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DYNAMIC CAPACITY ANALYSIS OF UNDIVIDED URBAN ROADS IN CENTRAL BUSINESS DISTRICTS

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ABSTRACT
Roadway capacity estimation plays a pivotal role in the planning, design, and operational management of road networks. It serves as a foundation for understanding traffic volume, composition, and other critical parameters, thereby enabling informed decisions related to infrastructure development and traffic regulation. Particularly for existing roadways, capacity assessment helps determine the traffic-handling capability of available lanes and roadway widths under prevailing conditions. In India, traffic on highways and urban roads is highly heterogeneous, comprising a wide range of vehicle types with diverse static and dynamic characteristics. While capacity estimation studies are fairly common for national highways, similar studies for urban roadways—especially in Central Business District (CBD) areas of major cities—are relatively scarce. These urban corridors often face challenges such as the absence of proper lane markings, high side friction, and obstructions caused by on-street parking, standing vehicles, illegal parking, and parking/un-parking maneuvers. These factors significantly affect the usable road width, contributing to reduced capacity and increased congestion.

This study focuses on estimating the capacity of an undivided urban roadway located within a CBD area, where traffic lanes are not physically marked. As such, capacity is estimated for the entire road width rather than on a per-lane basis. To account for heterogeneous traffic, dynamic Passenger Car Units (PCUs) are calculated using Chandra's method, which considers both speed and area occupancy ratios. The dynamic PCUs derived were found to be lower than the standard PCU values prescribed by IRC: 106-1990.The capacity analysis is carried out using the fundamental traffic flow relationship between speed, flow, and density. The findings of this study provide valuable insights for the development of effective traffic management strategies, aiming to enhance the operational efficiency and capacity of urban undivided roadways in densely developed CBD zones.

Keywords: *CBD area, Speed, Flow, Density, Dynamic PCU, Capacity*

1. INTRODUCTION
In most developed countries, roadway capacity values and speed–flow–density relationships have long served as foundational tools for the planning, design, and operation of road networks. These models are effective in contexts where traffic conditions are relatively homogeneous, with vehicles exhibiting uniform static and dynamic characteristics, and disciplined lane-based movement. However, such assumptions do not hold true for developing countries like India, where traffic is highly heterogeneous in nature.

Indian urban traffic is characterized by a wide mix of vehicle types—ranging from two-wheelers, auto-rickshaws, and cars to buses, trucks, and non-motorized vehicles—all sharing the same road space. The lack of strict lane discipline, absence of dedicated lanes, and minimal segregation among vehicle types lead to erratic movement patterns. This significantly impacts the effective roadway capacity and creates operational challenges such as frequent congestion, increased travel time, and reduced safety.

These challenges are particularly severe in the Central Business Districts (CBDs) of Indian cities, where high commercial activity, dense built-up areas, and historic road layouts further exacerbate traffic congestion. Despite rapid urban expansion and the development of new infrastructure in peripheral areas, the functional importance of CBDs has remained undiminished. As a result, the urban roads within these core areas are continuously subjected to rising traffic volumes and increased pressure on available infrastructure.

One of the major issues faced by such urban roads is the lack of on-street parking management, resulting in reduced effective carriageway width and increased side friction due to parking and un-parking maneuvers, standing vehicles, and illegal encroachments. These factors collectively reduce the road's capacity and deteriorate traffic flow conditions.

In this context, the present study aims to estimate the capacity of an undivided urban roadway under mixed traffic conditions, using Mahatma Gandhi Road in Vadodara, Gujarat, as a case study. This road is a historically significant corridor located in the heart of the city and forms part of the CBD with more than 1000 commercial establishments in the vicinity. The road experiences high traffic volume, with vehicle speeds ranging from 5 to 50 km/h throughout the day, and lacks any lane markings, making it an ideal candidate for assessing real-world urban capacity under mixed traffic conditions.

This study seeks to develop a more realistic estimation of roadway capacity using speed–flow–density relationships and dynamic PCU (Passenger Car Unit) values, thus contributing to better traffic management and infrastructure planning in similar urban contexts.

2. OBJECTIVES

The main aim of the study is to estimate the capacity of urban undivided roadway in CBD area. Following are the objectives to achieve main aim of the study.

1) To estimate the value of PCUs for heterogeneous traffic condition of vehicles in traffic stream.
2) To develop the new dynamic PCU values which is applicable to present roadway condition and prevailing traffic condition.
3) To compare the dynamic PCU values obtained with the values given in IRC: 106-1990.

