# Effect of Heavy Vehicles on PCU and Speed-Flow Characteristics on Heterogeneous Traffic on Urban Arterial Road

**Amit A Amin[1], Dr.L.B. Zala[2],**

[1]*Ph.D Research Scholar, GTU Chandkheda, Ahmedabad*
[2] *Retired Professors, Dept. of Civil Engineering, BVM Engineering college, Gujarat, India*

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**Abstract** -*Urban roads play a crucial role in the infrastructure of metropolitan cities, especially in developing countries like India, where these cities significantly contribute to national development. A well-planned and efficiently functioning road network is essential for the sustainable growth of any urban area. Urban roads are typically classified into Arterial, Sub-Arterial, Collector, and Local (Street) roads. Among these, Arterial roads are of prime importance as they connect major state and national highways and often serve as city bypasses. Understanding the traffic flow characteristics of Arterial roads is, therefore, essential for urban transportation planning. This study focuses on the SP Ring Road in Ahmedabad, selected as the representative Arterial Road stretches. Two midblock segments of 60 meters each were identified for detailed analysis: one near the Vastral and the other near the Odhav. Traffic flow and speed data were collected through video recordings, while road inventory and supplementary data were obtained through field surveys. The video data was analysed using Avidemux software and processed using Microsoft Excel to extract vehicle composition, traffic volume, and speed information. Vehicles were categorized with DPCU into Two-Wheelers(0.28), Three-Wheelers(0.79), Cars, SUVs (Big Cars) (1.49), Light Commercial Vehicles (LCVs)(2.1), Heavy Commercial Vehicles (HCVs)(1.6), and Multi-Axle Vehicles (MAVs)(5.76).Speed-flow-density relationships were developed to understand the traffic flow characteristics, $R^2$ value ranges from 0.3277 to 0.9327, the estimated road capacity was found to be 4475 PCU/hour. Mathematical speed models were developed and validated for all vehicles.*

***Key Words*: Speed-Flow, Avidemux, DPCU**

## 1.INTRODUCTION

The transport system plays a major role in developing countries because it links goods and passengers to the city. In the transport system, road transport plays a major role than any other mode of transportation. Most passengers (87%) and goods (60%) travel through road transportation. In a developing country like India where people have very much use of road transportation than any other transportation facility. Because of the major use of road transportation, in India, road transportation takes the share of 6.0 to12 %4% of GDP. India has a roadway network of 63 lakh kilometre of roads as of 31 March 2025. The roadway network of India takes up 85 percent of passenger traffic. In India, the roadway system has mainly two types of roads, the first category is rural roads, and the second category is urban roads. Now, these two categories contain different types of roads like expressways, national highways, state highways, district roads, and village roads. Now in the road transport system, the national highway takes a 2.13% share of total roads, similarly, the state highways have a 3% share, the district roads have a 10.17% share, the rural roads have 72.97% share, urban roads have 8.76% share and last the project roads have 5.71% share of roads.

### 1.1 Objectives of the Study

This study has been concentrated on estimation of dynamic passenger car unit (DPCU) values for different categories of vehicles under heterogeneous traffic conditions on mid-block stretches under arterial of Sardar Patel Ring Road (SPRR) of Ahmedabad city also to analyses the variation of DPCU with respect to traffic stream parameters. Two stretches of SPRR were selected based on variation of variation criterion such as wide variation in proportions of different categories of vehicles, should be free from the effects of road side frictions, access point of intersections parking facilities, bus stop curvature, gradient, and median opening. A straight road mid-block stretches of the selected urban roads has been selected for data collection purpose.

The scope of this study is limited to analysing traffic composition, traffic volume, and vehicle speeds using the videography-based data collection method. Using videographic recordings, essential traffic parameters such as speed, flow, and density for various classes o,f vehicles are extracted. These parameters are utilized to develop the speed–flow–density relationships for the selected midblock stretches. Furthermore, the capacity of the roadway is estimated from the speed–flow curve, with analysis performed using Microsoft Excel.

### 1.3 Research Methodology

In the present study Chandra methods has been adopted for evaluate DPCU value of different categories of vehicles. In mix traffic stream, speed of the vehicles is mostly affected among other traffic macroscopic parameter. In Chandra method speed is considered as basic parameter for determination of DPCU, in this study small car is considered as the standard design vehicles.

