Hall F, and Reisman E.,"Developing passenger car equivalents for heavy vehicles on freeways during queue discharge flow",Transportation Research, 36A, pp. 725-742, 2002
28. Highway Capacity Manual 1985. TRB, National Research Council, Washington, D.C., 2000
29. Arpan M, Satish C, S.Velmurugan., "Passenger car units at different levels of service for capacity analysis of multilane interurban highways in India," Journal of Transportation Engineering, 140, pp. 81-88, 2013.