3. LITERATURE REVIEW

In India, the Indian Roads Congress (IRC) is the apex body responsible for the formulation of guidelines, standards, and codes pertaining to road transportation. As per IRC:106-1990, fixed Passenger Car Unit (PCU) values were recommended for various categories of vehicles on urban roads. These values, however, are static and do not fully capture the dynamic and heterogeneous nature of Indian traffic. The guidelines further recommended using PCU values based on the percentage composition of vehicle types in the traffic stream, but did not account for prevailing variations in traffic volume, lane discipline, or road geometry.

Several studies have attempted to address these limitations by developing more context-sensitive PCU values:

Satish Chandra and Upendra Kumar (2003) analyzed data from two-lane roads in India, categorizing vehicles into nine types and deriving PCU values accordingly. Their study introduced adjustment factors based on lane width and demonstrated that roadway capacity declines as the proportion of traffic in the major direction increases.

V. Thamizh Arasan and Shriniwas S. Arkatkar (2010) estimated PCU values using microscopic simulation techniques. Their study revealed that PCU values are highly sensitive to traffic volume and roadway width, especially under mixed traffic conditions where vehicles with varying dynamic and static characteristics operate simultaneously.

S. Anand and V. C. Sekhar (1999) emphasized the importance of accurate PCU estimation for each vehicle type in the analysis of mixed traffic flows on highways.

Parvathy R., Sreelatha T., and Reebu Z. Koshy (2013) also focused on estimating PCU values for various vehicles under heterogeneous traffic, further supporting the need for revising standard PCU factors.

Chandra and Goyal (2001) studied the impact of gradient on two-lane road capacity and proposed a PCU estimation model based on two variables: (1) the speed ratio of a car to the subject vehicle and (2) the space occupancy ratio. They concluded that PCU increases linearly with gradient, indicating the importance of terrain in capacity evaluation.

Foundational research has also informed the theoretical understanding of traffic flow:

Greenshield (1935) introduced a linear relationship between speed and density, which formed the basis for the widely used parabolic relationship between speed and traffic flow.

Kadiyali et al. (1991) noted that the speed–flow relationship in Indian conditions has evolved due to changes in vehicle performance and traffic behavior.

Sahoo et al. (1996) observed a clear inverse relationship between traffic volume and vehicular speed, reinforcing the need to reassess capacity under growing congestion. Parker (1996) highlighted that traffic composition is a critical determinant of the capacity of arterial roads.

Kumar and Rao (1998) demonstrated that speed–density data could be effectively modeled using a linear relationship, particularly under Indian conditions.

Nixon (1976) studied suburban roads and found that mean free-flow speed increases linearly with carriageway width.

Ramanayya (1988) criticized the direct adoption of Western capacity standards for Indian conditions, as they do not consider the unique characteristics of mixed traffic prevalent in India.

Chandra (2004) proposed a capacity estimation procedure tailored to Indian two-lane roads under mixed traffic conditions.

Summary of Findings and Research Gaps:

The literature reveals a significant variation in estimated PCU values across different studies, highlighting the limitations of static PCU values under heterogeneous conditions. Most of the existing research has been focused on national highways or divided roads. Studies focusing on undivided urban roadways, especially within Central Business Districts (CBDs), remain limited despite the intense traffic activity and congestion they experience. Notably, opposing and same-directional traffic flows affect vehicle movement differently in undivided roadways, a factor that is insufficiently addressed in prior research. There is a pressing need to assess whether total traffic volume or directional volume has a more pronounced impact on class-wise vehicle speed in mixed traffic scenarios.

4. DATA COLLECTION & STUDY AREA

The selection of the study location was done with careful consideration to ensure minimal external interference and to obtain accurate traffic flow data. A straight road section without intersections, junctions, or pedestrian crossings was chosen to reduce the impact of turning movements and side frictions. The site selected for data collection is Mahatma Gandhi Road, located in the Central Business District (CBD) area of Vadodara City, Gujarat. To facilitate continuous and unobstructed traffic observation, a video camera was strategically mounted at Mandvi Gate, providing an elevated vantage point for recording vehicle movements along the selected stretch.

Roadway Characteristics

- Total Carriageway Width: 14.0 meters
- On-Street Parking: 2.3 meters (occupied on either side alternately)
- Effective Carriageway Width: 11.7 meters (available for bidirectional traffic flow)
- This effective width, being reduced by alternate-day parking practices, plays a significant role in influencing roadway capacity and vehicle manoeuvrability in both directions. The video recording method was employed to collect data for:

- Classified traffic volume counts
- Vehicle speed measurements

Recordings were made during peak traffic hours, at 5-minute intervals, for three hours in the morning (10:00 AM – 1:00 PM) and three hours in the evening (4:30 PM – 7:30 PM) over two consecutive weekdays. The peak hours were identified through a preliminary traffic survey conducted prior to the main study. Vehicles observed were classified into six categories based on their physical and operational characteristics:

1. Two-wheelers
2. Three-wheelers
3. Small cars
4. Big cars
5. Buses
6. Bicycles

To estimate vehicle speeds, a trap length of 30 meters was marked on the road. The time taken by each vehicle to traverse this section was recorded from the video footage. Using this travel time, the minimum and maximum speeds for each category were calculated, enabling further analysis of speed-flow-density relationships.

