EVALUATION OF PCU USING SIMULTANEOUS EQUATION MODEL AND CONVENTIONAL METHOD

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I. Abstract

Passenger car unit (PCU) is a relative weightage factor employed for finding various vehicle units when the traffic flow in the stream is heterogeneous. PCU has continually been a substantial concern in all research studies about estimating the highway capacity. In this study, an attempt has been made to determine PCU values and their variation at different vehicle compositions and carriageway widths. Data on eight straight sections of Shivamogga's NH-369 and NH-69 were used for the analysis. For the determination of the PCU of five individual vehicles, the conventional speed-based area method was used. The coefficients of each vehicle were determined using the Simultaneous Equations Model (SEM). The coefficients determined were used to define the vehicle's speed in a stream included in the PCU computation. Variations of PCUs at supposed compositions are plotted for the chosen 5.5-meter-wide section. For the observed composition, the PCU of a particular vehicle on selected eight straight sections is evaluated. The PCU of a vehicle at observed proportions and volume for each vehicle is calculated for different carriageway widths.

Key words: PCU, SEM, coefficients, carriageway width, individual vehicles

I. INTRODUCTION

Transportation of a nation is vital for a country's economic development. Highways are important for connecting one state to another, and their dominant position in all other transport corridors has long been established. It is also unavoidable to develop ribbons clusters along these kinds of roads. In India, most roads are single-lane or two-lane in width. These roads are often constructed with one and a half lane widths (5.5 m) due to budget constraints and are called intermediate-lane roads with traffic traveling in both directions. Traffic, especially in developed countries, generally referred to as uniform, follows an appropriate lane to accommodate a significant portion of similar-sized vehicles - mainly cars and a little portion of trucks and various distinct vehicles. Whereas in developing nations, varied traffic flow qualities are entirely different and managing the system is extremely challenging under integrated traffic flow. The precision of determining traffic flow on a highway hugely depends upon the accuracy of PCUs employed for transforming traffic volume counts of observed vehicle classification. PCU is a conventional unit for different types of vehicles when the traffic flow is heterogeneous. The two elements that can define a traffic stream at a concentration on traffic characteristics are traffic composition and traffic volume. This article is the part of research work of author aims to calculate the PCU value of the selected rural highways on midblock sections at various carriageway width.

III. Objectives of the Study

1. To develop SEM considering all the possible variations in the traffic flow to determine vehicle coefficients.
2. To determine variation of dynamic PCU values of each individual vehicles at different composition rate.
3. To find PCU values of each vehicle for obtained composition of vehicles at various widths of the carriageway.

IV. Literature Review

In this section, the research literature is endured into two parts. The first part explains the set of simultaneous equations and the second part describes the details of studies related to Passenger Car Units.

a) Related to Set of Simultaneous equations

L. Fox, H. D Husky, and J. H Wilkinson (1948) [1] have described four methods to explain simultaneous equations. The first three methods have been presented using regular desk computer systems. The last method, given by Hollerith, involves stamped card equipment. The Cholesky symmetric matrices approach is incorporated in this method. The solution of AX = I furnish the answer for n equations. Scott C. Himes and Eric T. Donnell (2010) [2] check the simultaneous equation system for both traffic flow and geometric design parameters. Models of the average velocities for both right and left routes were estimated for various geometric design features related to mean velocity and velocity variation in the left lane models. They confirmed that the possibility of multilane highway speed studies is estimated using simultaneous equations. The estimate of correlations with a single equation within a concurrent system or for the entire system, separate from Hooper's measure, is explained by Richard A. L. Carter and Anirudh L. Nagar (1977) [3], which primarily accounts for the identification of scarcities within a simultaneous system. To describe the matrix rank and consider linearly based and independent variables, Alok Kumar et al. (2016) [4] used a linear equation approach. They endeavored to distinguish the coefficient matrix's rank from the augmented matrix's rank. They concluded that the equations' system is unstable if both matrices are not similar to the overall system.

b) Related to Passenger Car Unit

Satish Chandra and Upendra Kumar (2002) [5] conducted an extensive study at 10 regions of two-lane roads in India's distinct spots. They grouped the vehicles into nine separate classes and PCUs were assessed by considering the carriageway width for every segment of the roadway. Adjustment factors for the lane width were calculated after analyzing the data. S. Chandra and P.K. Sikdar

(2000) [6] explained the dynamic nature of PCUs graphically by viewing the speed and composition of vehicles. They studied different road widths for five kinds of vehicles in Delhi's urban cities. This study pointed out that the method's suitability is the same if other cities have similar traffic conditions. Chandra, S Kumar, and V Sikdar (1995) [7] assessed data collected from urban roads and highlighted that PCUs are dynamic and depend on all factors influencing vehicle performance in the traffic flow. They mentioned that the PCU of a vehicle reduces as the volume of the particular vehicle increases in the traffic stream. Parvathy R, Sreelatha T and Reebu Z Koshy (2013) [8] asserted the purpose of PCU values for numerous kinds of vehicles by comparing results with PCU factors suggested by IRC code. They concluded that the average PCU values of other countries are unique to those used in India and are partly related to automobiles' length. Gholamali Behzadi and Faez Shakibaei (2016) [9] carried out research to achieve the equivalent bus vehicle along through city areas based on a comprehensive comparison of variables analyzing traffic flow in the case of base-flow and non-stop targeted vehicles. AIMSUN simulator software was used to replace the passenger cars with bus equivalents by observing their ratio. The result of this research shows the bus equivalent based on headway and density variables are 4.46 and 4.41 respectively. The value 4.58 can finally be considered as an equivalent passenger car across urban streets for understudied streets. Pooja et al. insisted that PCU's value is vital for analyzing traffic capacity and other associated applications. Various methods for estimating PCUs for different facilities under homogeneous and mixed traffic conditions are reviewed. This paper also presents the challenges of estimating PCU values and future directions for improving PCU estimation methods. The research by Subhadip Biswas, Indrajit Ghosh and Satish Chandra (2019) [11] demonstrate a Kriging-based approach to the prediction of PCU values under the conditions of undivided road transport. Speeds obtained via the method of Kriging are in great agreement with the speeds observed. To test the PCU of vehicle classification, these speeds were used. The PCU variance with changing traffic conditions was exposed by the degree of sensitivity analysis outcomes. The study also explores the 'Stream Equivalence Factor' approach, which can convert a mixed traffic flow to its homogeneous counterpart. The study's major outcomes are summarized below.

