iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** XII **Month of publication:** December 2018

DOI:

Field Evaluation of Dynamic PCU under Heterogeneous Traffic Conditions

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Abstract: In the present paper, dynamic nature of passenger car unit (pcu) values are analyzed under heterogeneous traffic conditions on two-lane urban roads in three unique locations of andhra pradesh state, india. The estimation of pcu values are based on speed and vehicle's projected area on the ground. Speed equations are developed to estimate the speed of vehicles for given traffic volume and composition. Later the acquired pcu values are compared with indian road congress recommended values. Finally the effect of carriageway width on pcu factors is also estimated.
Keywords: PCU, Heterogeneous traffic, Speed Equations, Carriageway width.

I. INTRODUCTION

Traffic on roads in India is termed to be highly heterogeneous in nature comprising of many variety of vehicles like cycles, cycle rickshaws, two-wheelers, three-wheelers, cars, trucks, bullock carts etc., mostly sharing the same space of the road. Heavy vehicles consume more space and more importantly they have lower performance comparing to the rest of the vehicles. Similarly smaller vehicles like two wheelers move in between heavy vehicles occupying less space. Hence major varying aspects such as speed, size, maneuverability, acceleration, spatial zone influence of various types of vehicles etc., makes harder to examine the traffic characteristics and to estimate the parameters like roadway capacity, density, level of service (LOS) etc., which are the essential fundamentals for design, planning, operation and layout of road sections. The analysis of the heterogeneous traffic is simplified by converting all the vehicle categories in the traffic stream into traffic stream consisting of only one type of vehicle. The most accepted type of vehicle is a passenger car. A particular sort of vehicle category in the traffic stream is converted into passenger cars by multiplying the number of vehicles of that particular category with a factor known as Passenger Car Unit.

Speed portrays the traffic performance measure of the roads and highways. It gives the basic fundamental relationships of traffic flow theory. In the mixed traffic, speed of one type of vehicle is affected by other vehicles in the traffic stream. Hence, speed equations for individual sort of vehicles were developed using traffic composition and spot speed values. In the present study, PCU values are calculated by using the methodology proposed by Chandra. S [1, 2], which is best suitable for the Indian traffic conditions.

In the first edition of Highway Capacity Manual, the term PCU was not utilized. Rather, two cars were considered in place of a single truck. Later in the second edition of HCM (1965) [3], the concept of PCU was first introduced as a measure to convert all different types of vehicles in traffic into equivalent number of passenger cars which helped in converting non uniform traffic stream into uniform traffic stream consisting only of passenger cars. Since then, research is being carried out till date throughout world for the evaluation of PCU factors. Different factors were considered for the calculation of passenger car equivalents. But till now, permutations and combinations of all different factors couldn't satisfy the value of PCU as no value fits the curve of regression perfectly.

Greenshields et al., (1947) [4] suggested a procedure known as basic headway method for the calculation of PCU. Webster & Cobbe (1966) [5] used headway method and obtained PCE value of 1.75 for medium and heavy goods vehicles. Miller (1968) [6] estimated PCE value by measuring additional time required by heavy vehicles over a passenger car to cross an intersection in which, he obtained a value of 1.85 for trucks. Werner & Morrall (1976) [7] suggested that headway method is best suited for the calculation of PCEs on low terrain level and at low level of service. John & Glauz (1976) [8] considered the percentage of grade, truck volume to capacity ratio and mixed vehicle flow and calculated the PCU values. Craus et al., (1980) [9] suggested equivalent delay method for the estimation of PCU values in which they considered that difference between delay caused by heavy vehicle to standard passenger cars and delay caused by slower passenger cars to standard passenger cars. The equivalent delay method assumes that faster vehicles are always resisted by slower vehicles causing queue formation. The proposed equation considered as the ratio of average delay time caused by one truck to average delay time caused by one passenger car. Hu & Johnson (1981) [10] described how to use 1965