## 2. Literature review

Various research has used different methods for passenger car unit and many approaches for modelling the speed-flow characteristics of different classes of vehicles on highways.[1] studied the effect of influencing parameters like gradient, lane width, shoulder width, traffic composition, directional split, slow-moving vehicles, and pavement surface conditions on the capacity of- lane road under mixed traffic conditions is evaluated, and adjustment factors for each condition are proposed. decreases with mixed traffic proportion but vehicular capacity increases for the same vehicular proportion. [2] The objective of the study is to analyse the analysis of estimated highway level of service concerning drivers' characteristics and traffic conditions. The field survey is carried out for traffic data collection at the same time the drivers were asked questions related to the traffic condition. The study revealed that the driver's age, gender, driving experience, etc., affect the v/c ratio on the perceived level of service. The plot of perceived level of service against v/c gives results that the relationship between perceived level of service and traffic condition has a linear form with large differences in slopes and breakpoints. The researchers suggest that drivers perceive no more than two or three levels of traffic conditions. Also, the study confirms that the low tolerance drivers appear to be level of service A to B and high tolerance drivers appear to be level of service D to E. [3] studied the variation of Passenger Car Unit (PCU) values with traffic volume and composition on eight urban arterial roads. Vehicles were grouped into five categories, and simultaneous equations were developed to estimate individual vehicle speeds. These equations were used to analyze how PCU values change with varying traffic volumes. The PCU values derived from the equations were validated against field data, and statistical tests confirmed no significant difference between the two, supporting the accuracy of the model. [4] This paper focuses on the area occupancy of vehicles in mixed traffic conditions. The passenger car unit is estimated with a different method for the eight-lane divided urban midblock stretches. For this study three methods are used for estimation the first method is to estimate the pcu using TRRL, the second method is based on the speed-area ratio and the third one is the occupancy based on the matrix solution. So, the study recommends that the area occupancy method for PCU estimation is used when heterogeneous traffic is available and all the vehicles have different static characteristics. For more understanding of traffic flow, the Wiedemann 74 VISSIM model is used. And the study shows that the newly developed area occupancy based on matrix solution can helfull in heterogeneous traffic conditions. [5] analyzing traffic characteristics, capacity, level of service, and signal design. The study reviewed various PCU estimation methods such as Speed Modeling (Chandra's method), Headway, Space Occupancy, Delay-Based, Multiple Linear Regression, Simulation, and others. It emphasized that traditional methods used in developed countries may not suit mixed traffic conditions found in India. The paper compared these methods, discussing their advantages, limitations, and challenges in application under heterogeneous traffic. Hareshkumar D. Golakiya and Ashish Dhamaniya (2019) studied the impact of pedestrian crossings on vehicle speed, traffic flow, and capacity at urban midblock sections. The research highlights that in India, pedestrians often cross roads unsafely, affecting traffic movement and increasing the risk of collisions. Data was collected from 15 six-lane midblock sections across six major cities New Delhi, Jaipur, Chandigarh, Noida, Surat, and Vadodara. The study developed speed–flow–density relationships and speed models, showing how pedestrian crossing flow significantly reduces stream speed and disrupts traffic flow. The findings stress the need for improved pedestrian facilities to enhance road safety and traffic performance. Manish Patkar and Ashish Dhamaniya (2020) investigated the impact of non-motorized vehicles (NMVs) on traffic stream characteristics at six urban arterial midblock sections. Using videography, speed–flow data was collected to develop and validate traffic speed models. The study found that an increase in NMV share leads to more disorganized traffic and significantly reduces stream speed and capacity. Specifically, road capacity decreased by 3.6% to 35.82% as NMV proportion increased from 5% to 25%. In the past, various techniques have been adopted to estimate PCU of vehicles. Werner and Morall (1976) proposed utilizing a headway ratio method to determine PCU values at low levels of service. Biswas (2021) examined the methods adopted for estimating PCU and evaluated the advantages and limitations of each approach. Passenger Car Unit (PCU) serves as a comparative weighting factor assigned to different vehicle categories' traffic volumes to address the diversity in mixed traffic scenarios. Numerous studies have been conducted to estimate PCUs for various vehicle categories. Some researchers have proposed fixed PCU values, while others have recognized the dynamic nature of PCUs. These studies have also explored how PCUs vary with factors such as traffic characteristics and road geometry. The review reveals that PCUs recommended in the literature are often tailored to specific regions due to variations in traffic patterns and driving norms among nations, leading to significant inconsistencies in outcomes. These disparities not only exist in the range of PCUs but also in how they fluctuate with different influencing factors. This study offers a comprehensive overview of research findings regarding PCU estimation on urban roads. Emer et al. (2021) initiated the study to establish the PCU values that cater to the local setting. This study was focused to estimate the PCU values of multilane highway in Addis Ababa city and determining the influence of traffic volume and width of road on the value of PCU. In this study, dynamic PCU method was adopted to determine the PCU values and linear regression analysis was performed for model development. The study result indicates that as the traffic volume and carriageway width increase, the PCU value also increases. It was also found that PCU values showed higher than those provided by highway capacity manual (HCM). Hence the PCU values obtained are reflecting the existing condition in the locality.

