MODELLING THE EQUIVALENCY FACTOR OF E-RICKSHAW UNDER HETEROGENEOUS TRAFFIC CONDITIONS

Amir Ali Khan*, Sachin Dass

Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonepat, Haryana, India

*E-mail of corresponding author: amirm640@gmail.com

Amir Ali Khan 0000-0002-3309-9831, Sachin Dass 0000-0003-1015-4807

Resume

E-rickshaws, as emerging transport modes, notably affect mixed traffic flow on urban roadways. To evaluate their influence relative to other vehicle types, this study aim was to determine the Passenger Car Unit (PCU) value for e-rickshaws, as the Indian Roads Congress has yet to assign one. Three analytical methods were used: Chandra's method, the homogeneous coefficient method, and multiple linear regression. Data were gathered via three-hour video recordings at three different locations, each in Hapur and Sonipat. Using VLC media player, vehicle speeds and counts were extracted for analysis. The data were then processed in SPSS and Excel to derive equivalency values and assess influencing factors. Results indicate that the e-rickshaw's PCU value increases with rising traffic speed, but decreases with higher e-rickshaw concentration. Additionally, when the traffic volume increases, but composition remains unchanged, the PCU value for e-rickshaws shows a declining trend. These findings can help to refine the traffic flow modelling in heterogeneous conditions.

Article info

Received 29 January 2025
Accepted 9 July 2025
Online 25 July 2025

Keywords:

e-rickshaw
equivalency factor
Chandra's method
homogeneous coefficient method
speed-based modelling

Available online: https://doi.org/10.26552/com.C.2025.046

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

E-rickshaws are the three-wheeled electric vehicles that can carry up to four passengers. They are becoming increasingly popular as a mode of transport in urban areas due to their low operating costs and environmental friendliness. The PCU (Passenger Car Unit) or PCE (Passenger Car Equivalency) or equivalency factor is a comparative weightage factor implemented to the volume of traffic of individual vehicle types to cope with variability in a mixed flow environment [1]. For analyzing various traffic factors, it is critical to compute equivalency factors. The precision of the equivalency factor for e-rickshaw is extremely important in traffic flow analysis due to its diverse uses. Even though there are a large number of e-rickshaws running on urban streets, the equivalency factor of an e-rickshaw is not available [2]. This research aim was to derive the equivalency factor of an e-rickshaw and the impact of various parameters on its value. It could aid the traffic planners in adequately coping with mixed traffic scenarios

The speed of traffic and the proportion of vehicle types in the stream significantly impact the equivalency factors of vehicle types. Many researchers [3-4] conducted studies to determine this impact on heavy vehicles, but there is no available significant research in the case of slow-moving vehicles. This study aim was to check this effect on the equivalency factor of e-rickshaw (slow-moving vehicle).

This research had the following purpose:

- To calculate the traffic speed.
- To calculate the equivalency factor of e-rickshaw.
- To check the impact of traffic speed on the equivalency factor of e-rickshaw.
- To check the impact of the composition of e-rickshaw on the equivalency factor of e-rickshaw.
- To check the effect of traffic volume on the equivalency factor of e-rickshaw.

This research results could be valuable for traffic planners and engineers as there is currently a lack of substantial research on the equivalency factor of e-rickshaws, and would aid them in effectively addressing this issue.

2 Literature review

2.1 Methods of equivalency factor estimation

Several methods are available for PCU estimations. However, different methods are used for different traffic and roadway conditions. Various methods published in reputed journals are (i) Chandra's method- proposed by [5], (ii) Homogeneous Coefficient method, (iii) Headway method- used by [6], (iv) Multiple linear regression- used by [7-8], (v) Speed based modelling - used by [9], (vi) Density method- used by [10], (vii) Huber's method- proposed by [11]. Among these methods, the Chandra's method, homogeneous coefficient method, multiple linear regression, and speed-based modelling are commonly used methods for heterogeneous or mixed traffic conditions, and the rest are used primarily for homogeneous conditions.

2.2 Factors affecting passenger car unit

The PCU or PCE of a vehicle is influenced by many traffic and geometric parameters. Some of the important factors mentioned in the reputed journals are described below: (i) Traffic speed, (ii) Traffic volume, (iii) Traffic composition, (iv) Carriageway width, (v) Shoulder width, (vi) Gradient of the road, (vii) Horizontal and vertical curvature of the road, (viii) Weather condition, (ix) Time, (x) Amount of rainfall, (xi) Type of terrain, (xii) Headway, (xiii) Level of service (LOS) and more.

2.3 Review of previous research papers

Passenger car unit for e-rickshaw was determined by Barman et al. (2025) on divided Indian urban roads. According to the study, the static PCU was 0.78 with a range of [0.53-1.80]. Additionally, when the traffic density increases, the PCU becomes less sensitive to the road's operating condition, according to a sensitivity analysis [12]. Khan and Dass (2025) estimated and compared PCU values using different methods of estimation and concluded that out of many methods, Chandra's method is best suited in mixed traffic conditions. The PCU of e-rickshaw was also calculated in this study, and it is smaller than 1 [13]. Kalogo and Costa (2024) accessed the PCU values due to change in width of roadway using speed based method and found out that the influence of a road's decreasing effective width on travel speed is substantial. Variations in travel speed have an impact on the comparable values for passenger cars [14]. Khan and Singh (2021) calculated the equivalency factor of an e-rickshaw on non-rural arterials in Sonipat, Haryana, using Chandra's approach and speed-based modelling. They found that the equivalency factor of e-rickshaw changes with varying traffic parameters. It was also concluded that there is no relationship between the carriageway width and the PCU value of E-rickshaw [2]. Sharma and Biswas (2021) presented a review of the literature on approaches of equivalency factor estimation and their relevance to urban arterials. Among the different ways of computing the PCU value of vehicle types present in the flow, the speed-based method (Chandra's method) is extensively employed, particularly on metropolitan routes. The effect of different traffic and geometric parameters on the PCU values of different vehicles was also discussed [1]. Vijay and Khatavkar (2019) used the Chandra's approach to determine the influence of lane width, horizontal radius, and speed on PCU values of different vehicle kinds. They found that when the speed increased, PCU values increased as well. It was concluded that the increase in lane width and radius substantially caused an increase in PCU value [15]. Rao et al. (2017) reviewed equivalency factor studies in both mixed and non-mixed flow scenarios. The major purpose of this research was to examine and define data trends, as well as to identify areas for future research in order to improve PCU values. Their research revealed that traffic and geometric characteristics must be taken into account while developing a model for calculating the most acceptable PCU values of vehicles that may be applied universally [15]. Tullu et al. (2021) used the Chandra's method and regression analysis to determine Passenger Car Units for urban roads in Addis Ababa, Ethiopia. The impact of traffic volume and carriageway width on equivalency factors was studied, and it was observed that increasing the values of both factors increases the PCU value of vehicles [16]. Biswas et al. (2017) used a kriging-based system to illustrate the impacts of vehicular volume and composition on velocity and equivalency values for vehicles on an intercity roadway under a heterogeneous traffic mix [17]. Patkar and Dhamaniya (2020) demonstrated the impact of non-motorized vehicle types on the operating speed and potential of mixed road transport in urban arterial mid-block segments. In nations such as India, combining non-motorized vehicles with motorized automobiles without lane driving is very common. The existence of NMVs (non-motorized vehicles) is observed to markedly slow down the speed of motorized vehicles and, thus, the stream speed. The reduced stream speed decreases the capacity of city road sections significantly. The percentage of non-motorized vehicles in a stream of traffic determines this decline in capacity [18]. Sekhar et al. (2016) studied the assessment of free flow speeds on inter-urban roadways. This research is primarily concerned with a review of the alternate meanings of (FFS) Free Flow speed reported in the literature. Bases for evaluating the free flow speed (FFS) for the two-lane intercity highways were also studied [19]. Mondal et al. (2017) published a paper on the estimation of PCU values and to check variations due to changes in traffic composition and traffic volume using the Chandra's method and found that any change in traffic parameters leads to a change in PCU values [20]. Variation in PCU values due to lane width, traffic volume, and composition using Chandra's method was studied by Mardani et al. (2015), and the result of the research shows that these parameters have a considerable impact on PCU values of vehicle types [21]. Dhananjaya et al. (2023) used Chandra's method to evaluate PCUs for midblock sections of Sri Lanka under mixed traffic situations. In the Colombo district of Sri Lanka, PCU values of ten vehicle classifications for four separate mid-block road sections were assessed. Field surveys were used to gather information about the two key variables in this method: category speed and vehicle area. The outcomes of the four-lane highways were integrated and contrasted with the currently present PCEs with the aim of recommending a revised set for general transport investigations in Sri Lanka [22].