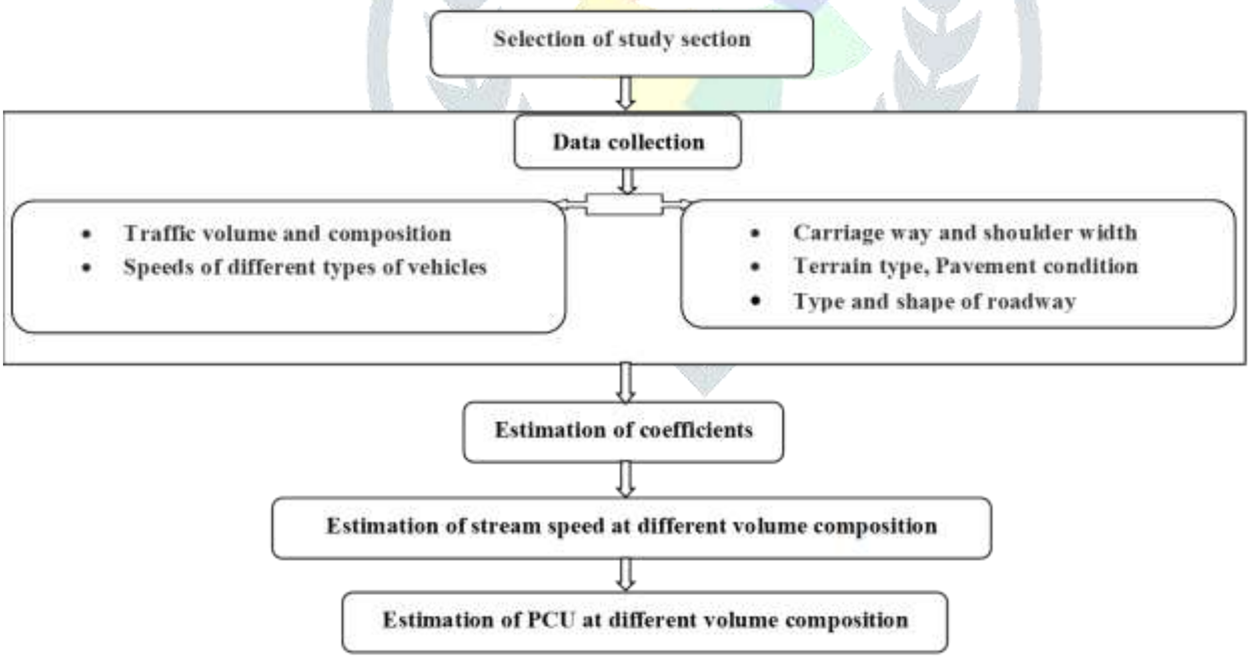
i. The PCU is very sensitive to traffic volume and vehicle category composition.

ii. For a given traffic composition of larger vehicles and heavy vehicles, increasing the volume tends to increase the PCU, while it decreases for two-wheelers and auto-rickshaws.

iii. The increase in the proportion of large vehicles in the traffic flow for the same amount of traffic results in higher occupancy of space. This means that the PCU of a large car and a large truck increases while it decreases for other vehicles. As the proportion of small vehicles, such as two-wheelers, rises in traffic flow, the opposite pattern is observed.

Most of the research studies pointed out in the literature are restricted to a divided city and interurban roadways. On undivided rural highways, traffic behaviour is entirely different from that on divided roadways. On this basis, the current research study's goal is to assess the PCU for undivided rural highways. The SEM concept was proposed to discover the coefficients of a specific vehicle, which is utilized as a tool to obtain the PCU of a specific vehicle.

V. Data Collection and Methodology



The data for carrying out the analysis was collected from eight straight sections located on Shivamogga's NH-369 and NH-69 (Karnataka, India). The selected sections were free from any grade, disengaged from on-street parking, bus stop or pedestrian crossflow in the vicinity of the area, guaranteeing minimal side friction on vehicle motions and away from crossing traffic. Initially, each vehicle's coefficients are calculated from the set of simultaneous equations by considering each vehicle's traffic volume and speed. The dynamic PCU estimation used in this study is influenced by conventional Satish Chandra’s method. This study considers five types of the most commonly used vehicles, namely, Car, Two-Wheeler (TW), Bus, Truck and Light Commercial Vehicles (LCV). The survey has been carried out to collect information on the routes of NH-369 and NH-69. Selected straight sections are as shown in Table 1. Study corridors are presented in Figure 1. Manual count procedure is used to collect traffic volume by selecting one hour as a usual counting period. The vehicle's speed is measured using a digital stopwatch for a trap length of 35 meters. The survey's overall period is six hours a day, carried out in clear, bright weather conditions from 7.00 am to 1.00 pm for seven days. Six hours of volume and speed data of a week should be taken as an average of six hours day data to evaluate a vehicle's coefficients. Only the procedure of the 5.5-meter-wide section is explained in this article. This section's average traffic volume and speed data for each vehicle are displayed in Tables 2 and 3. Figures 1 and 2 show the details of the collected traffic volume and the specific vehicle's speed during each hour. The total average traffic during each hour is shown in column 6 and the total average flow is ascertained at the bottom of Table 2, used to calculate the vehicle's coefficients. Table 4 presents the product of each vehicle's composition and speed during that specific hour, shown in the first five columns; $U=((\sum N)/6)/N$ is a constant term designated in the sixth column. Table 4 data is used as a 6x6 order matrix. Table 5 shows the inverse matrix of Table 4 using the Microsoft Excel MINVERSE function. Table 6 displays the coefficients for specific vehicles and constants U by choosing the MINVERSE function for the matrix of order 6x6 (Table 4) and the speed data of a particular vehicle of order 6x1 (Table 3). Table 7 shows the evaluated coefficients and constant. SEM built by a powerful Excel tool helps to solve complicated problems in a while. The coefficients obtained from SEM are useful to evaluate stream speed. The required specific order matrix is based on several variables and constant, as stated in equations 1 to 6. The PCU of the individual vehicle is evaluated by using the conventional speed-based area method by considering the evaluated stream speed and projected area of the vehicle (as shown in Table 8). The same process is adopted to calculate the PCU for other sections. The computed PCU of each vehicle for the selected sections at the observed composition is displayed in Table 9.