HCM to find PCEs based on speed. They used equation developed by John & Glauz (1976) to calculate PCE. Operating speeds were based on design charts obtained by research performance by the Mid-west Research Institute (MRI). The PCEs were calculated based on extended freeway segments. Huber (1982) [11] introduced the concept of using equal density to relate base flow rate and mixed flow rate for the calculation of PCE. At some common level of impedance, PCE values are related to ratio between the volumes of two streams. Van Aerde & Yagar (1984) [12] proposed a method for calculation of PCE based on relative rate of speed reduction. Speed flow relationships and filed observations were taken as inputs to form multiple linear regression model which estimates percentile speed based on free speed and speed reduction coefficients for each type of vehicle. Sumner et al., (1984) [13] suggested a procedure for calculation of PCE values on urban arterial roads between consecutive signalized intersections using NETSIM which is a microscopic simulation. The values are obtained from the vehicle –hour utilization of road that is added when large vehicles are introduced to traffic stream. Fan (1990) [14] applied the method of constant V/C method for determination of PCU for expressway in Singapore. Traffic streams with an equal V/C ratio will not necessarily have equal speed, density and therefore LOS. Even though density was used to define LOS, the author used V/C method because these freeways operate at LOS E. the study focused in congested flow conditions or V/C ratio above 0.67 and mentioned that it is unnecessary to calculate PCE at uncongested flow conditions. Using multiple linear regression and multiplying observed flow by V/C ratio, he found that commercial vehicles (CV) such as light and heavy trucks, buses, trailers has higher PCE than PCE used in US, UK for level terrain. Al. Kaisy (2002) [15] developed a new approach to quantify the effect of heavy vehicles on traffic which is great during congestion than during under-saturated conditions by deriving PCE using Queue Discharge Flow (QDF) capacity as equivalency criterion. Chandra and Kumar (2003) [16] suggested a methodology for estimation of PCE under mixed traffic conditions. They considered PCE as a function of projected area of vehicle on ground & speed and identified the effect of lane width on the capacity of a two-lane road under mixed traffic conditions.

The above mentioned studies clearly portrays that PCU of a specific vehicle sort is dynamic in nature. In developing countries like India where there is condition of mixed traffic, establishing precise PCU values is of greater significance as any bias in the PCU values leads to a drastic variation in the estimation of road/highway capacity. The present paper suggests a method to determine the dynamic PCU values on two-lane urban roads under varying vehicular composition and traffic volume. The main objective of this study is to determine the dynamic nature in PCU values with variation in traffic volume & composition and also to determine the effect of carriageway width on PCU values. The obtained values are then compared with static PCU values suggested by Indian Road Congress (IRC) 106:1990 [17], which gives the guidelines for capacity of roads in urban areas.

II. METHODOLOGY AND DATA

There are numerous strategies proposed by researchers around the world for the assessment of PCU based on the various factors as discussed in the above section. Among them, headway method is the mostly used method in developed countries which have lane discipline. But in developing countries like India, headway method cannot be used as there is no lane based traffic movements.

In the ongoing study, estimation of PCU values is done by using the methodology proposed by MM Nokandeh et al., [18] is used where physical area of the vehicle is considered instead of length of the vehicle. Because, the area of the vehicle indicates its maneuverability, impedance caused to other vehicles in the traffic stream. The basic principle used in the estimation of PCU is that PCU is directly proportional to the speed ratio of the car to the ith vehicle and inversely proportional to the space occupancy ratio with respect to the standard car.

$$PCU_i = \frac{V_c / V_i}{A_c / A_i} \tag{1}$$

Where V_c = speed of passenger car

V_i = speed of vehicle type (i)

A_c = area projected by passenger car

A_i = area projected by vehicle type (i)

Speed of a particular type of vehicle in the mixed traffic stream will be influenced by the other vehicles in the traffic stream. This influence can be mathematically modeled by developing speed equations with traffic volume and speed of different types of vehicles in the traffic stream using the regression analysis. If the traffic stream consists of seven vehicle types like two-wheeler (2W), three-wheeler (3W), car (C), SUV (S), LCV (L), Bus (B), Truck (T), the general forms of the equations are as follows:

$$V_{2W} = a_{0-2W} + a_{1-2W}\frac{n_{2W}}{V_{2W}} + a_{2-2W}\frac{n_{3w}}{V_{3w}} + a_{3-2W}\frac{n_C}{V_C} + a_{4-2W}\frac{n_S}{V_S} + a_{5-2W}\frac{n_L}{V_L} + a_{6-2W}\frac{n_B}{V_B} + a_{7-2W}\frac{n_T}{V_T} \quad (2)$$