3 Methodology

The methodology employed in this research is presented in Figure 1. Initially, the study area was chosen and data on traffic and geometry were collected and analyzed to determine the speed and equivalency factor. Subsequently, in this study was investigated the impact of traffic speed and the composition of e-rickshaws on the road and the traffic volume in the stream.

4 Study area and data collection

Three divided urban roads of Hapur city, Uttar Pradesh, and three divided urban roads of Sonipat city, Haryana, were considered as the study area. Both cities have similar kinds of traffic environments. The details of the selected roads is shown in Table 1 and maps displaying selected sites where traffic was measured are shown in Figures 2 and 3 for Hapur and Sonipat city, respectively. The criteria used to select the sites were that they must be divided roads and free of obstacles such as parking lots, crossroads, stoppages, etc. All the sites from both cities were in the urban environment. A section of a certain length on each road was marked for capturing the videos. The 3-hour long videos were captured on each site. Later, those videos were interpreted to determine the average speed and volume count of each vehicle type with the help of VLC Media Player. Speed and volume data were extracted in 15-minute intervals. A total of 12 intervals of 15 minutes were extracted from 3-hour-long videos. Using a VLC media player, captured videos were slowed down to note down the traffic volume and Frame-by-frame analysis was done to divide the video footage into separate frames so that the movements of vehicles could be precisely examined to help in determining the speed of vehicles. Dimensions of cars and e-rickshaws were

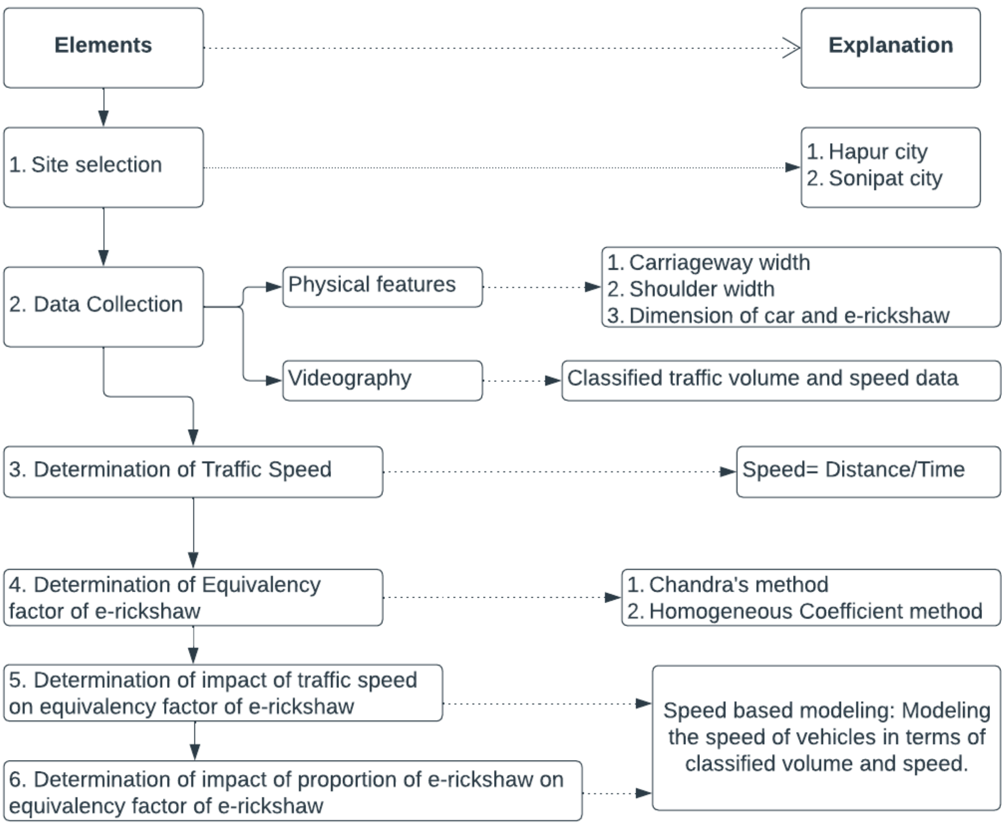

Figure 1 *Adopted methodology*

measured as well, as shown in Table 2. The average traffic composition and hourly volume obtained from the captured videos for Hapur City are presented in Figure 4 and for Sonipat City in Figure 5.

***Table 1** Detail of selected roads*

City	Site	Carriageway width (m)	Shoulder width (m)
Hapur City	Site 1	7.02	5.24
	Site 2	9.91	3.21
	Site 3	6.79	4.81
Sonipat City	Site 1	4.11	2.54
	Site 2	7.22	5.80
	Site 3	4.73	1.75