Figure- 1 Cross-section of Study Section at M. G. Road

Figure-2 Traffic Congestion during Peak Hour on M. G. Road

4.1 Traffic Volume Data

Traffic volume is a fundamental parameter in the **geometric design of pavements** and plays a crucial role in fulfilling various functional and operational requirements of roadway infrastructure. For traffic engineers, accurate traffic volume data serves as the basis for analysing flow characteristics, designing appropriate roadway geometry, and implementing effective traffic management measures. Traffic volume data provides insights into:

- Flow rate (in vehicles per hour or PCUs per hour)
- Vehicle composition by category
- Peak flow characteristics

In the present study, classified traffic volume counts were recorded over a two-day period, covering six hours per day—comprising three hours in the morning peak (10:00 AM – 1:00 PM) and three hours in the evening peak (4:30 PM – 7:30 PM). The total traffic flow and the percentage composition of each vehicle type are summarized in Table 1. The data indicate that traffic conditions remained consistent over both days, suggesting that the traffic pattern observed was normal and representative of typical weekday operations.A closer examination of the data reveals that two-wheelers and three-wheelers dominated the traffic stream, accounting for the highest proportion of total vehicle volume. This reflects the typical urban traffic pattern in Indian cities, where compact and flexible vehicle types are preferred due to congestion and limited road space.

Table-1 Traffic Volume and Traffic Composition

Vehicle Category	**Day-1 (6 hrs.)**		**Day-2 (6 hrs.)**		**Total Volume (12 hrs.)**	
	No. of Vehicles	Vehicle Composition in %	No. of Vehicles	Vehicle Composition in %	No. of Vehicles	Vehicle Composition in %
Two Wheeler	22237	66.57	21661	64.84	43898	66.10
Three-Wheeler	6927	20.74	7574	22.67	14501	21.83
Car Small	1099	3.29	962	2.88	2061	3.10
Car Big	526	1.57	460	1.38	986	1.48
Bus	82	0.25	87	0.26	169	0.25
Cycle	2534	7.59	2263	6.77	4797	7.22
Total	**33405**	100.00	**33007**	98.81	**66412**	100.00

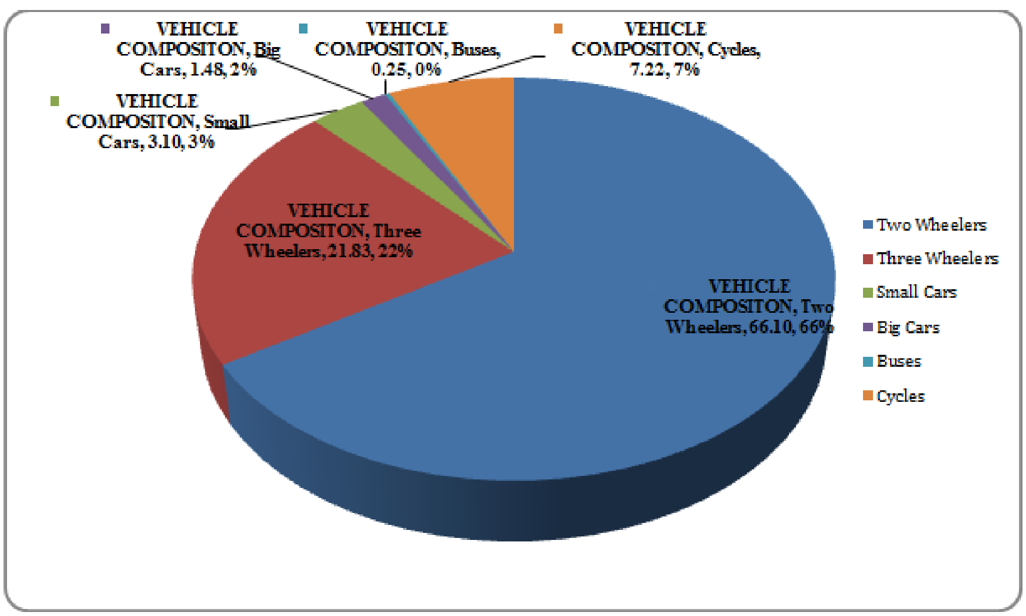

Figure-3 Traffic Composition on M.G. Road

4.2 Speed Data

To ensure accuracy in speed measurement, the study stretch was selected to be straight and free from intersections, allowing vehicles to maintain a consistent trajectory without interruptions. The trap length—a predefined 30-meter section—was used to determine vehicle speeds based on the time taken to traverse the distance.