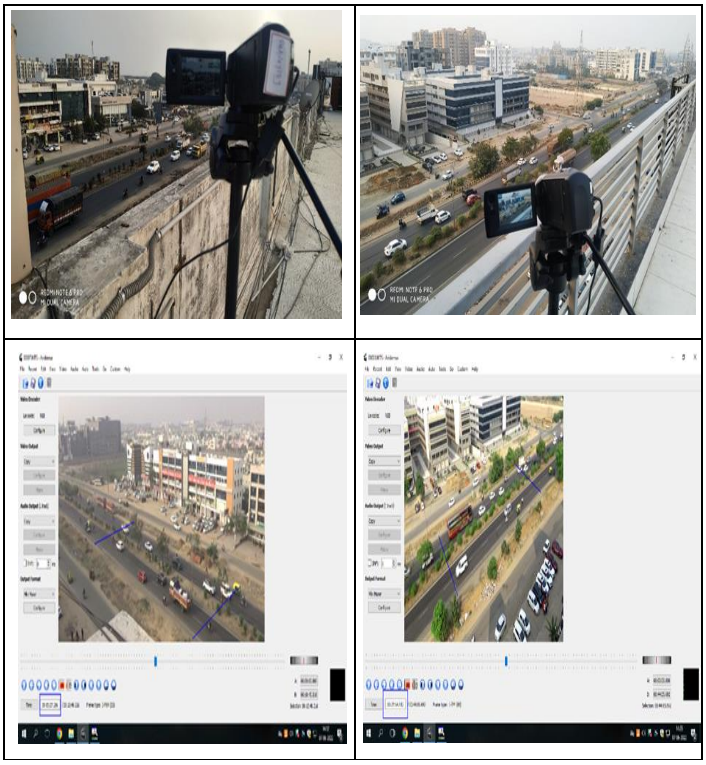


*Figure 1 Selected stretches of the Sardar Patel ring road and AVIDEMUX Screenshot*

## 3. Data Collection and Data Extraction

In this study, traffic data was collected from two stretches of the Sardar Patel Ring Road in Ahmedabad, mainly near Vastral and Odhav. A 60 metre straight stretch was selected in each area, avoiding intersection, roadside stalls, and curves to ensure accurate results. These roads were on flat terrain and had mixed traffic. Sardar Patel Ring Road of Ahmedabad city under ideal roadway and weather conditions. All the locations on level terrain have 7.5 m pavement width and 1.1 m paved the shoulders. Data collection was conducted during day time using the videography technique. Traffic flow and speed data were collected 2 hours in the morning 9:00 a.m. to 11:00 a.m. and 2h in the evening 4:00 p.m. to 6:00 p.m. in the winter season using video recording techniques and road inventory surveys carried out manually during conditions of good visibility. Video-recording techniques were used to capture accurate data at a rate of 1/25 At Vastral, the camera was placed on a residential building terrace, and at Odhav, on a commercial building. Longitudinal trap of 60 metres in length was made on the road surface for measuring the speed. The video cameras were positioned on both sides for up and down vehicle movement in such a way on top of high-rise buildings that each vehicle can be easily tracked throughout the entire trap, especially at the entry and exit points on both sides The number of vehicles passing through the stretch was counted for each lane and direction. Speed was calculated by noting the time when the front bumper of a vehicle crossed the start and end points of the stretch. Initially, data was collected in 1-minute intervals, but it was later changed to 5-minute intervals for better accuracy. Vehicles were classified into categories such as two-wheelers, three-wheelers, cars, SUVs, light commercial vehicles (LCVs), heavy commercial vehicles (HCVs), and multi-axle vehicles (MAVs). This method provided accurate measurements of speed, volume, and vehicle types under mixed traffic conditions on the SP Ring Road. Data extraction was done manually by playing the video in the laboratory on a projector screen for the selected locations. Consequently, traffic volume, composition, vehicular speed, 85th percentile speed of each category, and time headway form the collected video data.

## 4. Traffic Volume Count Survey

Analysis of the percentage of vehicle traffic composition gives an idea of the proportion of a wide variety of vehicles. The study shows that two-wheelers average (34%) both LHS and RHS and car both side 27.5%and 29% , i.e., motorcycles, have the highest percentage in the traffic stream, trucks have the lowest percentage in the traffic stream, and the percentage of cars shows slight variation in volume of traffic. All these traffic distributions Average percentage composition of both stretches, LHS and RHS, shown in Table-1, indicate significant differences in vehicle behaviour across the two stretches. Understanding these variations can help in developing targeted traffic management strategies to improve flow and safety on the roads.