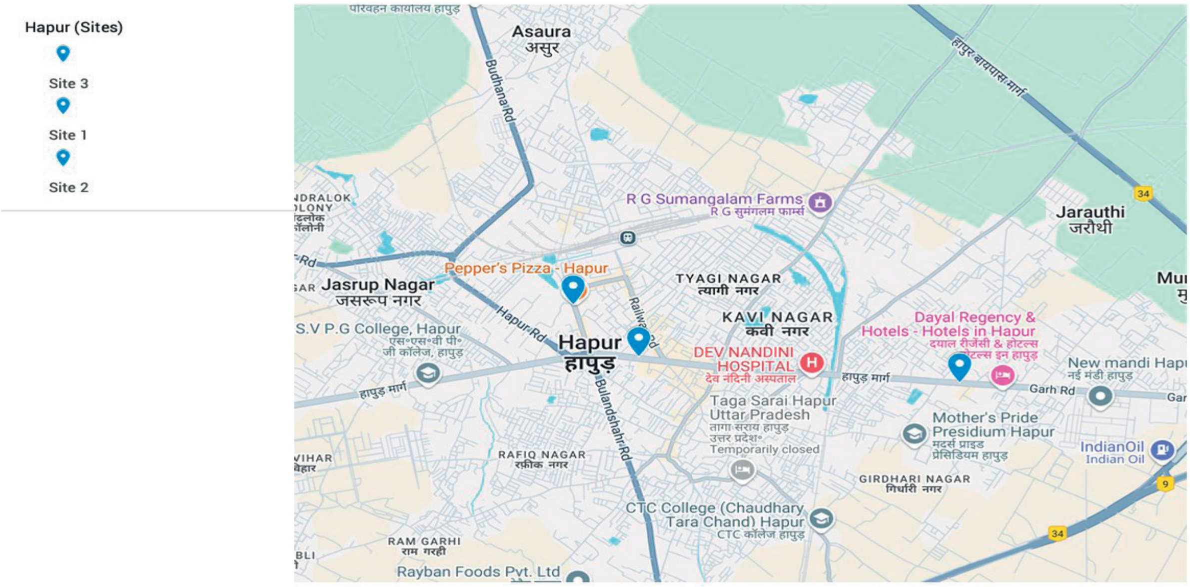

***Figure 2** Map displaying selected sites of Hapur city*

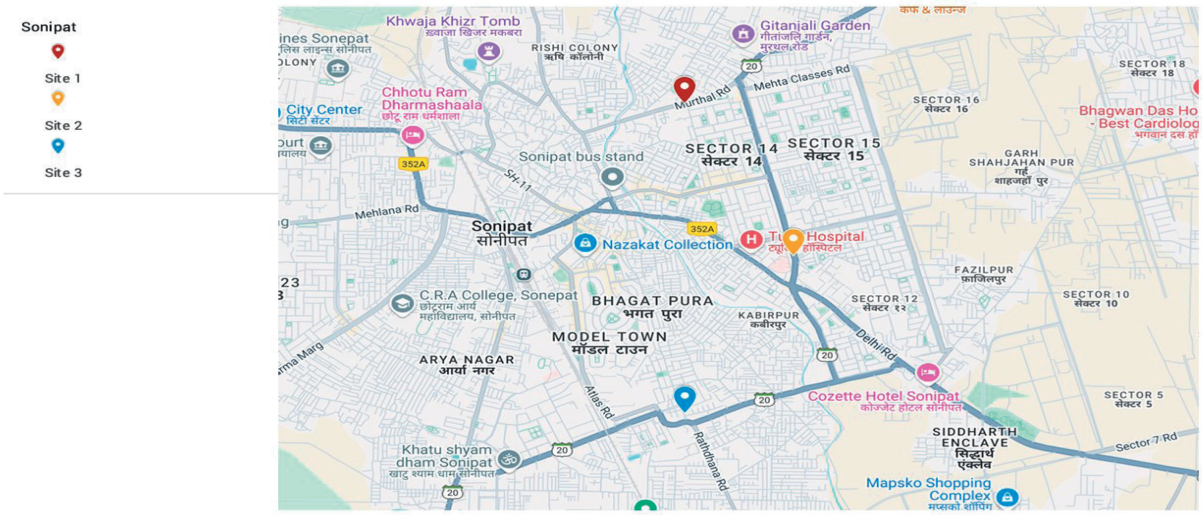

***Figure 3** Map displaying selected sites of Sonipat city*

***Table 2** Observed area of car and E-rickshaw*

Vehicles	Area (length * width) of the vehicle in m²
Car	5.360
E-rickshaw	2.720

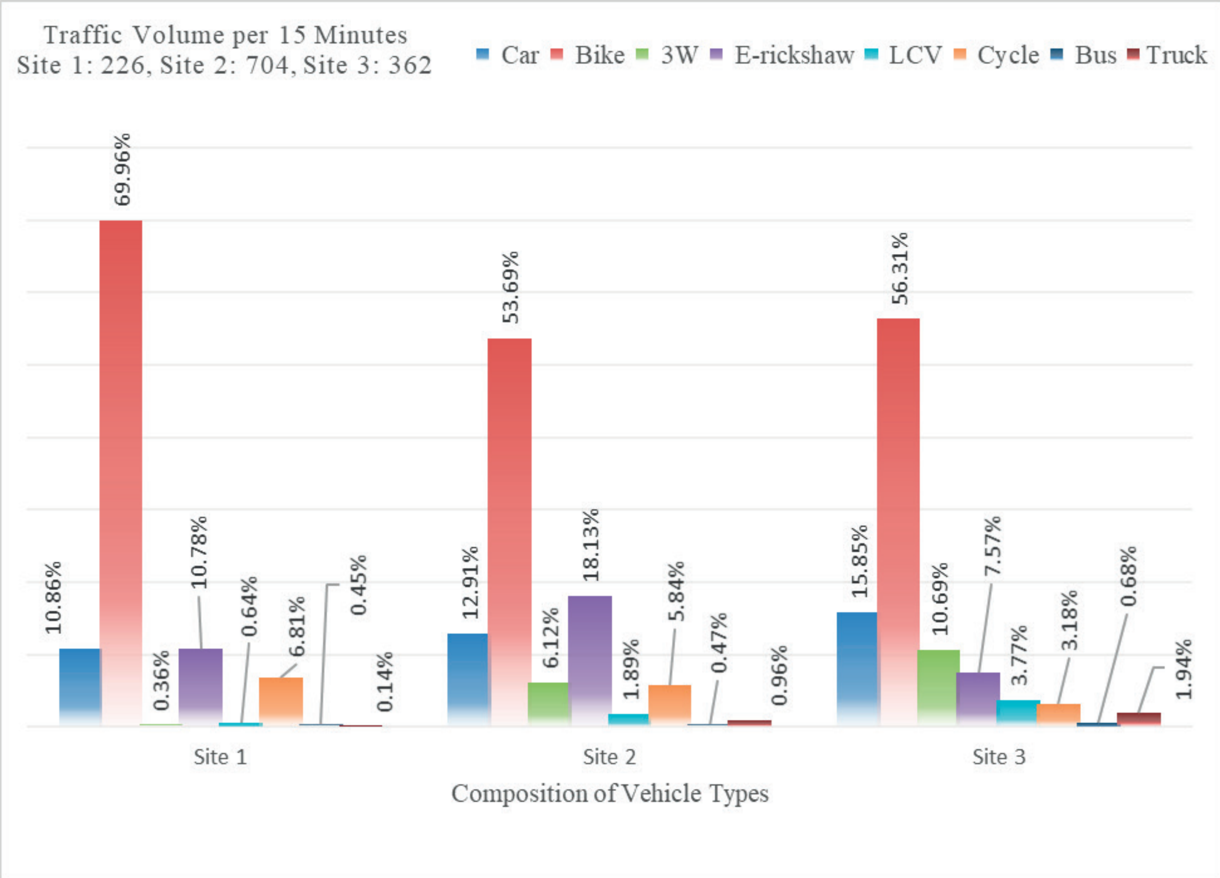

Figure 4 *Traffic volume and composition obtained from three sites of Hapur City*

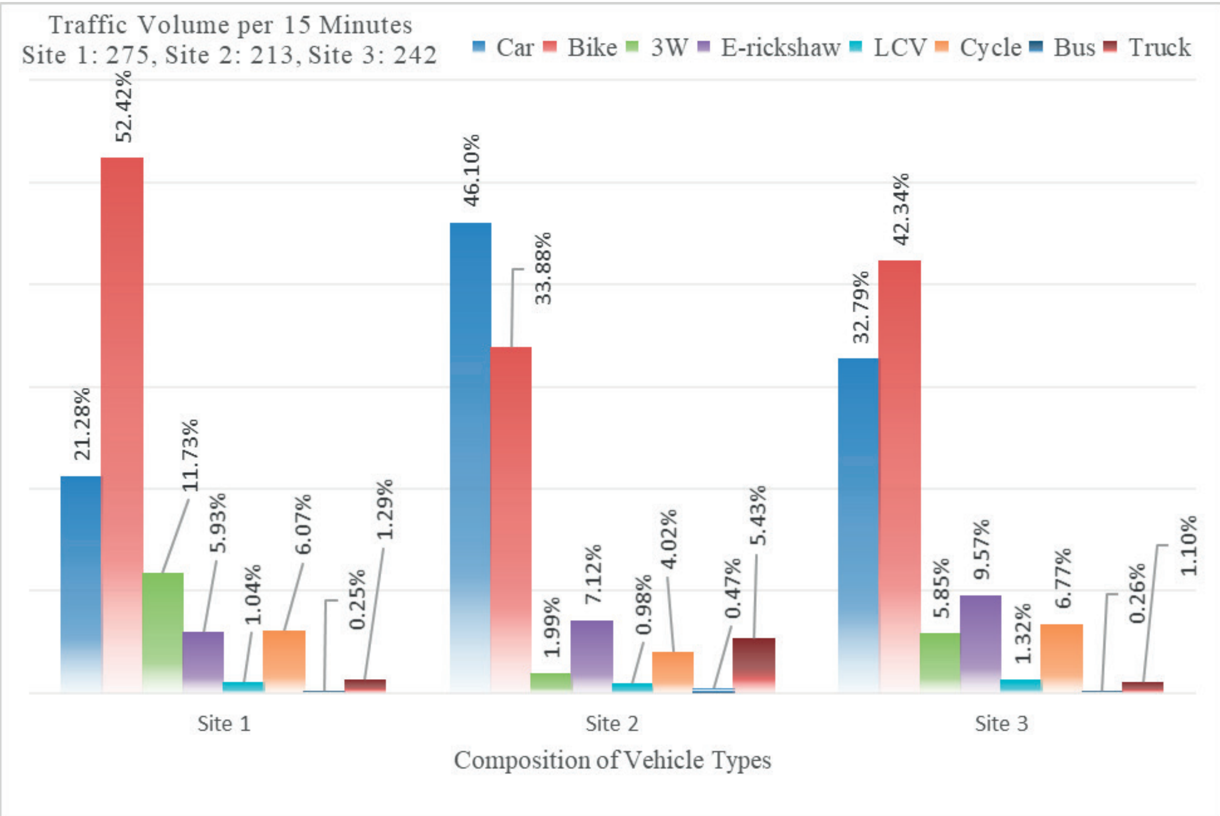

Figure 5 *Traffic volume and composition obtained from three sites of Sonipat City*

5 Determination of the traffic speed

Frame-by-frame analysis was used to extract the time required by individual vehicles to pass the designated section from the captured videos using a VLC media player. Time taken to cross the selected areas of a certain length by vehicle type was noted. The section of a certain length was marked on the road using masking tape so that entry and exit points are visible in the captured videos to help in determining the time required to cross that section by different vehicles. The length of section was measured manually by measuring tape and then the speed of each vehicle category was estimated. The estimated speed of each vehicle category was then converted into space mean speed using Equation (1), and then the average speed of traffic was estimated. The mean speed of traffic in m/s for the roads of Hapur city and Sonipat city is shown in Figure 6. A descriptive analysis of traffic speed obtained from the selected sites is shown in Table 3. Space mean speed of car and e-rickshaw is shown in Table 4.

$$V_s = n / \left(\sum_{i=1}^{n} 1/(V_i) \right), \tag{1}$$

where V_s is space mean speed, n is the number of vehicles, and V_i is the vehicle category.