$$V_{3W} = a_{0-3W} + a_{1-3W}\frac{n_{2W}}{V_{2W}} + a_{2-3W}\frac{n_{3w}}{V_{3w}} + a_{3-3W}\frac{n_C}{V_C} + a_{4-3W}\frac{n_S}{V_S} + a_{5-3W}\frac{n_L}{V_L} + a_{6-3W}\frac{n_B}{V_B} + a_{7-3W}\frac{n_T}{V_T} \quad (3)$$

$$V_C = a_{0-C} + a_{1-C}\frac{n_{2W}}{V_{2W}} + a_{2-C}\frac{n_{3w}}{V_{3w}} + a_{3-C}\frac{n_C}{V_C} + a_{4-C}\frac{n_S}{V_S} + a_{5-C}\frac{n_L}{V_L} + a_{6-C}\frac{n_B}{V_B} + a_{7-C}\frac{n_T}{V_T} \quad (4)$$

$$V_S = a_{0-S} + a_{1-S}\frac{n_{2W}}{V_{2W}} + a_{2-S}\frac{n_{3w}}{V_{3w}} + a_{3-S}\frac{n_C}{V_C} + a_{4-S}\frac{n_S}{V_S} + a_{5-S}\frac{n_L}{V_L} + a_{6-S}\frac{n_B}{V_B} + a_{7-S}\frac{n_T}{V_T} \quad (5)$$

$$V_L = a_{0-L} + a_{1-L}\frac{n_{2W}}{V_{2W}} + a_{2-L}\frac{n_{3w}}{V_{3w}} + a_{3-L}\frac{n_C}{V_C} + a_{4-L}\frac{n_S}{V_S} + a_{5-L}\frac{n_L}{V_L} + a_{6-L}\frac{n_B}{V_B} + a_{7-L}\frac{n_T}{V_T} \quad (6)$$

$$V_B = a_{0-B} + a_{1-B}\frac{n_{2W}}{V_{2W}} + a_{2-B}\frac{n_{3w}}{V_{3w}} + a_{3-B}\frac{n_C}{V_C} + a_{4-B}\frac{n_S}{V_S} + a_{5-B}\frac{n_L}{V_L} + a_{6-B}\frac{n_B}{V_B} + a_{7-B}\frac{n_T}{V_T} \quad (7)$$

$$V_T = a_{0-T} + a_{1-B}\frac{n_{2W}}{V_{2W}} + a_{2-T}\frac{n_{3w}}{V_{3w}} + a_{3-T}\frac{n_C}{V_C} + a_{4-T}\frac{n_S}{V_S} + a_{5-T}\frac{n_L}{V_L} + a_{6-T}\frac{n_B}{V_B} + a_{7-T}\frac{n_T}{V_T} \quad (8)$$

Where 'V' is the speed of the vehicle in m/s, 'n' is the number of vehicles crossing a point per second (vps). The coefficients in the above equations represent the interaction of vehicle type on the speed and the constant term represents the free flow speed of the vehicle type.

Data was collected from two-lane urban roads at three different locations in the city of Srikakulam and Vizianagaram of Andhra Pradesh, India. The main motto for selecting the locations are, they have uniform characteristics in terms of carriage way width, direction and were free from obstructions.

A video camera was mounted on the stand and was placed at sufficient height so as to cover the trap length of 50meters of carriageway. Video was recorded at peak hours for three hours during weekdays. Later the recorded video was played in the computer lab to collect traffic volume data and speed of various vehicle types.

The vehicles observed at all the locations were classified into seven types such as two-wheeler (2W), three wheeler (3W), car (C), SUV (S), LCV (L), Bus (B) and Truck (T). Traffic volume count was done with 15minutes interval for a period of 3hours. Traffic composition was evaluated from the obtained traffic volume data.

Speed of all the vehicles was evaluated by measuring the time taken to cover the trap length of 50 meters with the accuracy of 0.01s. The average projected area of vehicle on the ground is given in the Table 1. The average traffic composition observed at each location is given in the Table 2.