Table 1 Percentage Average Vehicles Composition both stretches

| Sr No | Vehicle type | LHS | RHS |
|---|---|---|---|
| 1 | 2W | 34 | 34 |
| 2 | 3W | 11.5 | 13 |
| 3 | Car | 27.5 | 29 |
| 4 | SUV | 10.5 | 8 |
| 5 | LCV | 6 | 6 |
| 6 | HCV | 7 | 7 |
| 7 | MAV | 3.5 | 3 |

### 4.1 Speed parameters

The speed of each vehicle of all categories was calculated by using travel time and length of stretch. The spot speed is usually measured by measuring time taken by vehicle to traverse a fixed distance less than 90m (Mathew, 2019). The PCU factor is based on the mean speed values of different vehicle classes. This is calculated by dividing the mean speed value of passenger cars by the mean speed value of any vehicle class. The average speed of different vehicle categories at different both stretches left and right carriageway of highway is presented in Table 2 and 3.

The speed data collected from both Vastral and Odhav stretches shows noticeable variation across vehicle types and directions. Two-wheelers recorded the highest mean speed, with 46.0 km/h on the left carriageway and 43.5 km/h on the right. Three-wheelers averaged 33.0 km/h (left) and 31.0 km/h (right), showing more variability in speed. Cars and SUVs had higher average speeds, with cars reaching 49.5 km/h (left) and 51.0 km/h (right), while SUVs averaged 49.0 km/h (left) and 45.0 km/h (right). Light commercial vehicles (LCVs) showed a drop in speed on the right side (36.5 km/h) compared to the left (42.5 km/h). Buses maintained similar speeds on both sides, around 38–39.5 km/h, but with high-speed variations. Among multi-axle vehicles, speeds ranged between 32.5–40.0 km/h on the left and 34.0–38.0 km/h on the right. Generally, heavier vehicles such as 3-axle and 4-axle trucks, and semi-trailers, showed lower mean speeds and higher variations, especially on the right carriageway. This data highlights that lighter vehicles tend to move faster, and there's more speed variability in right-side traffic, possibly due to overtaking or lane usage patterns.

Table 2 Average speed individual vehicles of both the stretches Left carriageway

| Vehicle Type | Left Carriageway Speed(kmph) | | | |
|---|---|---|---|---|
| | Mean | Max | Min | Std.Dev |
| 2w | 46.0 | 53.5 | 33.5 | 4.5 |
| 3w | 33.0 | 52.0 | 18.0 | 7.9 |
| Car | 49.5 | 59.5 | 35.0 | 2.5 |
| SUV | 49.0 | 72.5 | 24.0 | 10.0 |
| LCV | 42.5 | 67.0 | 29.0 | 9.6 |
| BUS | 38.0 | 64.5 | 24.0 | 10.9 |
| 2A4T | 35.5 | 53.5 | 26.0 | 6.6 |
| 2A6T | 44.0 | 54.0 | 26.0 | 6.5 |
| 3A10T | 40.0 | 56.5 | 28.5 | 8.1 |
| 4A12T | 38.0 | 58.0 | 24.0 | 8.8 |
| 5A14T | 35.0 | 53.0 | 25.0 | 7.3 |
| ST-14T-4A | 33.0 | 53.5 | 24.0 | 7.7 |
| ST-18T-2AT | 36.5 | 43.5 | 27.0 | 4.5 |
| ST-18T-3AT | 37.5 | 38.0 | 26.0 | 5.6 |
| ST-22T-3AT | 32.5 | 41.0 | 28.5 | 4.7 |

Table 3 Average speed individual vehicles of both the stretches Right carriageway

| Vehicle Type | Right Carriageway Speed(kmph) | | | |
|---|---|---|---|---|
| | Mean | Max | Min | Std.Dev |
| 2w | 43.5 | 56.5 | 23.0 | 6.9 |
| 3w | 31.0 | 54.0 | 15.5 | 9.9 |
| Car | 51.0 | 61.0 | 33.0 | 4.7 |
| SUV | 45.0 | 62.5 | 21.0 | 8.2 |
| LCV | 36.5 | 55.5 | 18.0 | 8.5 |
| BUS | 39.5 | 61.5 | 20.0 | 11.2 |
| 2A4T | 35.5 | 48.0 | 30.5 | 3.7 |
| 2A6T | 38.0 | 54.0 | 25.0 | 11.3 |
| 3A10T | 37.5 | 57.5 | 18.5 | 9.7 |
| 4A12T | 36.0 | 57.5 | 23.0 | 8.2 |
| 5A14T | 34.5 | 49.0 | 20.5 | 6.5 |
| ST-14T-4A | 34.0 | 57.0 | 23.0 | 8.3 |
| ST-18T-2AT | 36.0 | 53.5 | 21.0 | 6.7 |
| ST-18T-3AT | 38.0 | 39.5 | 31.5 | 4.4 |
| ST-22T-3AT | 34.0 | 43.0 | 28.5 | 3.5 |