Table 3 *Descriptive statistics (traffic speed in m/s)*

City	Site	Mean	Median	Standard deviation	Minimum	Maximum
Hapur	Site 1	6.495	6.720	0.505	5.248	6.875
	Site 2	8.319	8.330	0.171	8.026	8.618
	Site 3	9.909	9.841	0.438	9.179	10.614
Sonipat	Site 1	8.801	8.509	1.054	8.173	12.014
	Site 2	9.329	9.407	0.258	8.799	9.662
	Site 3	9.955	9.965	0.280	9.514	10.328

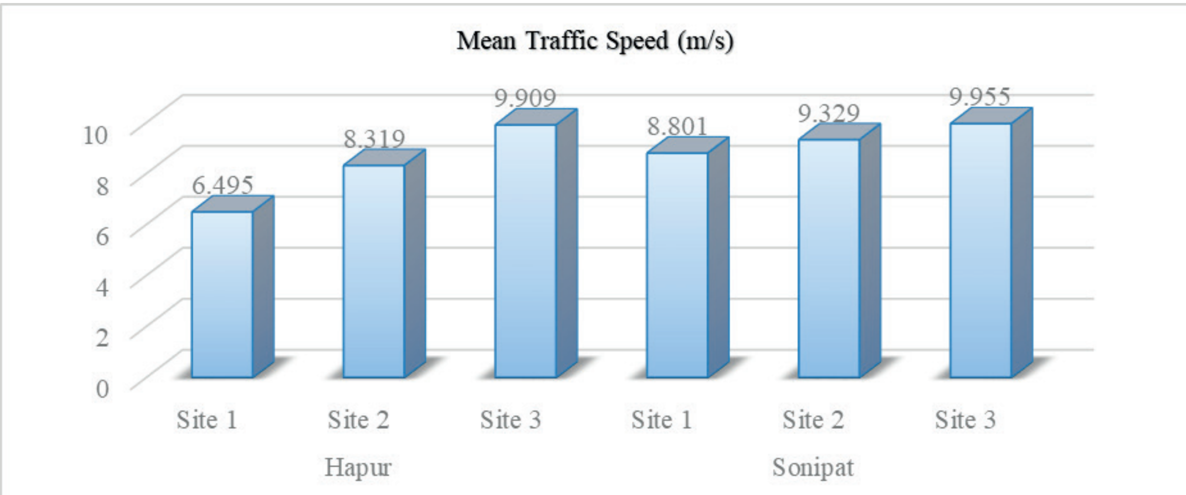

Figure 6 *Traffic mean speed (m/s)*

Table 4 *Space mean speed of car and E-rickshaw in m/s*

City	Site	Car	E-rickshaw
Hapur	Site 1	8.085	5.549
	Site 2	10.225	6.633
	Site 3	12.344	6.832
Sonipat	Site 1	10.374	6.992
	Site 2	11.560	7.713
	Site 3	11.815	8.489

6 Determination of equivalency factor of e-rickshaw

The equivalency factor of e-rickshaw was determined using the method based on the Chandra's approach and the homogeneous coefficient method and the multiple linear regression method. According to Chandra and Kumar (2003), the PCU or equivalency factor is a function of vehicle speed and area, and it may be computed as: [23].

$$PCU_e = \frac{V_c/V_{er}}{A_c/A_{er}}, \quad (2)$$

where V_c, V_{er} are the speed of car and e-rickshaw respectively, and A_c, A_{er} are the area of car and e-rickshaw respectively. Dasani et al. (2020) used the Homogeneous coefficient method for the PCU or equivalency factor determination. The equivalency factor, using the homogeneous coefficient method, can be calculated as [24].

$$PCU_e = \frac{V_c/V_{er}}{L_c/L_{er}}, \quad (3)$$

where L_c and L_{er} are the lengths of car and e-rickshaw, respectively. The only difference between the two methods is that area of a vehicle is considered in Chandra's method, and the length of the vehicle is considered in the case of the homogeneous coefficient method.

Multiple linear regression method is a direct method for estimating the PCU of a vehicle. The average speed of passenger cars is expressed based on classified traffic volumes in a form of multiple linear equation:

$$V_c = X_0 + \sum_{j=1}^{n} X_j N_j . \quad (4)$$

If a stream consists of eight different types of vehicles, then Equation (4) can be expanded as:

$$V_c = X_0 + X_c N_c + X_b N_b + X_{ar} N_{ar} + X_{er} N_{er} + + X_l N_l + X_{cy} N_{cy} + X_{bs} N_{bs} + X_{tr} + N_{tr,} \quad (5)$$

where V_c = average speed of passenger cars, N_j = volume of vehicle category "j", X_0 = intercept, X_c, X_b, X_{ar}, X_{er}, X_l, X_{cy}, X_{bs}, X_{tr} are the regression coefficients for car, bike, auto-rickshaw, e-rickshaw, light commercial vehicle, cycle, bus, truck, respectively; N_c, N_b, N_{ar}, N_{er}, N_l, N_{cy}, N_{bs}, N_{tr} are the volume of car, bike, auto-rickshaw, e-rickshaw, LCV, cycle, bus, truck respectively in the stream; n = number of vehicle categories. Coefficients are determined exercising regression technique. The PCU of a vehicle category "j" $(PCU)_j$ is estimated as:

$$(PCU)_j = \frac{x_j}{x_1}, \quad (6)$$

where x_1 is the weightage factor for the standard vehicle (car).

To utilize multiple linear regression method, the mean speed of car was regressed based on classified traffic volume for selected sites consist of car, bike, auto-rickshaw, e-rickshaw, bus, truck, cycle and LCV with the help of SPSS (Statistical Package for the Social Sciences) software. Obtained coefficients for site 1 of Hapur site and site 1 of Sonipat city are listed in Table 5. Similar procedures were employed for other sites. After obtaining the coefficients, the PCU of e-rickshaw was developed which is listed in Table 6.

After analyzing the collected data, equivalency factors of e-rickshaw, using Equations (2), (3), (5) and (6), were developed for Hapur and Sonipat cities, which are shown in Table 6. From Table 6, it is clear that multiple linear regression method does not provide accurate result as there is a significant disparity in the obtained result. On the other hand, values obtained by Chandra's method and homogeneous coefficient method are accurate comparatively. Out of all three methods, Chandra's method is the most reliable.

A comparative analysis of the three methodologies employed is shown in Figure 7. Among the three methodologies evaluated, the Chandra's method consistently produced the lowest and most stable PCU values for e-rickshaws across all selected sites, with values ranging from 0.739 to 0.917. This suggests that, under this approach, e-rickshaws are perceived as occupying relatively less road space and operating at lower speeds compared to standard vehicles. The Homogeneous Coefficient Method yielded the PCU estimates within a range of 1.093 to 1.355. In contrast, the Multiple Linear Regression Method demonstrated

***Table 5** Obtained coefficient for Equation (5)*

Hapur City: Site 1	X_0	11.075	Sonipat City: Site 1	X_0	7.124
	X_c	-.047		X_c	.056
	X_b	.005		X_b	-.007
	X_{ar}	.074		X_{ar}	.019
	X_{er}	-.080		X_{er}	.020
	X_l	-.025		X_l	.041
	X_{cy}	-.027		X_{cy}	-.063
	X_{bs}	-.220		X_b	.176
	X_{tr}	-.090		X_{tr}	.297

Table 6 *Developed Equivalency Factor of E-rickshaw*

City	Site	Chandra's method	Homogeneous coefficient method	Multiple linear regression method
Hapur	Site 1	0.739	1.093	1.702
	Site 2	0.782	1.156	2.333
	Site 3	0.917	1.355	2.736
Sonipat	Site 1	0.752	1.111	0.357
	Site 2	0.761	1.127	7.703
	Site 3	0.772	1.152	4.830