III. DATA ANALYSIS

Regression analysis was done by using the traffic volume count (n) and speed of the vehicles (v) observed at each location. All the coefficients and constants that are obtained after the analysis are substituted in the above mentioned equations [(2)-(8)] to obtain the final velocities.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue XII, Dec 2018- Available at www.ijraset.com

Table 1 Average projected area of vehicles on the ground

Vehicle Category	Length (m)	Width (m)	Projected Rectangular Area (m^2)
2W	1.87	0.64	1.16
3W	3.20	1.40	4.48
Car	3.72	1.44	5.36
SUV	4.58	1.77	8.11
LCV	6.10	2.10	12.81
Bus	10.10	2.43	24.54
Truck	7.50	2.35	17.48

The obtained final velocities and the average projected area of vehicles on the ground are substituted in the equation (2) proposed by Chandra .S to obtain the dynamic PCU values. The obtained dynamic PCU values at all the locations for each vehicle category is given in the Table 3.

Table 2 Average traffic composition observed at each location

S. No	Location	Carriageway Width (m)	PCU for						
			2W	3W	Car	SUVs	LCV	Bus	Truck
1	Bypass Rd., SRKLM	5.82	48.2	17.4	12.7	5.8	4.9	6.1	4.8
2	Phool Baugh Rd., VZM	6.46	60.7	21.1	5.6	2.5	2.7	4.8	2.7
3	8O Ft. Rd., SRKLM	7.1	69.1	11.7	9.5	4.9	1.7	1.3	1.9

Table 3 PCU values obtained at each location for each vehicle category

S. No	Location	Carriageway Width (m)	PCU for						
			2W	3W	Car	SUVs	LCV	Bus	Truck
1	Bypass Rd., SRKLM	5.82	0.231	0.95	1.00	1.55	3.01	5.26	4.09
2	Phool Baugh Rd., VZM	6.46	0.257	1.02	1.00	1.65	3.18	5.49	4.29
3	8O Ft. Rd., SRKLM	7.1	0.271	1.07	1.00	1.84	3.54	5.94	4.66

The traffic stream in India mostly consists of mixed vehicle types occupying same carriageway width for their movement. The effect of carriageway width on PCU values are shown in below Figure 1. From the figure, it is clear that as the carriageway width increases, the PCU value also increases linearly. This is because, vehicles move freely on wider roads and speed of the vehicle types also increases. But there won't be linearity in the speed values as each vehicle type differs in their dimensions, engine throughput, acceleration, maneuverability etc.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue XII, Dec 2018- Available at www.ijraset.com

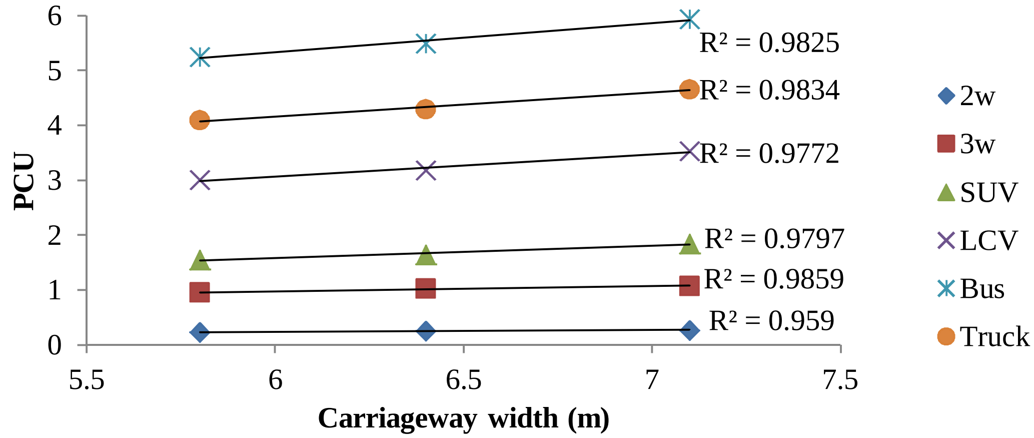

Figure 1 Effect of carriageway width on PCU

Relationship between carriageway width and PCU of each type of vehicles present in the traffic stream is given in the Table 4 below.