### 4.2 Frequency Distribution of speed of the different categories of vehicles

Tabl e 4 and 5 and figure 2 shows the frequency distribution of vehicle speeds on both stretches of the SP Ring Road reveals clear differences across vehicle types. Two-wheelers and cars show the highest speeds, with 98th percentile speeds reaching up to 57.5 km/h and 60–61 km/h respectively. Their median speeds are also high, around 46.0 km/h for two-wheelers and 49.5–51.0 km/h for cars, indicating consistent and faster movement. SUVs and LCVs also travel at relatively high speeds but show a wider range between their 15th and 98th percentile speeds, pointing to more variable driving patterns. Three-wheelers, buses, and light commercial vehicles fall into the moderate speed category, with median speeds between 31.0 and 42.5 km/h, and lower percentiles dropping to 21–28 km/h. This suggests these vehicles often move slowly, possibly due to traffic conditions or road sharing with heavier vehicles. Heavy trucks and trailers, such as multi-axle and semi-trailer types, are the slowest group, with median speeds mostly between 29.0 and 38.0 km/h, and minimum percentiles often below 30 km/h. In general, the left carriageway supports slightly higher speeds across most vehicle types compared to the right, especially for fast-moving vehicles like cars and two-wheelers. Overall, the data reflects that lighter vehicles travel faster and more steadily, while heavier vehicles move slower with greater speed variation. These findings highlight the importance of proper lane management, especially in mixed-traffic urban roads, to maintain smoother and safer traffic flow.

Table 4 Average Frequency Distribution for both the stretches Left Carriageway Speed(kmph)

| Vehicle Type | Left Carriageway Speed(kmph) | | | |
|---|---|---|---|---|
| | 98th | 85th | 50th | 15th |
| 2w | 55.5 | 50.5 | 46.0 | 41.5 |
| 3w | 49.5 | 41.5 | 33.0 | 25.0 |
| Car | 60.5 | 55.5 | 49.5 | 44.5 |
| SUV | 70.0 | 59.5 | 49.0 | 39.0 |
| LCV | 62.5 | 53.0 | 42.5 | 32.5 |
| BUS | 60.0 | 49.0 | 38.0 | 26.0 |
| 2A4T | 49.5 | 43.0 | 35.5 | 29.0 |
| 2A6T | 57.5 | 51.0 | 44.0 | 37.5 |
| 3A10T | 56.5 | 48.0 | 40.0 | 31.5 |
| 4A12T | 56.0 | 47.0 | 38.0 | 29.5 |
| 5A14T | 50.0 | 42.5 | 35.0 | 27.5 |
| ST-14T-4A | 47.5 | 40.5 | 33.0 | 25.0 |
| ST-18T-2AT | 40.5 | 36.5 | 33.0 | 28.0 |
| ST-18T-3AT | 43.0 | 37.5 | 33.5 | 27.5 |
| ST-22T-3AT | 39.0 | 24.5 | 29.0 | 25.0 |

Table 5 Average Frequency Distribution for both the stretches Right Carriageway Speed(kmph)

| Vehicle Type | Right Carriageway Speed(kmph) | | | |
|---|---|---|---|---|
| | 98th | 85th | 50th | 15th |
| 2w | 57.5 | 50.5 | 43.5 | 36.5 |
| 3w | 51.0 | 41.5 | 31.0 | 21.0 |
| Car | 61.0 | 56.0 | 51.0 | 46.0 |
| SUV | 61.5 | 53.5 | 45.0 | 36.0 |
| LCV | 54.5 | 45.5 | 36.5 | 28.0 |
| BUS | 61.5 | 50.5 | 39.5 | 27.0 |
| 2A4T | 43.0 | 39.5 | 35.5 | 31.5 |
| 2A6T | 61.5 | 50.0 | 38.0 | 26.5 |
| 3A10T | 57.0 | 47.5 | 37.5 | 27.5 |
| 4A12T | 52.5 | 44.5 | 36.0 | 27.5 |
| 5A14T | 48.0 | 41.5 | 34.5 | 26.0 |
| ST-14T-4A | 51.0 | 43.0 | 34.0 | 26.0 |
| ST-18T-2AT | 46.0 | 39.0 | 36.0 | 25.5 |
| ST-18T-3AT | 43.5 | 39.0 | 38.0 | 30.0 |
| ST-22T-3AT | 40.0 | 36.5 | 32.0 | 28.5 |