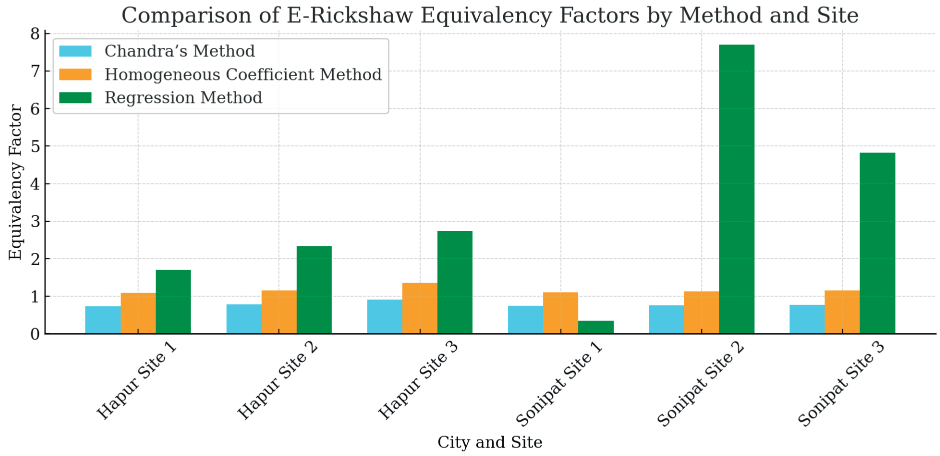

Figure 7 *Comparative analysis of developed PCU values of e-rickshaw*

Table 7 *Impact of traffic speed on equivalency factor of E-rickshaw*

City	Site	Traffic Speed (m/s)	Equivalency Factor of E-rickshaw	
			Chandra's method	Homogeneous Coefficient Method
Hapur	Site 1	6.495	0.739	1.093
	Site 2	8.319	0.782	1.156
	Site 3	9.909	0.917	1.355
Sonipat	Site 1	8.801	0.752	1.111
	Site 2	9.329	0.761	1.127
	Site 3	9.955	0.772	1.152

the greatest variability in PCU values, with estimates spanning from as low as 0.357 (Sonipat Site 1) to as high as 7.703 (Sonipat Site 2). This wide fluctuation highlights the method's high sensitivity to site-specific traffic dynamics, making it particularly responsive to local variations in flow patterns, vehicle interactions, and operational characteristics.

7 Impact of traffic speed on equivalency factor of e-rickshaw

To check the impact of traffic speed on the equivalency factor of e-rickshaw, the traffic speed and equivalency factor of e-rickshaw, as shown in Figure 6 and Table 7, respectively, were correlated, as shown in Table 7.

The obtained relationship between the equivalency factor of e-rickshaw and the mean traffic speed for Hapur and Sonipat cities is shown in Figures 8 and 9, respectively. The equivalency factor of e-rickshaw estimated using both approaches (Chandra's method and Homogeneous Coefficient method) is high for the site having a higher mean traffic speed. After analyzing the results, the models obtained between the traffic speed and equivalency factor of e-rickshaw are shown in Table 8, along with the r squared value. As the relationship between the equivalency factor and traffic speed is exponential, the equivalency factor of e-rickshaw is exponentially correlated with the traffic speed for both

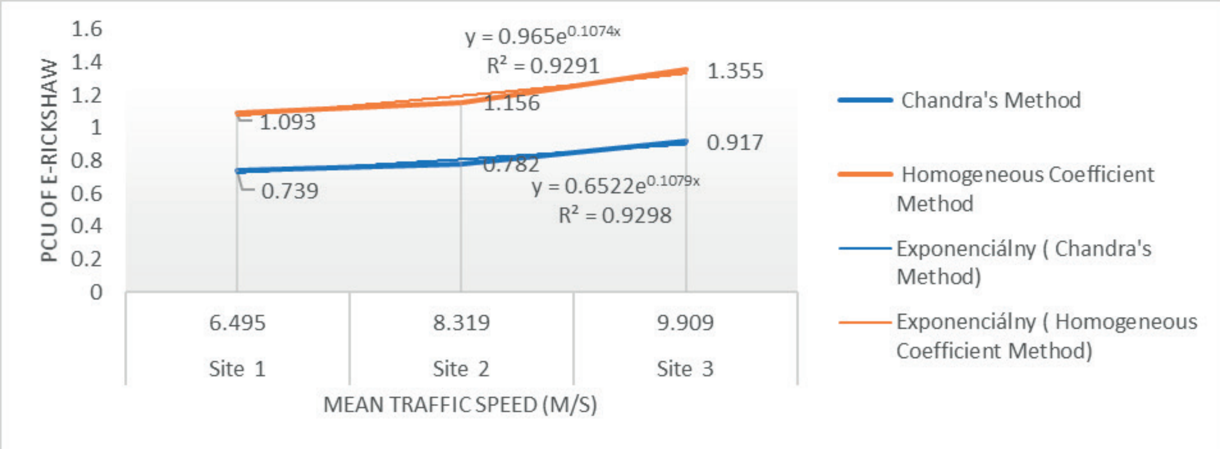

Figure 8 *Relationship between the equivalency factor of E-rickshaw and average traffic speed (m/s) for Hapur City*

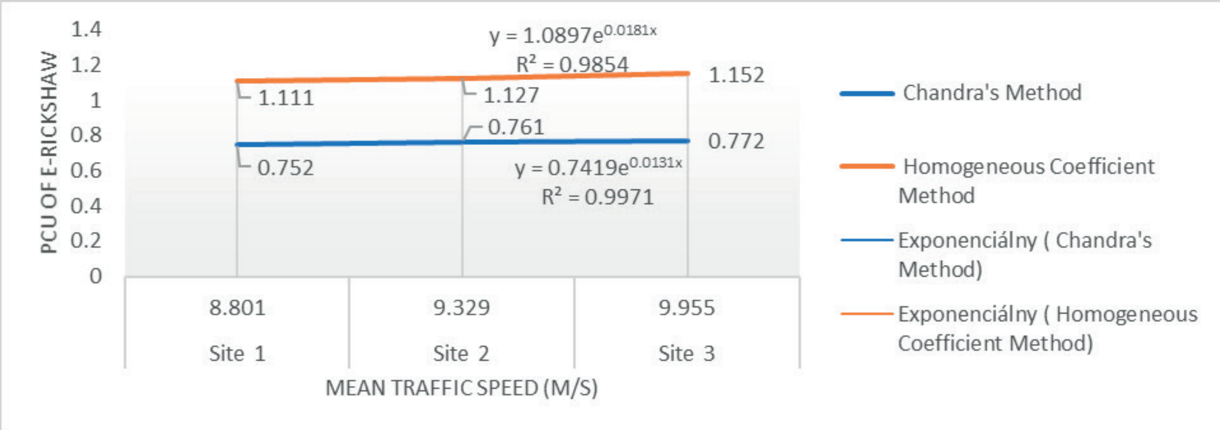

Figure 9 *Relationship between equivalency factor of E-rickshaw and mean traffic speed (m/s) for Sonipat City*

Table 8 *Obtained model for impact of traffic speed on equivalency factor of E-rickshaw*

City	Method	Obtained Model	R squared value
Hapur	Chandra's method	$y = 0.6522e^{0.1079x}$	$R^2 = 0.9345$
	Homogeneous Coefficient method	$y = 0.965e^{0.1074x}$	$R^2 = 0.9338$
Sonipat	Chandra's method	$y = 0.7419e^{0.0131x}$	$R^2 = 0.9971$
	Homogeneous Coefficient method	$y = 1.0897e^{0.0181x}$	$R^2 = 0.9855$

Abbreviations: y= equivalency factor of e-rickshaw, x= mean traffic speed (m/s)

Hapur and Sonipat cities. After analyzing the results, the models obtained between the traffic speed and equivalency factor of e-rickshaw have r squared value greater than 0.90 for each case.

8 Relation between equivalency factor of e-rickshaw and composition of e-rickshaw

Speed-based modelling was used to check the impact of the proportion of e-rickshaw ([2, 25]). According to this modelling, the speed of different vehicles can be modelled in terms of volume and speed of vehicle types as Equations (7) and (8). Later, the modelled speed can be used in Chandra's, and Homogeneous coefficient method to estimate the equivalency factor of the e-rickshaw.

$$V_c = a_{0-c} + a_{1-c}(n_c/V_c) + a_{2-c}(n_b/V_b) + a_{3-c}(n_{ar}/V_{ar}) + a_{4-c}(n_{er}/V_{er}) + a_{5-c}(n_l/V_l) + a_{6-c}(n_{cy}/V_{cy}) + a_{7-c}(n_{bs}/V_{bs}) + a_{8-c}(n_{tr}/V_{tr}), \tag{7}$$

$$V_{er} = a_{0-er} + a_{1-er}(n_c/V_c) + a_{2-er}(n_b/V_b) + a_{3-er}(n_{ar}/V_{ar}) + a_{4-er}(n_{er}/V_{er}) + a_{5-er}(n_l/V_l) + a_{6-er}(n_{cy}/V_{cy}) + a_{7-er}(n_{bs}/V_{bs}) + a_{8-er}(n_{tr}/V_{tr}), \tag{8}$$

Volume and speed of vehicle types for 15-minute intervals were interpreted from the captured videos of sites of Hapur city and used in Equations (7) and (8) for speed-based modelling to check the impact. These equations were regressed using the SPSS software, and Microsoft excel to find out the speed of cars and e-rickshaws, and then the equivalency factor of e-rickshaw was estimated. Multiple linear regression was employed in the SPSS software to model the speeds. For modelling the speed of the car, the dependent variable is the speed of the car and the independent variables are the ratio of volume and the speed of available vehicle categories respectively. Similarly, the speed of the e-rickshaw was modelled with the speed of the e-rickshaw being the dependent variable. Later, the composition of the e-rickshaw was increased and decreased, keeping the proportion of other vehicle types constant to check its impact on the equivalency factor of e-rickshaw. The observed composition of e-rickshaw on site 1, site 2, and site 3 are 11%, 18%, and 8%, respectively.