Table 1: Details of selected study stretches

Section	Section Distance from Shivamogga, Km	Length, m	Carriageway width, m (include bituminous shoulder)
NH-369	7.10	320	5.5
NH-369	10.60	350	6.0
NH-369	19.30	400	7.0
NH-369	25.80	320	9.5
NH-369	34.50	410	10.5
NH-69	10.20	350	9.0
NH-69	20.10	450	9.0
NH-69	32.40	450	9.0

(Source: Google Earth Pro)

Fig 1: Selected study corridors

Table 2: Average traffic volume of each vehicle during the study hours

Time	Car	Bus	TW	LCV	Truck	Total Volume *N
7am to 8am	79	19	140	32	19	289
8am to 9am	113	18	240	36	20	427
9am to 10am	137	24	253	39	24	477
10am to 11am	163	27	244	43	23	500
11am to 12am	150	23	248	40	18	479
12am to 1 pm	143	22	236	34	17	452
Average composition (%)	29.92	5.07	51.87	8.54	4.61	
Range (%)	20 – 30	5 - 15	5 - 15	5 - 15	5 – 15	

Average of N = (∑N)/6
= 437

*N = Total average traffic during one hour.

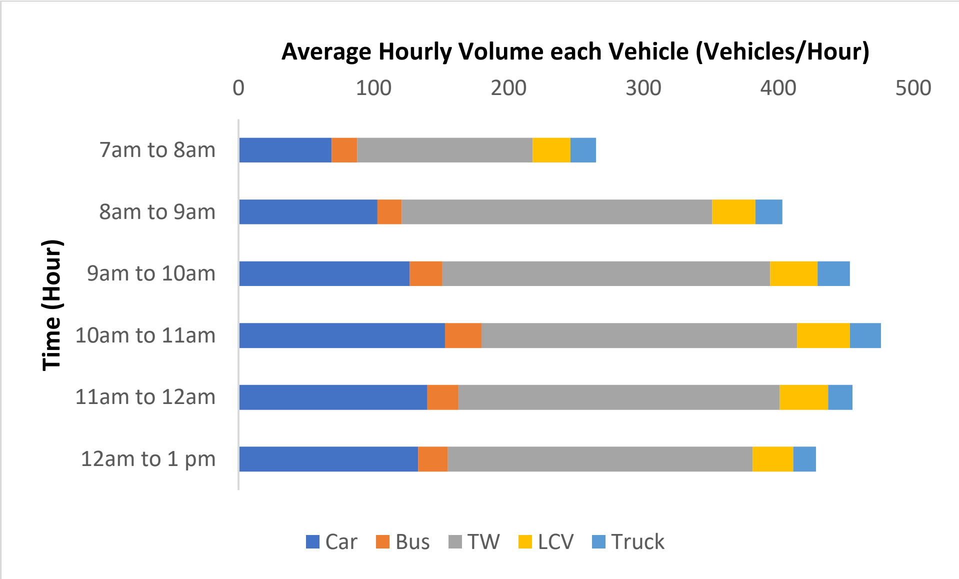


Fig 2: Average Hourly volume of each individual vehicle during each hour.

Table 3: Average speed of each vehicle during each individual hour.

Time	Average speed, kmph				
	Car	Bus	TW	LCV	Truck
7am to 8am	54.35	51.12	47.82	49.32	47.84
8am to 9am	52.97	50.28	46.72	48.21	46.98
9am to 10am	51.57	49.29	45.84	47.21	45.83
10am to 11am	52.10	49.66	46.57	48.42	46.34
11am to 12am	52.17	49.49	46.54	48.23	46.43
12am to 1 pm	52.46	49.82	46.92	48.33	46.58
Average hourly speed, kmph	**52.60**	**49.94**	**46.74**	**48.29**	**46.67**