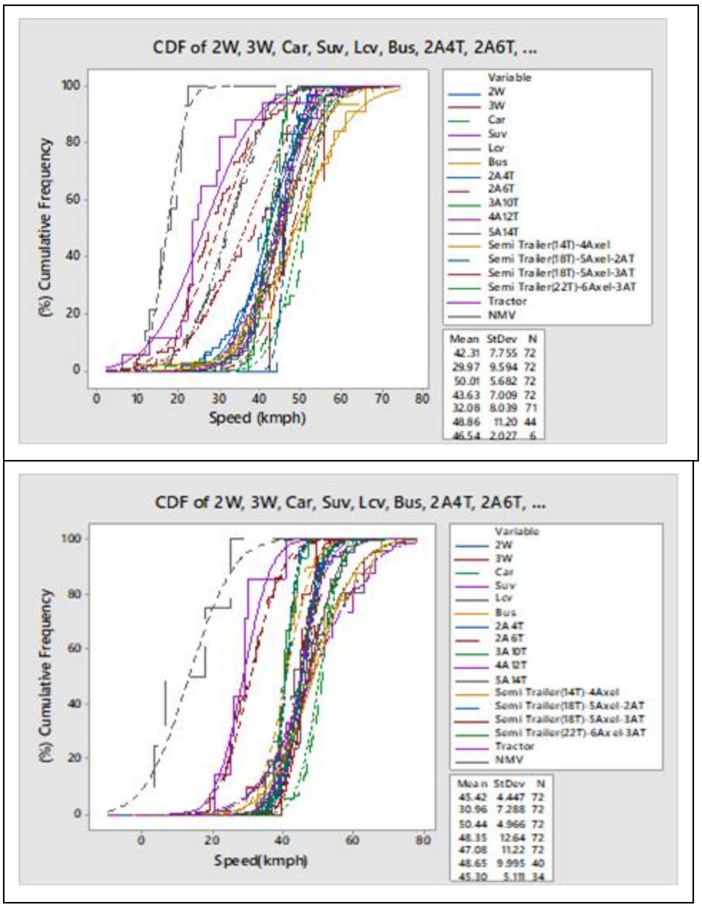



*Figure 2 Cumulative frequency distribution curve*

3PCU Estimation

In mixed traffic condition flow changes with changing the speed of vehicles of each category also the different kind of vehicles affects traffic flow differently. This change may affect PCU also because in the mixed traffic condition the different categories of vehicles like two-wheelers, auto-rickshaw(three-wheeler), cars, SUVs (big cars), Light commercial vehicles, Buses, Heavy commercial vehicles like two axel and three axel trucks, Multi axel vehicles like four axel ruck, five axel truck, a truck with trailer (Tractor-trailer truck), etc. These vehicles move at different speeds in traffic flow and they also have different physical dimensions. These factors affect PCU very much because small size vehicles like two-wheeler, auto-rickshaw, and small cars have more speed compared to larger size vehicles like trucks and because of their small size these vehicles also have more mobility in traffic. But on the other hand, large vehicles like truck, buses, and MAVs requires more area and they also move slowly compared to small size vehicle in traffic. Because of all of these conditions PCU estimation is required. The precise or accurate PCU estimation gives a better understanding of traffic flow characteristics and it also helps develops the different traffic management facilities. So, for PCU estimation all traffic flow parameters should be considered like stream speed, vehicle composition, capacity, etc. So, Chandra (2004) gives the idea of dynamic PCU values for different categories of vehicles for different traffic flow conditions. So, to estimate the dynamic PCU values following equation1 is used.

$$PCU = [Vc/Vi]/[Ac/Ai] \quad (1)$$

In Which, Vc= Average speed of the standard car, Vi= Average speed of the subject vehicle Ac= Projected area of the standard car, Ai= Projected area of the subject vehicle

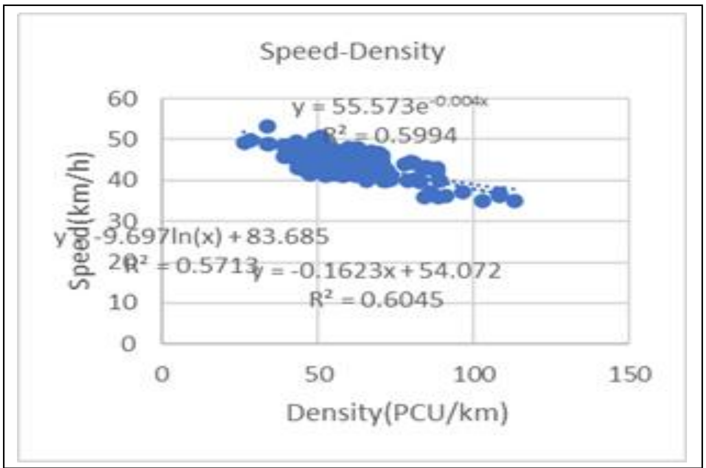
*Table 6. Estimated PCU Value for different categories of vehicles*