Notation: V_c and V_{er} are the modelled speed of cars and e-rickshaw, respectively; (n/V) is the ratio of volume and speed of respective vehicles, where c

Figure 10 *Impact of proportion of e-rickshaw on equivalency factor of e-rickshaw for Site 1*

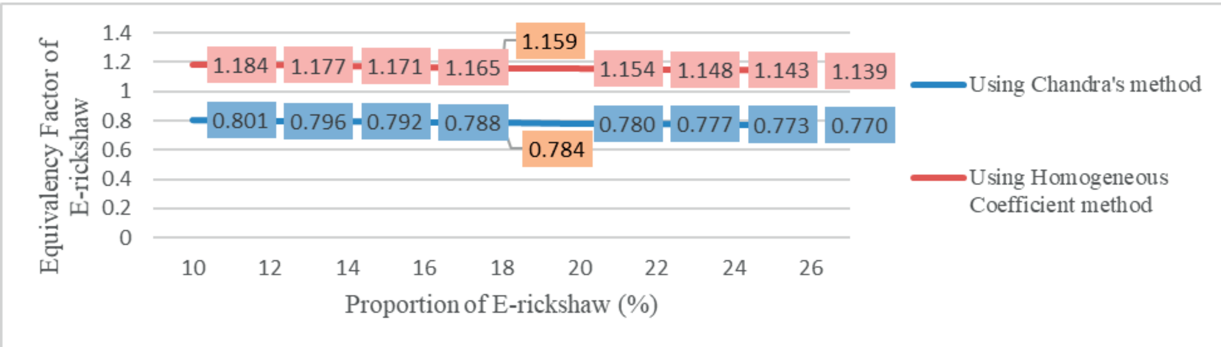

Figure 11 *Impact of proportion of e-rickshaw on equivalency factor of e-rickshaw for Site 2*

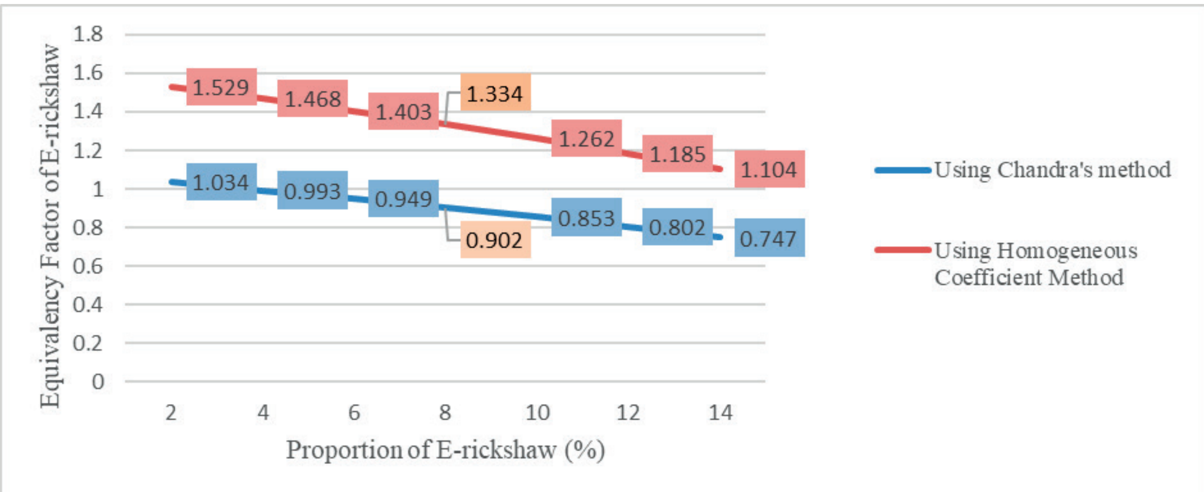

Figure 12 *Impact of proportion of e-rickshaw on equivalency factor of e-rickshaw for Site 3*

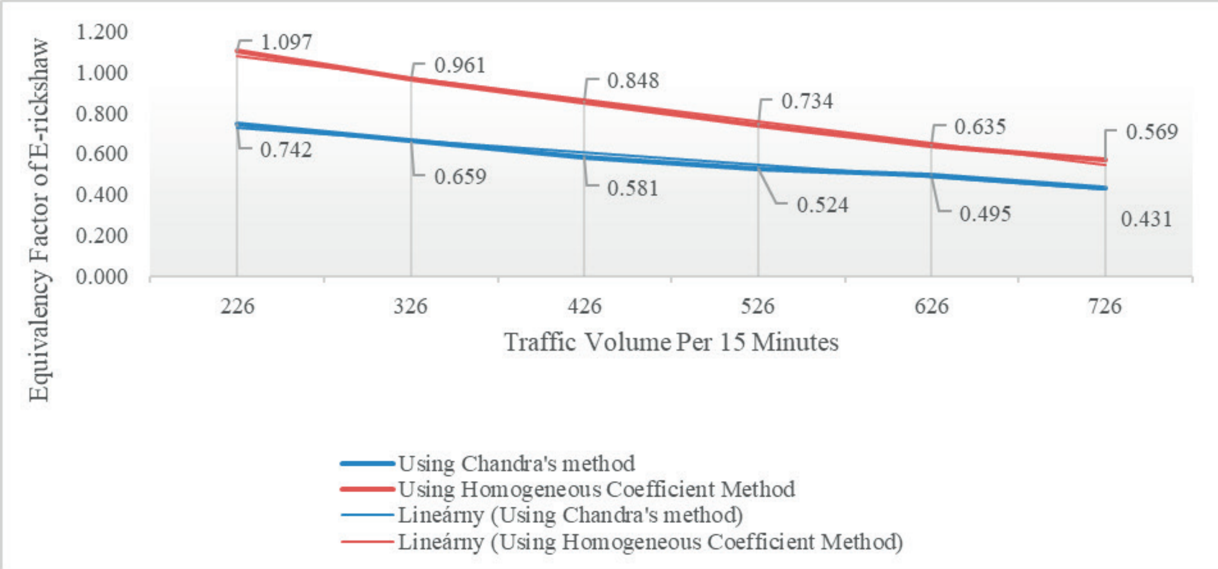

Figure 13 *Impact of traffic volume on equivalency factor of e-rickshaw for site 1 of Hapur City*

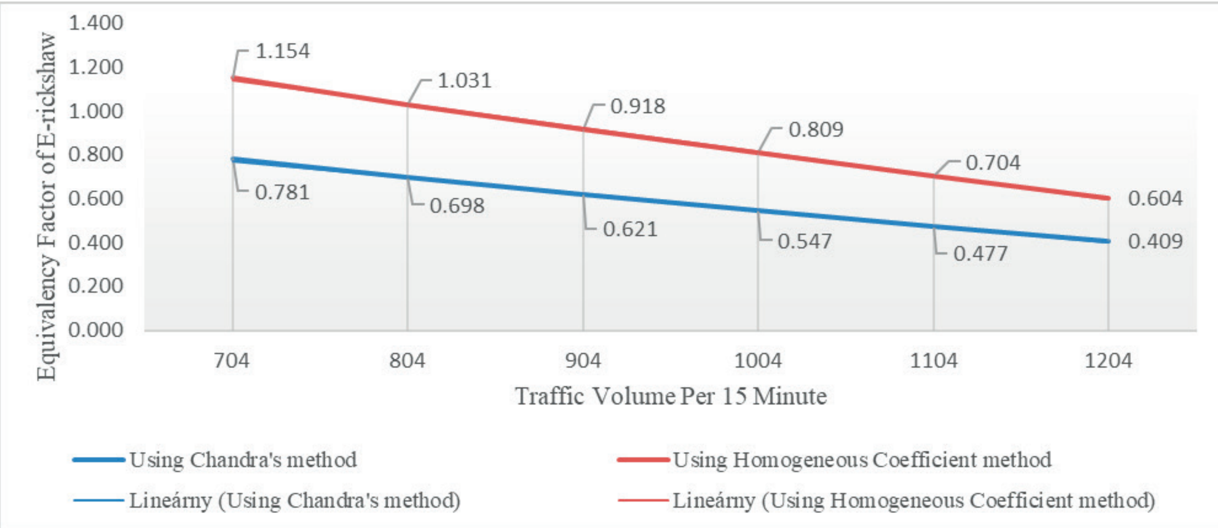

Figure 14 *Impact of traffic volume on equivalency factor of e-rickshaw for site 2 of Hapur City*