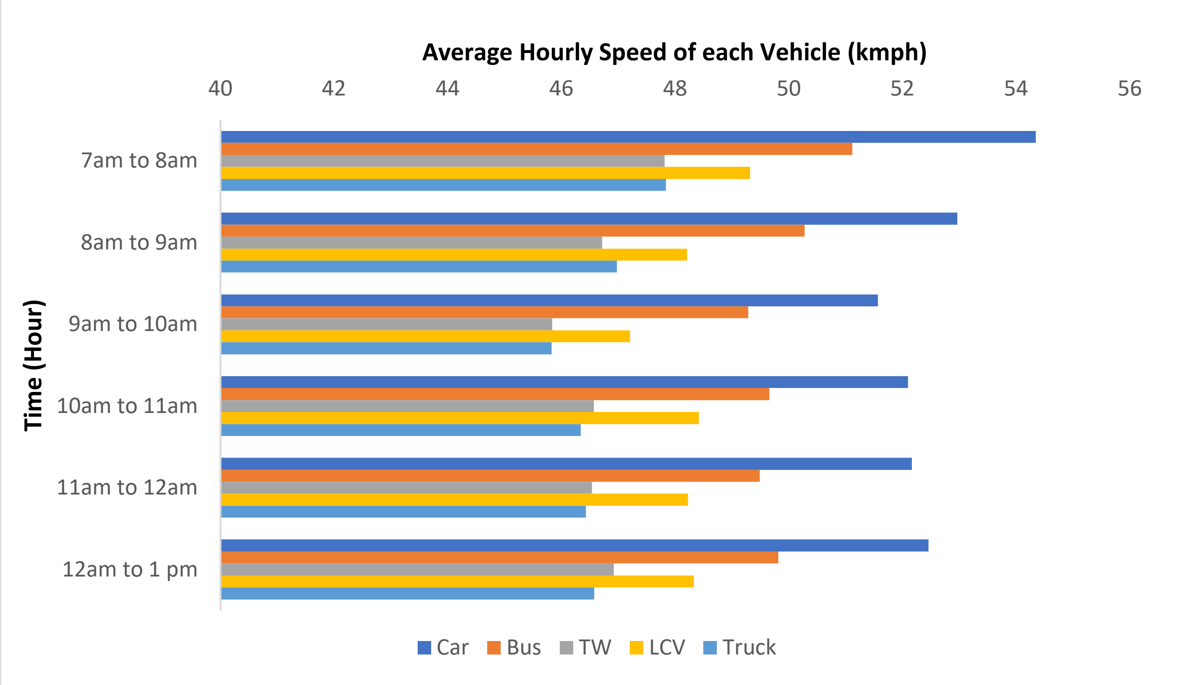


Fig 3: Average Hourly Speed of each individual vehicle during each hour.

Table 4: Product of volume composition and speed during each individual hour with constant (Produce a matrix of order 6x6)

Volume composition*speed of vehicle					Constant (U)
Car	Bus	TW	LCV	Truck	((∑N)/6)/N
14.86	3.36	23.17	5.46	3.15	1.51
14.02	2.12	26.26	4.06	2.20	1.02
14.81	2.48	24.31	3.86	2.31	0.92
16.98	2.68	22.73	4.16	2.13	0.87
16.34	2.38	24.10	4.03	1.74	0.91
16.60	2.42	24.50	3.64	1.75	0.97

Table 5: Inverse matrix of Table 4 data

Car	Bus	TW	LCV	Truck	Constant (U) ((∑N)/6)/N
-0.08	0.56	-0.92	0.96	-1.00	0.49
0.48	-4.87	5.92	-5.16	5.42	-1.65
-0.03	-0.20	0.45	-0.45	0.42	-0.15
0.11	0.04	-0.27	-0.14	2.10	-1.81
-0.28	2.48	-2.02	3.68	-5.01	1.12
1.01	3.15	-5.91	1.88	-5.71	5.40

Table 6: Result of Matrix after using MMULT function for each vehicle and constant

0.96	0.88	0.92	1.13	0.79
0.57	1.06	1.14	-0.01	0.97
1.13	1.12	1.00	0.92	1.05
1.24	0.90	0.82	1.40	1.25
1.37	1.68	0.89	1.33	0.87
0.66	-1.16	0.03	-0.40	-0.71

Table 7: Coefficients of each specific vehicle when they operate in a stream

		Vehicle Type					Constant
		Car	Bus	TW	LCV	Truck	U
Coefficients	1	0.96	0.57	1.13	1.24	1.37	0.66
	2	0.88	1.06	1.12	0.90	1.68	-1.16
	3	0.92	1.14	1.0	0.82	0.89	0.03
	4	1.13	-0.01	0.92	1.40	1.33	-0.40
	5	0.79	0.97	1.05	1.25	0.87	-0.71

The following equations are employed to find the value of the individual vehicle's coefficient for the car's stream speed during six individual hourly volumes.

$Vc_1 = c_1Vc_1nc_1 + c_2V_{B1}n_{B1} + c_3V_{TW1}n_{TW1} + c_4V_{L1}n_{L1} + c_5V_{T1}n_{T1} + c_6(U_1)$ --- 01
$Vc_2 = c_1Vc_2nc_2 + c_2V_{B2}n_{B2} + c_3V_{TW2}n_{TW2} + c_4V_{L2}n_{L2} + c_5V_{T2}n_{T2} + c_6(U_2)$ --- 02
$Vc_3 = c_1Vc_3nc_3 + c_2V_{B3}n_{B3} + c_3V_{TW3}n_{TW3} + c_4V_{L3}n_{L3} + c_5V_{T3}n_{T3} + c_6(U_3)$ --- 03
$Vc_4 = c_1Vc_4nc_4 + c_2V_{B4}n_{B4} + c_3V_{TW4}n_{TW4} + c_4V_{L4}n_{L4} + c_5V_{T4}n_{T4} + c_6(U_4)$ --- 04
$Vc_5 = c_1Vc_5nc_5 + c_2V_{B5}n_{B5} + c_3V_{TW5}n_{TW5} + c_4V_{L5}n_{L5} + c_5V_{T5}n_{T5} + c_6(U_5)$ --- 05
$Vc_6 = c_1Vc_6nc_6 + c_2V_{B6}n_{B6} + c_3V_{TW6}n_{TW6} + c_4V_{L6}n_{L6} + c_5V_{T6}n_{T6} + c_6(U_6)$ --- 06

In the above equations

Vc_1, V_{TW1}, V_{L1}, V_{B1} V_{T1} - - - V_{T6} are speeds of Car, TW, LCV, Bus and Trucks from first hour to sixth hour.

nc_1, n_{TW1}, n_{L1}, n_{B1}, n_{T1} - - - n_{T6} are composition of (Particular vehicle/Total vehicles) Car, TW, LCV, Bus and Trucks from first hour to sixth hour.

c_1, c_2, c_3, c_4, c_5 and c_6 are coefficients for Car, Bus, TW, LCV and Trucks and constant U when the vehicles in the stream.

U_1, U_2, U_3, U_4, U_5 and U_6 are Constant terms from first-hour to sixth-hour computed from ratio of total average volume of six hours to total vehicle volume during each hour.