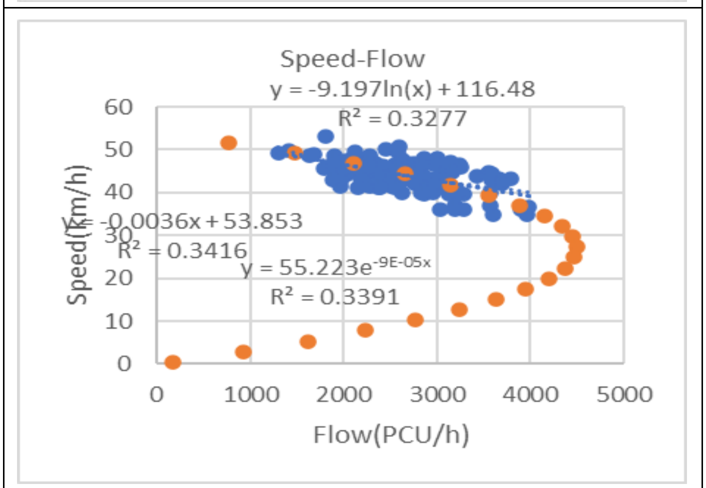
| Sr no | Type of Vehicles | Estimated PCU from Chandra's Method | Suggested PCU from Indo HCM |
|---|---|---|---|
| 1 | 2w(Two-Wheeler) | 0.28 | 0.22 |
| 2 | 3w (Three-Wheeler) | 0.79 | 0.9 |
| 3 | 4Sc (Small Car) | 1 | 1 |
| 4 | 4Bc (Big Car) | 1.49 | 1 |
| 5 | LCV (Light commercial vehicle) | 2.1 | 2.38 |
| 6 | Bus | 5.65 | 4.6 |
| 7 | 2A4T | 1.6 | 2.07 |
| 8 | 2A6T | 4.74 | 3.9 |
| 9 | 3A10T | 5.76 | 3.9 |
| 10 | 4A12T | 6.09 | 5.9 |
| 11 | 5A14T | 6.47 | 5.9 |
| 12 | ST-14T-4A | 7.34 | 5.9 |
| 13 | ST-18T-2AT | 7.84 | 5.9 |
| 14 | ST-18T-3AT | 8.38 | 5.9 |
| 15 | ST-22T-3AT | 8.93 | 5.9 |

## 5. Speed- Flow – Density Relationship

The speed-flow-density relationship is a fundamental concept in traffic flow theory, describing how traffic speed, volume (flow), and vehicle density interact under varying roadway conditions. Under free-flow conditions, as density increases, the flow also increases since more vehicles are present without significantly affecting speed. However, beyond a critical density, increased congestion leads to a sharp decline in speed, causing the flow to drop as well eventually. This relationship typically forms a parabolic curve when plotted as flow versus density, and a downward-sloping curve for speed versus density. In heterogeneous traffic, such as on the SP Ring Road, the presence of mixed vehicle types with varying sizes and speeds distorts the ideal relationships. For example, heavy vehicles slow down the overall stream speed and occupy more space, increasing density at a faster rate than flow. As a result, the peak flow is reached at lower densities compared to homogeneous conditions. Understanding this relationship is crucial for effective traffic management and capacity estimation on urban arterial roads. The speed–flow–density relationship is a core element of traffic flow theory, illustrating the interdependence of three fundamental parameters: speed (v), flow (q), and density (k), where the relationship is mathematically expressed as $q = v \times k$. In general, when a road is under free-flow conditions, vehicles move at or near the desired speed with minimal interaction, and as density increases, the traffic flow also increases because more vehicles are moving efficiently through the roadway stretches. However, as density continues to rise, the space available between vehicles reduces, leading to more frequent interactions and reduced speeds. Beyond a certain critical density, the flow reaches its maximum (known as capacity) and begins to decline due to increasing congestion and declining speeds. This creates a parabolic flow–density curve where flow first increases with density and then decreases, while the speed–density curve typically shows a declining trend, and the speed–flow curve shows a rising trend followed by a drop after peak flow.