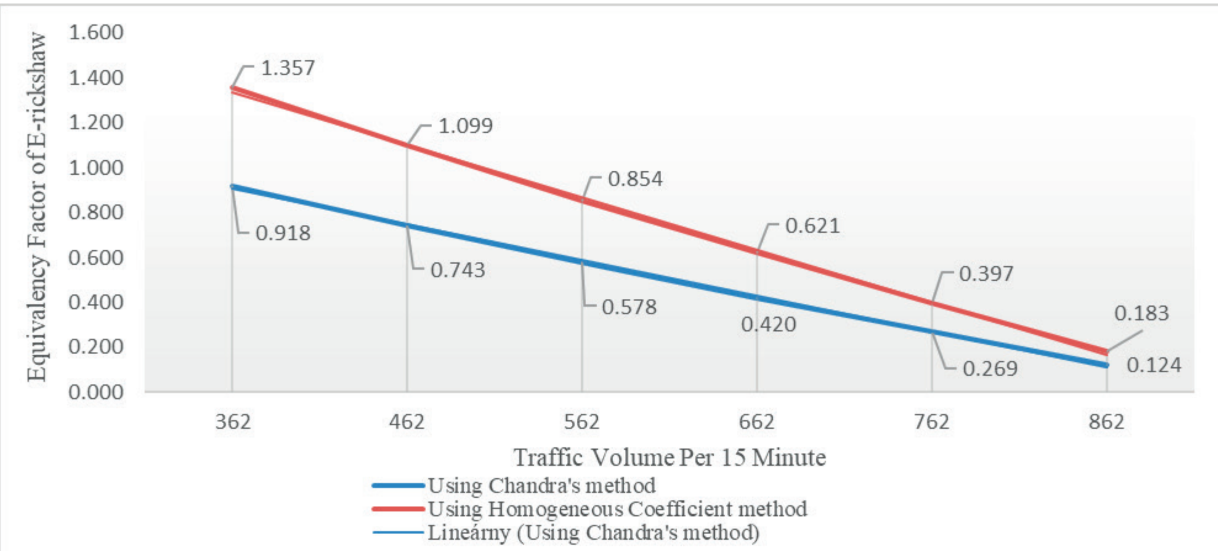

Figure 15 *Impact of traffic volume on equivalency factor of e-rickshaw for site 3 of Hapur City*

is for car, b is for bike, a_r is for autorickshaw, er is for e-rickshaw, l is for LCV, cy is for cycle, bs is for bus, and tr is for Truck. And a_0, a_1, ……., a_8 are the coefficients.

Figures 10, 11, and 12 show the impact of the composition of E-rickshaw on the equivalency factor of e-rickshaw, and it can be concluded that on increasing and decreasing the proportion of e-rickshaw keeping the proportion of other vehicles' types as constant, the equivalency factor of e-rickshaw decreases and increases respectively.

9 Impact of traffic volume on equivalency factor of e-rickshaw

To check the impact of traffic volume on equivalency factor of e-rickshaw, Equations (7) and (8) were regressed using the SPSS software and Microsoft excel. For site 1 of Hapur city, the traffic volume was increased by 100 vehicles per 15 minutes at a time from 226 vehicles per 15 minutes to 336 vehicle per 15 minutes to check the impact then from 336 to 446 vehicles per 15 minutes while keeping the composition of vehicle types' constant. Overall traffic volume was increased from 226 vehicles per 15 minutes to 726 vehicles per 15 minutes with an interval of 100 vehicles per 15 minutes in each step. Similar process was employed for site 2 and site 3. From Figures 13, 14 and 15, it is clear that when the traffic volume increases in the stream, equivalency factor of e-rickshaw decreases.

10 Conclusions and discussion

The country's traffic is of a mixed nature. To effectively analyze this mixed traffic, the concept of PCU was developed to assess various types of vehicles on a common basis. Thus, the Equivalency factor or PCE or PCU is an important parameter considered to assess a mixed traffic stream [26]. Estimating the PCE values is crucial for traffic capacity assessments, level of service measurements, signal design and synchronization, determining saturation flow rates, and creating traffic flow models. The precision of PCE values is thought to have a big impact on traffic flow analysis because of the large number of applications.

Significant research is not available for determination of the equivalency factor of e-rickshaw as e-rickshaws are a new vehicle type. In this study, equivalency factors of E-rickshaw were estimated using two methods, namely the Chandra's method and the Homogeneous coefficient method, with the help of data from three sites each from two cities, Hapur city, and Sonipat city. The videography method was employed to collect the classified traffic volume and speed data. After analyzing the data, it was found that the equivalency factor of e-rickshaw is less than 1 when estimated using the Chandra's method and is greater than 1 in the case of the homogeneous coefficient method.

The impact of traffic speed on the equivalency factor of e-rickshaw was also checked in this study, and it was found that the equivalency factor of e-rickshaw is higher on the sites having greater mean traffic speed. This effect was also checked using six sites, three sites each from Hapur city and Sonipat city. The developed models between the equivalency factor and traffic speed show that the relationship between the equivalency factor and traffic speed is exponential, i.e., the equivalency factor of e-rickshaw is exponentially correlated with the traffic speed for both Hapur and Sonipat cities. After analyzing the results, the models obtained between traffic speed and equivalency factor of e-rickshaw have r squared value greater than 0.90 for each case.

A study was conducted to analyze the impact of the composition of e-rickshaws on the speed of traffic in Hapur city. The analysis was carried out using a speed-based modelling approach. The volume and speed of each vehicle type in the traffic stream were modelled using SPSS software and Microsoft Excel. Equivalency factors for e-rickshaws were developed based on the modelled speed. The proportion of e-rickshaws was varied, while keeping the volume count of other vehicle types constant. The results showed that as the proportion of e-rickshaws increased, the value of the equivalency factor decreased, and as the proportion decreased, the value of equivalency factor increased.

A study on impact of traffic volume on equivalency factor was also conducted for sites of Hapur city. This study was also carried out using the speed-based modelling approach. To check the impact, traffic volume in the stream was increased in an interval of 100 vehicles per 15 minutes keeping the composition of different vehicle types constant. Then, the speed based equations were solved. it was found that on increasing the traffic volume, equivalency factor decreases.

11 Practical implications and recommendations

The findings of this study have several practical applications in the field of traffic engineering and urban planning. By establishing a more accurate equivalency factor for e-rickshaws, the traffic flow models can better represent their impact on road capacity and congestion levels. This is especially important in cities where the e-rickshaws form a significant part of the vehicle mix and traditional passenger car unit (PCU) values fail to capture their unique operating characteristics.

Transportation planners can use the derived equivalency factors to design the more realistic traffic simulations, optimize signal timings, and improve intersection performance. The policymakers and city authorities can also refer to these findings when formulating regulations or infrastructure plans that involve the integration or control of e-rickshaw traffic.

12 Limitations and future scope of the study

While this study sheds light on how the e-rickshaws interact with mixed traffic and how their equivalency factor can be modelled, there are a few limitations worth noting.

Data collection was confined to specific locations and time frames, which might not fully reflect the wide variability in traffic patterns. The localized traffic behaviour could have introduced some level of bias, potentially influencing the accuracy of the results. It would also be valuable to conduct similar studies in different cities, especially those with unique traffic compositions or infrastructure. Using the traffic simulations or real-time data analytics could further improve the precision of equivalency factor of e-rickshaw and help to adapt the findings to changing traffic scenarios.

To deepen the analysis, future research could make use of advanced statistical methods-like sensitivity analysis-to better understand how different factors affect the equivalency factor of e-rickshaw calculated in the study.