To obtain coefficients, c_1 to c_6 for Car's stream speed, the matrix of size 6X6 (right of the equation) equated to the matrix of size 6X1 (left of the equation). The same process is recited for the remaining four vehicles by considering the same 6x6 matrix with the corresponding 6x1 matrix.

Table 8. Physical Dimensions of Vehicles

Type	Dimensions (L x B), m x m	Area, m^2
Passenger Car	3.72 x 1.44	5.36
Bus	10.10 x 2.43	24.54
TW	1.87 x 0.64	1.20
LCV	6.10 x 2.10	12.80
Truck	7.50 x 2.35	17.63

Present research study embraced the PCU model recommended by Chandra and Kumar (2003) as given in Equation

$PCUi = (Vi/Vc)/(Ai/Ac)$

Where,

PCUi is PCU of ith Vehicle.

Vc and Vi are average speeds for cars and type ith vehicles respectively in the traffic stream.

Ac and Ai are the projected rectangular areas of the cars and ith vehicles on the road (shown in Table 8). The rectangular areas are a sign of pavement occupancy, crucial in operational characteristics of traffic flow. In this study, Vc and Vi were determined using the SEM is as shown in Figure 9.

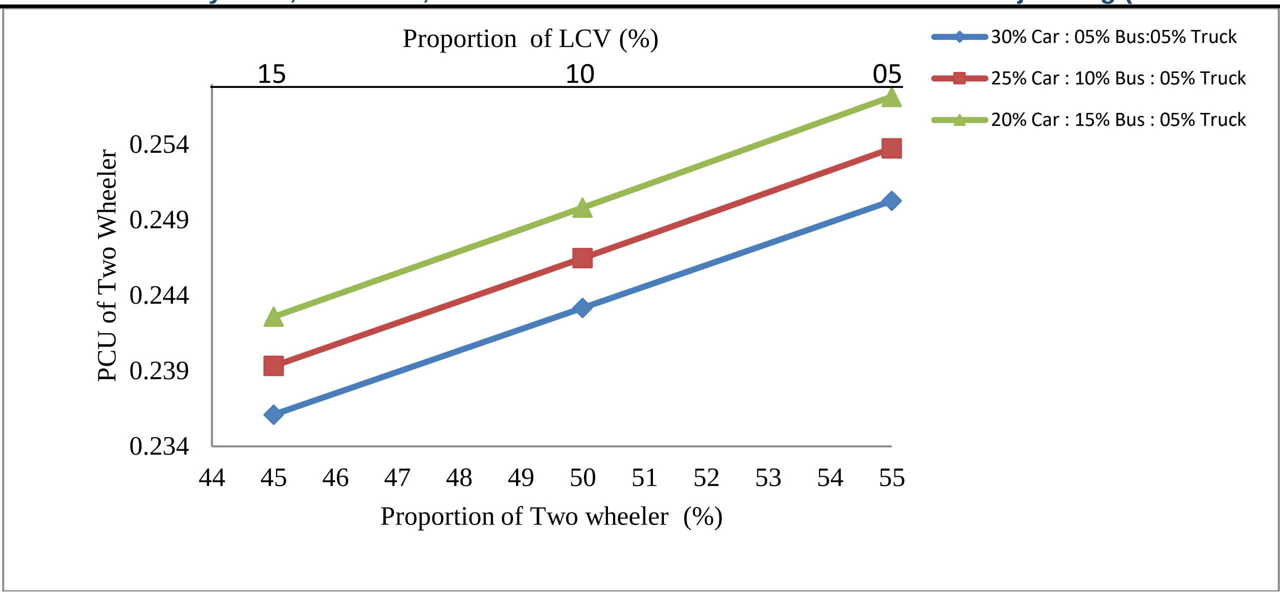


Fig 4: PCU of TW at different composition of traffic

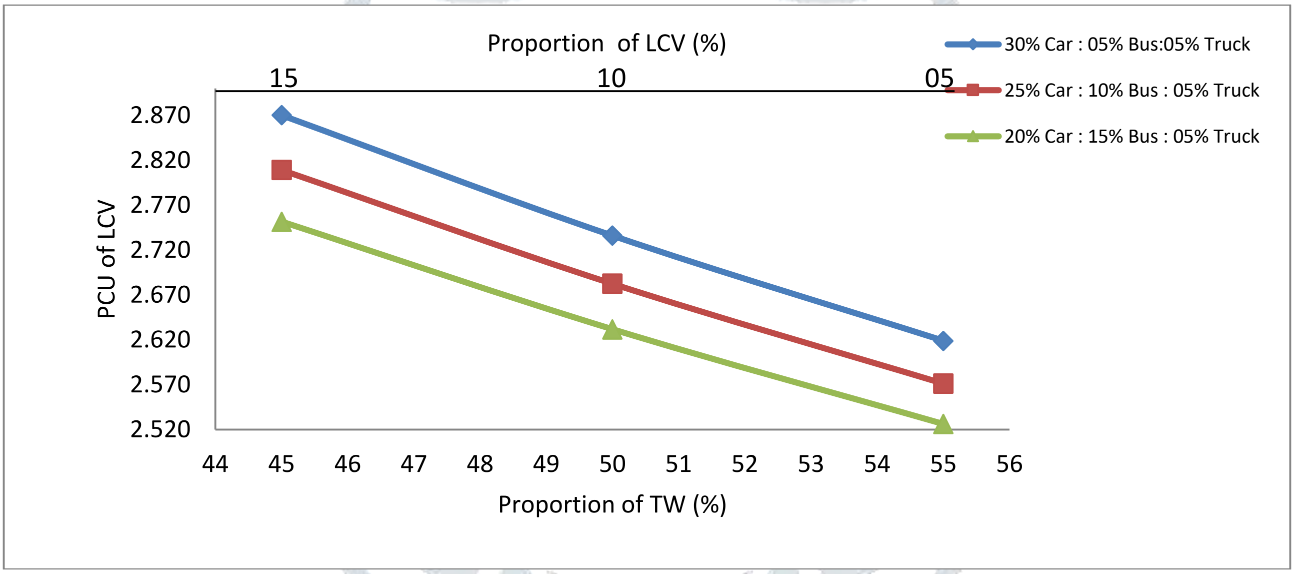


Fig 5: PCU of LCV at different composition of traffic

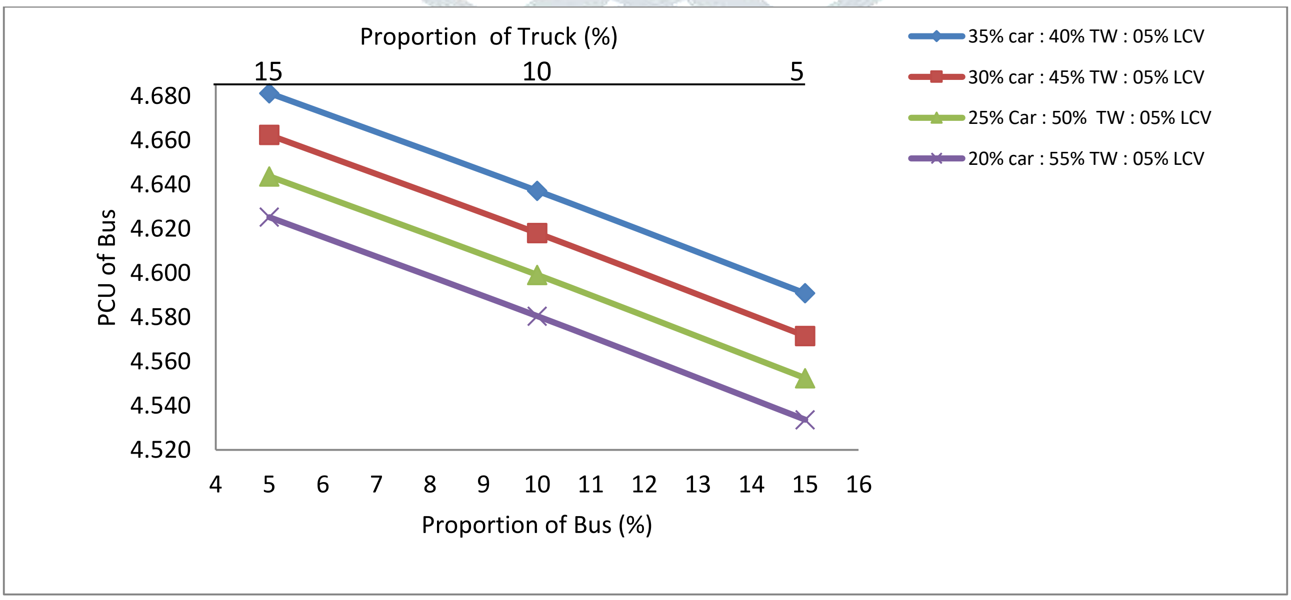


Fig 6: PCU of Bus at different composition of traffic