In the context of heterogeneous traffic, such as on SP Ring Road, where vehicles range from two-wheelers to multi-axle trucks, this relationship becomes more complex. The diverse dimensions, dynamic behavior, and performance characteristics of each vehicle type cause uneven spacing and inconsistent speed profiles. For example, slower-moving or larger vehicles like HCVs and MAVs increase localized density and reduce overall stream speed, thereby shifting the critical density and flow values. The presence of non-lane-based movements, frequent overtaking, and inconsistent headways further distort the ideal curves. In such traffic, PCU values and effective density become dynamic rather than fixed. This often results in early breakdown of flow, reduced capacity, and higher variability in speed and flow at the same density levels. Understanding the true nature of the speed–flow–density relationship under such mixed traffic is essential for planning signal timings, designing road geometry, estimating realistic roadway capacities, and formulating traffic management strategies tailored for urban Indian roadways. The relationship between speed, flow, and density was analyzed using three traffic flow models: Greenshield, Greenberg, and Underwood. Among the speed-density models, the Underwood model showed the best fit, with an $R^2$ value of 0.6147, followed closely by the Greenshield model ($R^2$ = 0.6045). This indicates a moderately strong relationship between speed and density, with Underwood's exponential form slightly outperforming the others. For the speed-flow relationship, all three models showed relatively weak correlations, with $R^2$ values ranging from 0.3277 to 0.3439, suggesting that speed alone may not be a strong predictor of traffic flow. In contrast, the flow-density relationship demonstrated the strongest correlations, with all models performing well. The Greenberg model had the highest $R^2$ of 0.9327, followed by Greenshield (0.9163) and Underwood (0.8754). This indicates that traffic flow is most accurately explained by density, and logarithmic or linear models like Greenberg and Greenshield provide reliable fits. Overall, the study shows that density has a stronger influence on flow than on speed, and models like Greenberg are more effective in capturing this behavior.



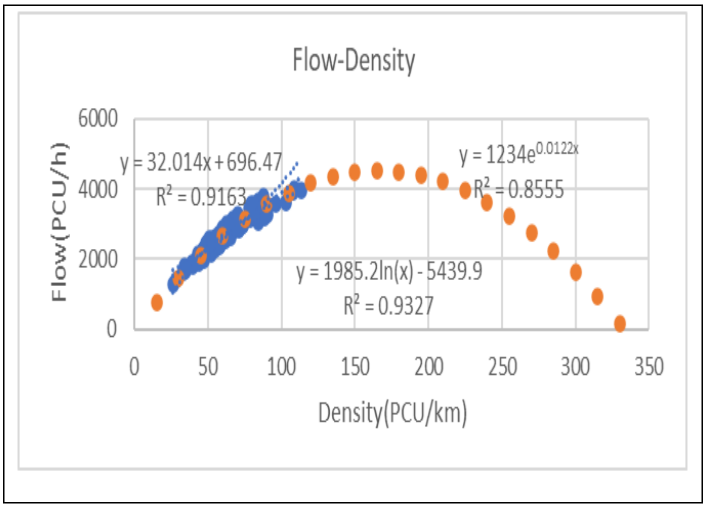




Figure 3 Speed Flow density relationship

*Table 7* Speed Flow density equations for both stretches

| Relationship | Model Name | Equation | $R^2$ |
|---|---|---|---|
| Speed-Density | Greenshield model | y = -0.1623x + 54.072 | 0.6045 |
| | Greenburg model | y = -9.697ln(x) + 83.685 | 0.5713 |
| | Underwood model | $y = 55.573e^{-0.004x}$ | 0.6147 |
| Speed-Flow | Greenshield model | y = -0.0036x + 53.853 | 0.3416 |
| | Greenburg model | y = -9.197ln(x) + 116.48 | 0.3277 |
| | Underwood model | $y = 55.223e^{-9E-05x}$ | 0.3439 |
| Flow-Density | Greenshield model | y = 32.014x + 696.47 | 0.9163 |
| | Greenburg model | y = 1985.2ln(x) - 5439.9 | 0.9327 |
| | Underwood model | $y = 1234e^{0.0122x}$ | 0.8754 |

## 6. Conclusion

In this study, the effect of PCU estimating methods on roadway capacity determination is observed for two-lane rural roads. The case study stretches considered here are Vastral and Odhav; Both the road stretches are a part of Sardar Patel ring road Ahmedabad city. The dynamic PCU concept by Chandra and Sinha (2001) and the method suggested in Indo-HCM (2017). The PCU values determined by the dynamic PCU concept are dependent on the dynamic characteristics of a vehicle. Speed- Flow-Density relationship (Figure 3 and Table 4 AND 5) for both the road stretches using Greenshield's Linear Model, Greenburg and Underwood model. Ultimately, the capacity of the two highways was estimated with different PCU values obtained from different PCU value estimating methods. The analysis of traffic flow relationships using Greenshield, Greenberg, and Underwood models reveals that flow-density relationships are best described by these models, with the Greenberg model showing the highest accuracy ($R^2$ = 0.93). This indicates a strong link between traffic density and flow on the studied road stretches. In contrast, the speed-density and speed-flow relationships are less accurately predicted, with moderate to low $R^2$ values (around 0.3 to 0.6), suggesting that factors other than speed alone influence traffic flow and density. Among the speed-density models, the Underwood model performed slightly better, while all speed-flow models showed relatively weak correlations. Overall, the findings emphasize that traffic density is a key factor in modeling flow, and logarithmic models like Greenberg provide better predictions in mixed traffic conditions. These insights can help in traffic management and planning for urban roads to optimize flow and reduce congestion.

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