Table 4 Relationship between carriageway width and PCU

Vehicle Type	Relation between PCU (y) and Carriageway Width (x)	R^2 Value
2w	y = 0.0306x + 0.0562	0.959
3w	y = 0.0949x + 0.4053	0.9859
SUV	y = 0.2227x + 0.2465	0.9797
LCV	y = 0.4080x + 0.6181	0.9772
Bus	y = 0.5288x + 2.1603	0.9825
Truck	y = 0.4376x + 1.5333	0.9834

The PCU values depend on traffic volume. In order to analyze the amount of variation in the PCU of a vehicle type due to the variation in traffic volume, speed equations [(2)-(8)] are solved for different traffic volume keeping the traffic composition constant on Bypass Road, Srikakulam. The traffic volume was varied from 500 vehicles per hour (vph) to 2000vph with the interval of 500vph. Figure 2 shows the variation in PCU of three-wheeler (3W) and truck with traffic volume. The trends show that with increase in traffic volume, the PCU values decreases and also the PCU of bus decreases drastically compared to PCU of 3W. This is because, as the volume increases, density increases and leads to decrease in the speed of vehicles. Speed of the large vehicles like trucks decreases drastically compared to smaller vehicles like two-wheelers because large vehicles need more space for their movement whereas smaller vehicles have greater maneuverability and can move in-between the large vehicles.

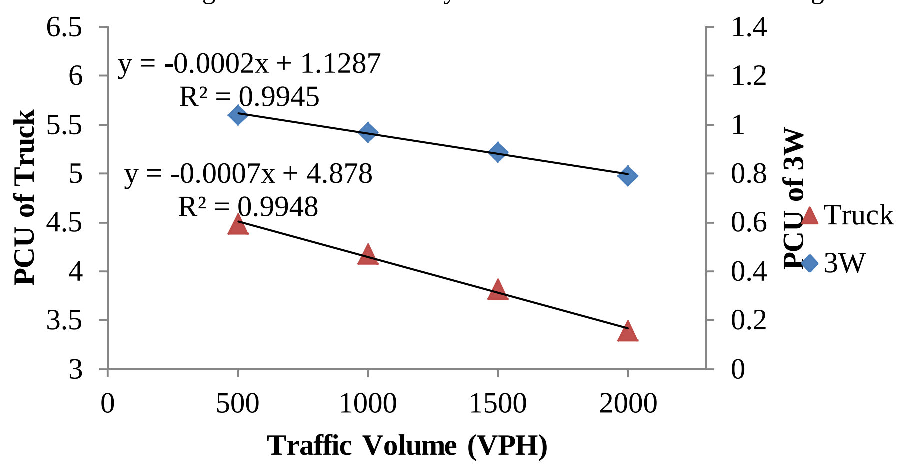

Figure 2 Variation in PCU of truck and 3W with Traffic Volume on Bypass Road, Srikakulam

Similarly, in order to analyze the variation of PCU values with variation in traffic composition, speed equations [(2)-(8)] are solved for different traffic composition on Bypass Road, Srikakulam. Figure 3 shows the variation in PCU of two-wheeler (2W) with traffic composition of 2W varying from 45% to 60% and 3W varying form 25% to 10% keeping the traffic composition of car(C), SUV (S), LCV(L), bus(B) & truck (T) constant at 5%, 5%, 5%, 10% & 5% respectively. The traffic volume was also varied from 500vph to 1500vph to generate three curves. The trends from the figure show clearly that the PCU of 2W increases as their proportion in the traffic stream increases. The decrease in proportion of 3W increases the PCU value of 2W. This is because, more number of 3W leads to occupy more space on the two-lane road forcing the 2W to move with lower speed unless there is a gap for overtaking and vice versa.