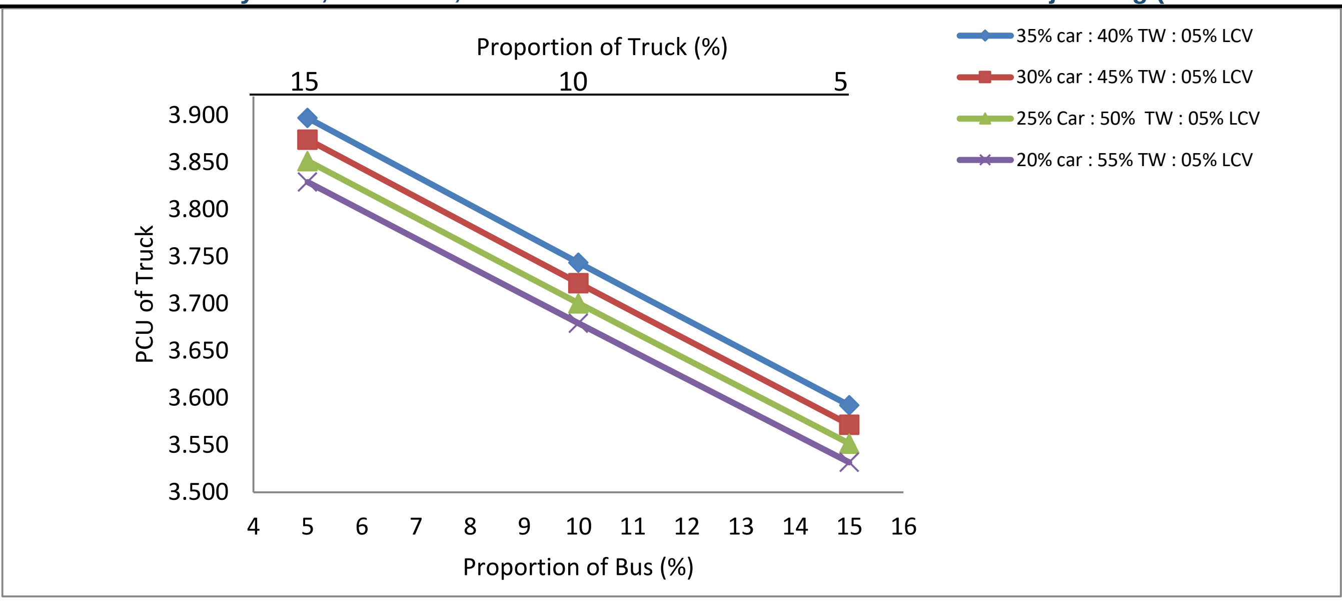


Fig 7: PCU of Truck at different composition of traffic

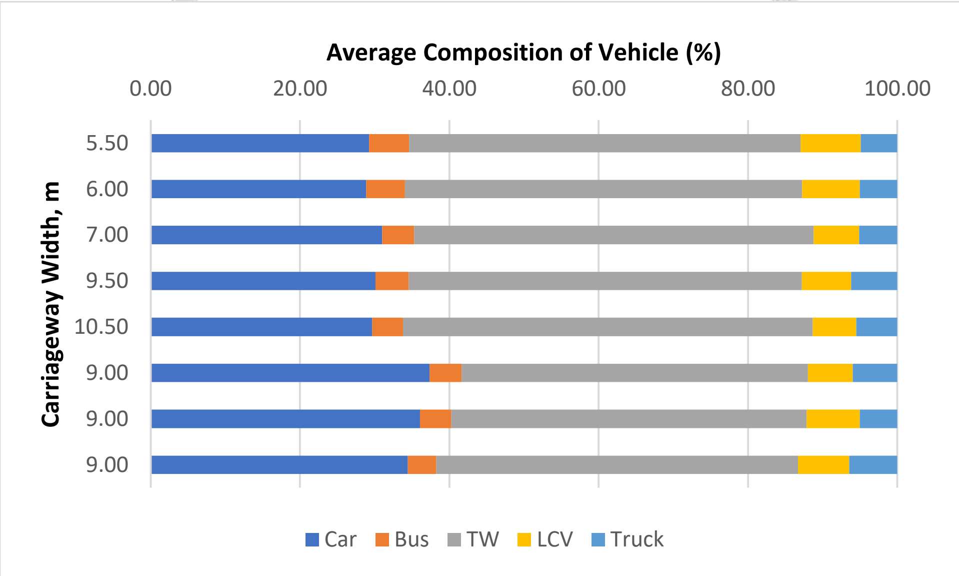


Fig 8: Observed composition of vehicles on each section

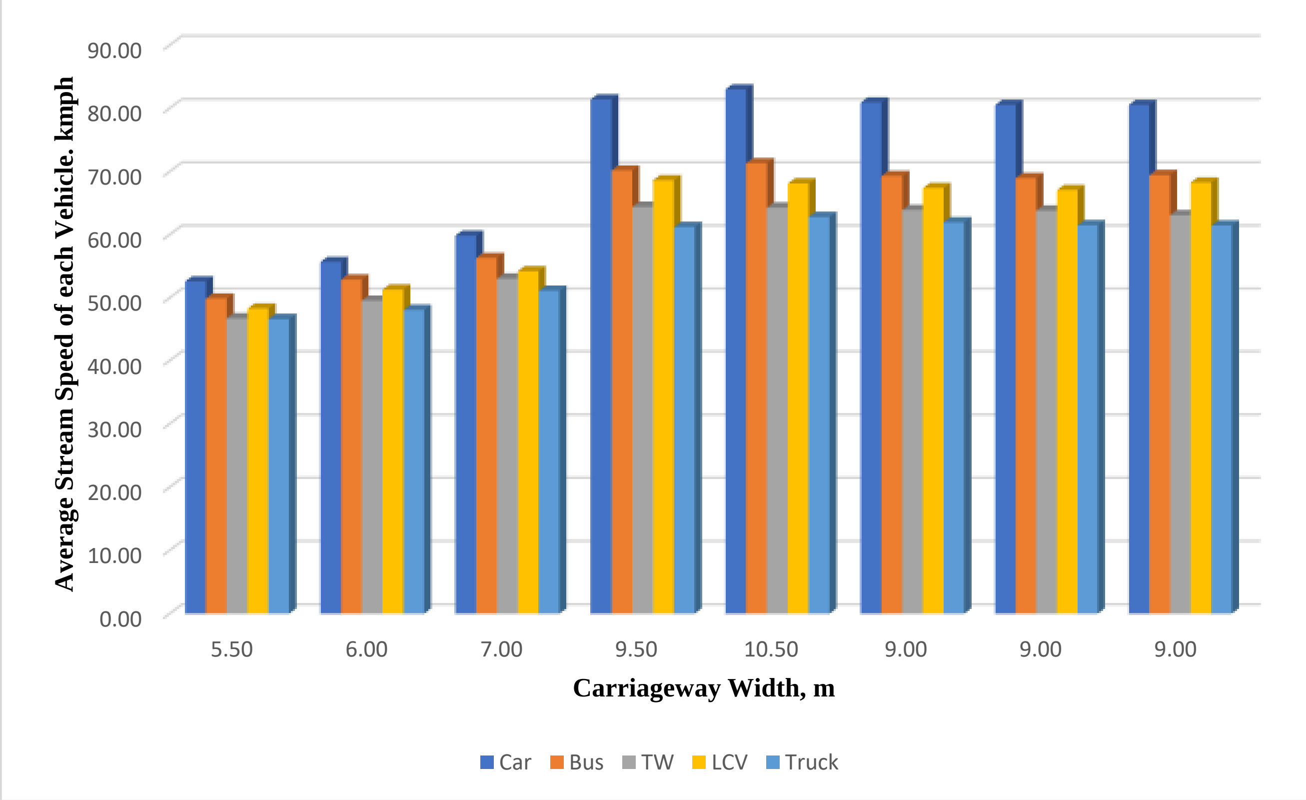


Fig 9: Estimated Average stream speed of vehicles on each section

Table 9: PCU of individual vehicle on each section

		PCU			
Section	Carriageway width	Bus	TW	LCV	Truck
NH-369	5.50	4.83	0.25	2.60	3.71
NH-369	6.00	4.82	0.25	2.59	3.81
NH-369	7.00	4.86	0.25	2.64	3.85
NH-369	9.50	5.31	0.28	2.83	4.37
NH-369	10.50	5.33	0.28	2.86	4.30
NH-206	9.00	5.35	0.28	2.87	4.30
NH-206	9.00	5.35	0.28	2.87	4.31
NH-206	9.00	5.31	0.29	2.82	4.31