Acknowledgements

The authors received no financial support for the research, authorship and/or publication of this article.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] SHARMA, M., BISWAS, S. Estimation of passenger car unit on urban roads: a literature review. *International Journal of Transportation Science and Technology* [online]. 2021, **10**(3), p. 2383-298. ISSN 2046-0430, eISSN 2046-0449. Available from: https://doi.org/10.1016/j.ijtst.2020.07.002

[2] KHAN, A. A., SINGH, G. Development of PCU value of e-rickshaw on urban roads. In: *Advances in Water Resources and Transportation Engineering. Lecture Notes in Civil Engineering, vol 149*. MEHTA, Y. A., CARNACINA, I., KUMAR, D. N., RAO, K. R., KUMARI, M. (Eds.) [online]. Singapore: Springer, 2021. ISBN 978-981-16-1302-9, eISBN 978-981-16-1303-6. Available from: https://doi.org/10.1007/978-981-16-1303-6_10

[3] SRINIVASA RAO, R., GUPTA, V. S. S. R., NITESH, Y., RAO, G. V. Review on passenger car unit studies in homogeneous and heterogeneous traffic flow-a perspective. *International Journal of Civil Engineering and Technology*. 2017, **8**(8), p. 1279-1289. ISSN 0976-6308,eISSN 0976-6316.

[4] DHAMANIYA, A., BARI, C. S., PATKAR, M. Capacity analysis of urban arterial midblock sections under mixed traffic conditions. *International Journal of Intelligent Transportation Systems Research* [online]. 2022, **20**(2), p. 409-421. ISSN 1348-8503, eISSN 1868-8659. Available from: https://doi.org/10.1007/s13177-022-00298-1

[5] CHANDRA, S., KUMAR, V., SIKDAR, P. K. Dynamic PCU and estimation of capacity of urban roads. *Indian Highways*. 1995, **23**(4), p. 17-28. ISSN 0376-7256.

[6] WERNER, A., MORRALL, J. F. Passenger car equivalencies of trucks, buses, and recreational vehicles for two-lane rural highways. *Transportation Research Record*. 1977, **615**, p. 10-17. ISSN 0361-1981, eISSN 2169-4052.

[7] MINH, CH. C., MAI, T. T., BINH, T. H., SANO, K. The delay estimation under heterogeneous traffic conditions. *Journal of the Eastern Asia Society for Transportation Studies*. 2010, **8**, p. 1583-1595. eISSN 1881-1124. Available from: https://doi.org/10.11175/easts.6.1496

[8] ADAMS, C. A., ABDUL, M. ZAMBANG, M., BOAHEN, R. O. Effects of motorcycles on saturation flow rates of mixed traffic at signalized intersections in Ghana. *International Journal of Traffic and Transportation Engineering* [online]. 2015, **4**(3), p. 94-101. ISSN 2325-0062, eISSN 2325-0070. Available from: https://doi.org/10.5923/j.ijtte.20150403.03

[9] RAO, R. S., YADAV, N. Determination and comparison of PCU on urban roads under mixed traffic conditions - a case study. In: Conference Urbanization Challenges in Emerging Economies: proceedings [online]. 2018. Available from: https://doi.org/10.1061/9780784482025.064

[10] TIWARI, G., FAZIO, J., PAVITRAVAS, S. Passenger car units for heterogeneous traffic using a modified density method. In: 4th International Symposium on Highway Capacity: proceedings. 2000. p. 246-257.

[11] HUBER, M. J. Estimation of passenger - car equivalents of trucks in traffic stream. *Transportation Research Record*. 1982, 869, p. 60-70. ISSN 0361-1981, eISSN 2169-4052.

[12] BARMAN, S., DEVI, N. S., BISWAS, S. Determining passenger car unit for e rickshaw on divided Indian urban roads. *Journal of The Institution of Engineers (India): Series A* [online]. 2025. ISSN 2250-2149, eISSN 2250-2157. Available from: https://doi.org/10.1007/s40030-025-00890-0

[13] KHAN, A. A., DASS, S. Revisiting PCU values of various vehicles in mixed traffic conditions: estimation and comparison. *Communications - Scientific Letters of the University of Zilina* [online]. 2025, **27**(2), p. D76-D89. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2025.025

[14] KALOGO, E., COSTA, D. G. N. Determining of appropriate passenger car unit values due to a change in effective width of roadway. *Engineering and Technology Journal* [online]. 2024, **09**(05), p. 4172-4178. eISSN 2456-3358. Available from: https://doi.org/10.47191/etj/v9i05.38

[15] VIJAY, B. G., RAJENDRAKHATAVKAR Comparative study of methods used for a capacity estimation on two lane undivided national highways. *Journal of Traffic and Transportation Engineering* [online]. 2019, **7**(1). ISSN 2325-0062, eISSN 2325-0070. Available from: https://doi.org/10.17265/2328-2142/2019.01.004

[16] HORDOFA TULLU, H., TUCAY QUEZON, E. Determination of passenger car unit for urban roads: a case study in Addis Ababa. *American Journal of Construction and Building Materials* [online]. 2021, **5**(2), p. 57-63. ISSN 2640-0022, eISSN 2640-0057. Available from: https://doi.org/10.11648/j.ajcbm.20210502.13

[17] BISWAS, S. CHAKRABORTY, S. CHANDRA, S., GHOSH, I. Kriging-based approach for estimation of vehicular speed and passenger car units on an urban arterial. *Journal of Transportation Engineering, Part A: Systems* [online]. 2017, **143**(3). ISSN 2473-2907, eISSN 2473-2893. Available from: https://doi.org/10.1061/JTEPBS.0000031

[18] PATKAR, M., DHAMANIYA, A. Influence of nonmotorized vehicles on speed characteristics and capacity of mixed motorized traffic of urban arterial midblock sections. *Journal of Transportation Engineering, Part A: Systems* [online]. 2020, **146**(4). ISSN 2473-2907, eISSN 2473-2893. Available from: https://doi.org/10.1061/JTEPBS.0000325

[19] SEKHAR, C. R., NATARAJU, J., VELMURUGAN, S., KUMAR, P., SITARAMANJANEYULU, K. Free flow speed analysis of two lane inter urban highways. *Transportation Research Procedia* [online]. 2016, **17**, p. 664-673. ISSN 2352-1457, eISSN 2352-1465. Available from: https://doi.org/10.1016/j.trpro.2016.11.121

[20] MONDAL, S. CHAKRABORTY, S., ROY, S. K., GUPTA, A. Estimation of passenger car unit for heterogeneous traffic stream of urban arterials: case study of Kolkata. *Transportation Letters* [online]. 2017, **15**(10), p. 1276-1288. ISSN 1942-7867, eISSN 1942-7875. Available from: https://doi.org/10.1080/19427867.2017.1293313

[21] MARDANI, N. M., CHANDRA, S., GHOSH, I. Passenger car unit of vehicles on undivided intercity roads in India. *Procedia Computer Science* [online]. 2015, **52**, p. 926-931. eISSN 1877-0509. Available from: https://doi.org/10.1016/j.procs.2015.05.167

[22] PAPER, O. S., LANKA, S., OPTIMIZATION, L., LANKA, S. Passenger car units for different midblock sections in Sri Lanka under mixed traffic condition. *Journal of Applied Engineering Science* [online]. 2023, **21**(2), p. 375-383. ISSN 1451-4117. Available from: https://doi.org/10.5937/jaes0-36600

[23] CHANDRA, S., KUMAR, U. Effect of lane width on capacity under mixed traffic conditions in India. *Journal of Transportation Engineering* [online]. 2003, **129**(2), p. 155-160. ISSN 2473-2907, eISSN 2473-2893. Available from: https://doi.org/10.1061/(ASCE)0733-947X(2003)129:2(155)

[24] DASANI, Y. R., VALA, M., PATEL, B. Estimation of dynamic equivalency factor under heterogeneous traffic condition on urban arterial road - a case study of Porbandar city. In Transportation Research. Lecture Notes in Civil Engineering, vol 45. MATHEW, T., JOSHI, G., VELAGA, N., ARKATKAR, S. (Eds.) [online]. Singapore: Springer, 2020. ISBN 978-981-32-9041-9, eISBN 978-981-32-9042-6, p. 465-474. Available from: https://doi.org/10.1007/978-981-32-9042-6_37

[25] DHAMANIYA, A., CHANDRA, S. Conceptual approach for estimating dynamic passenger car units on urban arterial roads by using simultaneous equations. *Transportation Research Record: Journal of the Transportation Research Board* [online]. 2016, **2553**(1), p. 108-116. ISSN 0361-1981, eISSN 2169-4052. Available from: https://doi.org/10.3141/2553-12

[26] METKARI, M., BUDHKAR, A., KUMAR MAURYA, A. A Review of passenger car equivalence for Indian conditions. Conference on Emerging Frontiers in Technology For Rural Area EFITRA 2012: proceedings. 2012.