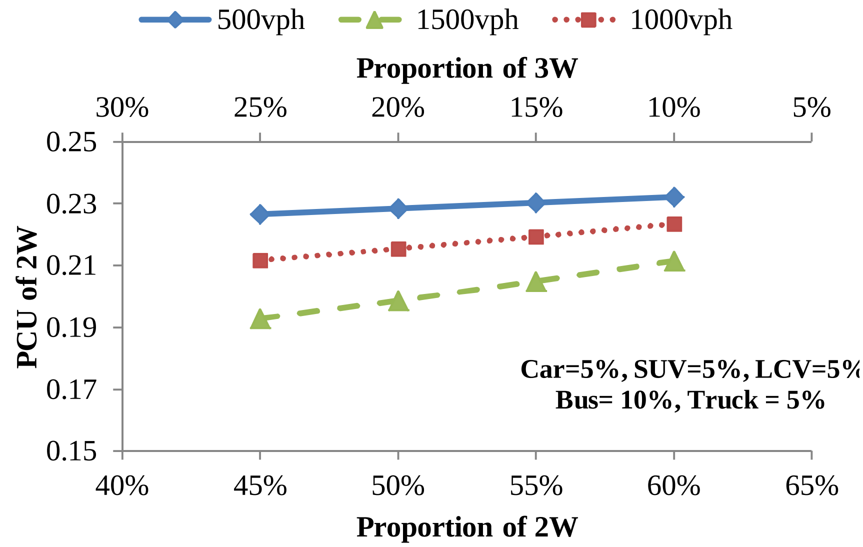

Figure 3 Variation in PCU values of 2W with Traffic Composition and Volume

Indian Road Congress (IRC 106:1990) [18] provided guidelines for capacity of roads in urban areas in which static PCU values were provided. Figure 4 shows the comparison of IRC 106:1990 recommended PCU values and obtained PCU values at 80 feet road, Srikakulam. The obtained PCU value of 2W and 3W are less than the values recommended by IRC 106:1990. SUVs were included in the category of cars and bus & trucks were included in the category of heavy vehicles in the IRC 106:1990 even though their physical dimensions, maneuverability, engine throughput etc. differ from each other. This reduces the efficiency for calculation of precise capacity of the road/highway.

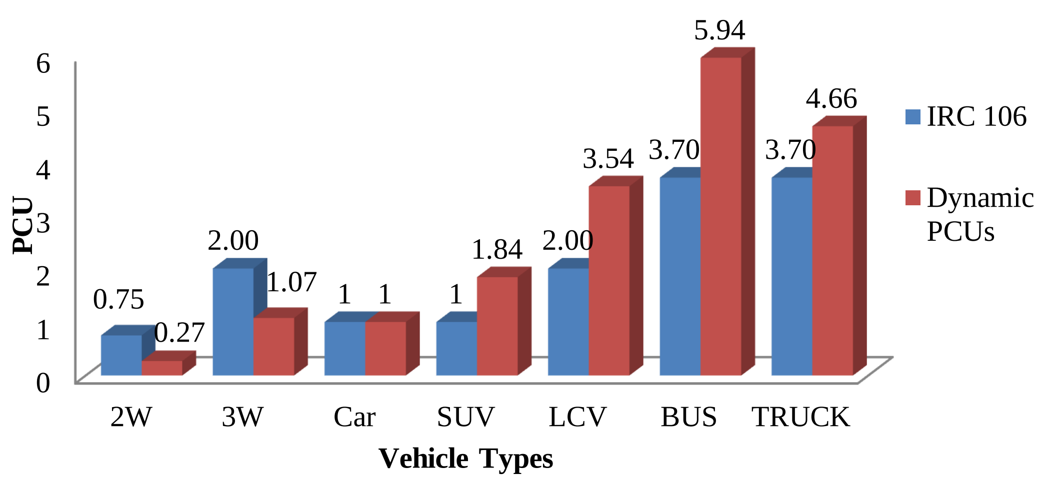

Figure 4 Comparison of obtained PCUs at 80 ft. Road, Srikakulam with IRC 106:1990

IV. SUMMARY AND CONCLUSIONS

The main aim of this study is to demonstrate the dynamic nature of PCU values on two-lane urban roads under mixed traffic conditions. PCU values are calculated as the ratio of speed ratio of the car to space occupancy ratio with respect to the standard car. Speed equations are modeled for each type of vehicle category with speed observed and traffic volume count using regression analysis. Later these speed values are used to evaluate the PCU values. Speed equations are very sensitive to change in traffic composition and volume. The conclusions observed in the present study are as follows:

A. As the width of carriageway increases, PCU values of the vehicles also tends to increase and for heavy vehicles, the increment of PCU values can be seen at a faster rate.
B. As the traffic volume in the traffic stream builds, the PCU values diminish. Heavy vehicles like buses and trucks tend to show drastic reduction in their PCU values compared to smaller vehicles like two-wheelers.
C. The increase in composition of 2W, and the decrease in composition of 3w at uniform rate tend to increase in PCU value of 2w. This is because 2W occupies less space compared to 3W.
D. The new PCU values obtained from the site are quite different from the values recommended by IRC 106:1990. It is found that the PCU of 2W and 3W were smaller and PCU of LCV and other heavy vehicles were higher than the values given by IRC 106:1990.

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