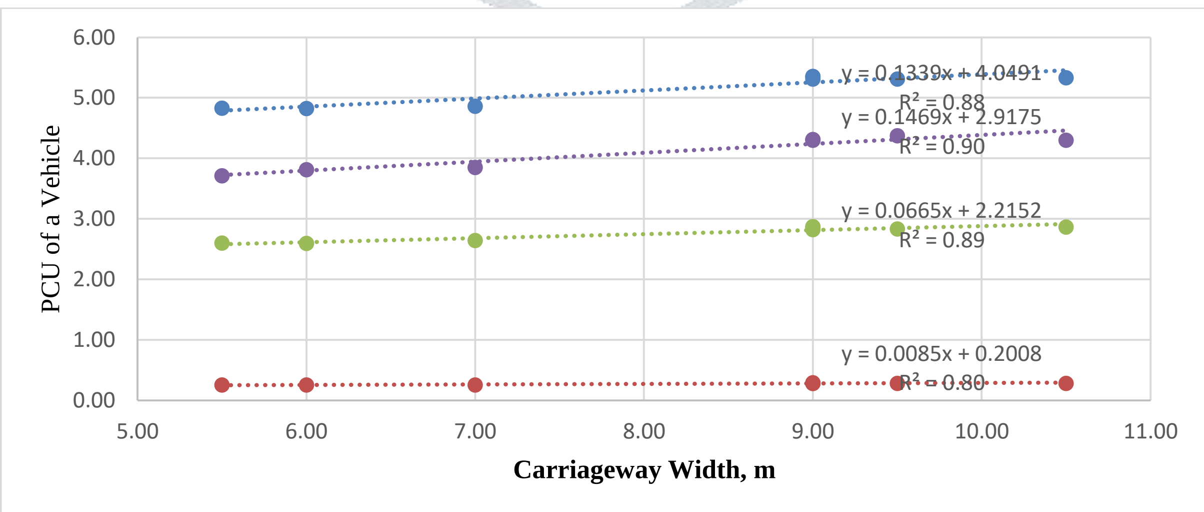


Fig 10: PCU of a vehicle on carriageway width, m

VI. RESULTS AND DISCUSSION

- The SEM consists of a set of linear equations used to obtain the precise outcome for a stream's variables. To solve multiple equations with multiple unknowns, the order matrix n x m is used; n is the number of rows corresponding to the number of equations, and m is the number of columns corresponding to the number of unknown variables. The outcome shown in Table 7 presents the vehicle's coefficients when they are in a traffic stream. During each hour, the coefficients' value may be negative or positive, i.e., based solely on the difference in composition of the volume and speed of each vehicle. The obtained coefficients are essential for determining the dynamic PCU of a vehicle.
- Figures 4 to 7 show the variation of PCU values in different vehicles' composition at 5.5 m carriageway width. For all possible car and bus composition, the TW PCU increases as the percent of LCV decreases and visa-versa. TW PCU value increment is mainly due to the lesser space occupancy of LCV. The PCU value of TW ranges from 0.250 to 0.257, 0.243 to 0.250 and 0.236 to 0.243 at 5, 10 and 15 percent of LCV. The PCU value trend for LCV is reverse due to ample space utilization of TW at their higher proportion. The PCU value for LCV ranges from 2.619 to 2.526, 2.736 to 2.632, 2.870 to 2.752 at 5, 10 and 15 percent of LCV. Whereas the PCU of Bus and Truck at all possible variations of car and TW, decreases as the percent of bus increases, this is due to lesser speed and higher space occupancy of these vehicles. The bus's PCU value ranges from 4.591 to 4.534, 4.637 to 4.580 and 4.681 to 4.625, and the PCU of Trucks ranges from 3.592 - 3.532, 3.744 to 3.679 and 3.897 to 3.829 at 5, 10 and 15 percent of bus. However, the trend may not be the same for all carriageway widths and geometric conditions of the roadway.
- Figure 8 and 9 indicate the observed composition and calculated average stream speed of a vehicle on each section. The estimated speed corresponds to the composition is used to find the PCU of a vehicle.
- Table 9 indicates that the two-wheeler PCU remains constant for the carriageway width from 5.5 m to 7.0 m and almost same for remaining stretches. This is mainly due to a smaller fluctuation in the stream speed of these vehicles relative to other vehicles. PCU on NH-69 slightly increases due to a higher car percentage, responsible for other vehicles' free movement due to higher stream speed.
- Figure 10 shows that the highest coefficient of determination (0.9) is obtained for Truck and the lowest (0.8) for TW. This is due to small efficient operating speed of Truck over the width of carriageway as compared to other vehicles.

VII. CONCLUSIONS

From the current study, the following conclusions are discussed below.

- To evaluate the PCU for undivided rural highways and its effect of traffic and geometric attributes on the PCU of each kind of vehicle, SEM concept was proposed to estimate the coefficients of a specific vehicle, which is used as a tool to obtain the PCU of a vehicle.
- Many scholars have developed methods for the vehicle type to measure/ evaluate PCU. For the same vehicle type, all these methods produce different PCU values. In the present study, the PCU values were evaluated using the equation presented by Chandra and Kumar (2003) which is more appropriate for Indian and many Asian countries.
- The PCU of the vehicle is a dynamic parameter. It depends on various variables, such as traffic composition, volume level, road width, etc. Figures 4 to 7 shows the variation of PCU values in different vehicle composition at 5.5 m carriageway width. For all possible car and bus composition, the TW PCU increases as the percent of LCV decreases. The PCU value trend for LCV is reverse due to ample space utilization of TW at their higher proportion. The PCU of Bus and Truck at all possible variations of car and TW, decreases as the percent of bus increases. This is due to lesser speed and higher space occupancy of these vehicles.
- The results shows that all PCU value of vehicles increases with the increase in width of the carriageway when the composition of the vehicles is almost the same.

VIII. Future scope:

PCU will also differ with other geometric factors (such as gradient, horizontal curvature, and so on). In future research studies, the impact of those elements requires to be investigated.

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