Vehicle Speeds were Recorded by:

- Capturing video footage at 5-minute intervals during the study period.
- Sampling vehicles of each category (two-wheelers, three-wheelers, small cars, big cars, buses, and bicycles).
- Measuring the time each vehicle took to cross the 30-meter trap length.

Table-2 Sample Size for Speed Calculation

Vehicle Category	**Day-1**		**Day-2**		**Total Sample**	
	No. of Samples	Sample in %	No. of Samples	Sample in %	No. of Samples	Sample in %
Two Wheeler	4136	52.83	5385	51.04	9521	51.80
Three Wheeler	1674	21.38	2556	24.23	4230	23.02
Car Small	807	10.31	882	8.36	1689	9.19
Car Big	224	2.86	278	2.64	502	2.73
Bus	75	0.96	88	0.83	163	0.89
Cycle	913	11.66	1361	12.90	2274	12.37
Total Sample	**7829**	100	**10550**	100	**18379**	100.00

Table-3 Speed Statistics of Individual Vehicles

Vehicle Category	**Max. Speed (km/h)**	**Min. Speed (km/h)**	**Mean Speed (km/h)**	**Standard Deviation**	**Variance**
Two-Wheeler	46.50	7.65	20.60	4.92	24.24
Three-Wheeler	36.00	7.81	18.57	4.33	18.79
Car Small	36.49	6.97	17.50	4.79	22.91
Car Big	29.24	7.67	17.77	4.43	19.65
Bus	26.86	7.60	16.58	4.46	19.93
Cycle	24.39	6.45	13.43	2.83	8.03

4.3 Determination of PCU Values

The main problem in analysis of speed-flow relationship is heterogeneity of traffic. The vehicles in traffic stream have different static and dynamic characteristics which produces impedance. Generally, passenger car unit (PCU) is adopted considering passenger car as standard vehicle. The PCU values are derived by Chandra's method for this study. The basic concept used to estimate the PCU is that it is directly proportional to the ratio of clearing speed and inversely proportional to the space occupancy ratio with respect to the standard design vehicle (a car).

PCU_i = Speed ratio of the car to the i^{th} vehicle

Space ratio of the car to the i^{th} vehicle (1)

$PCU_i = V_c / V_i$

A_c / A_i

Where,

PCU_i = passenger car unit value of i^{th} type vehicle

V_c / V_i = speed ratio of the car to the i^{th} vehicle

A_c / A_i = space ratio of the car to the i^{th} vehicle

V_c = speed of the car (km/h)

V_i = speed of i^{th} type vehicle (km/h)

A_c = static (projected rectangular) area of a car (m^2)

A_i = static (projected rectangular) area of i^{th} type vehicle (m^2)

The first variable as speed ratio will be the function of composition of traffic stream as the speed of any vehicle type depends upon its own proportion and type and proportions of other vehicles. Therefore, speed of vehicle will be true representation of overall interaction of a vehicle type due to presence of other category and of other types. The second variable represents the pavement occupancy with respect to car. Table-4 shows the different vehicle categories used for the study and their average dimensions to determine the dynamic PCU values. Table-5 shows the determined dynamic PCU values of different vehicle categories calculated by Chandra's method and recommended PCU values as per IRC: 106-1990. It is the clear evidence that derived dynamic PCU values are lesser as compared to recommended PCU values given by IRC due to the effect of vehicle composition and speed parameter of vehicles of each category in the traffic stream.

Table-4 Vehicle Categories and Their Sizes

Sr. No.	**Vehicle Category**	**Length (m)**	**Width (m)**	**Projected Rectangular Area (m^2)**
1	Two Wheelers	1.87	0.64	1.20
2	Three Wheelers	3.2	1.4	4.48
3	Small Cars	3.72	1.44	5.36
4	Big Cars	5.0	1.8	9.00
5	Buses	10.1	2.43	24.54
6	Cycles	1.9	0.45	0.86

Table-5 Passenger Car Unit for different Vehicle Category

Vehicle Category	Derived Dynamic PCU Values by Chandra's Method	Recommended PCU Value(As per IRC: 106-1990) Percentage composition of Vehicle type in traffic stream	
		5%	10% and above
Two Wheelers	0.19	0.5	0.75
Three Wheelers	0.79	1.2	2.0
Small Cars	1.00	1.0	1.0
Big Cars	1.68	---	---
Buses	4.90	2.2	3.7
Cycles	0.21	0.4	0.5

5. SPEED-VOLUME-DENSITY RELATIONSHIP

The speed, volume and density are the important components of traffic and knowledge of traffic characteristics is useful for estimating the traffic carrying capacity of a road. This relationship helps the traffic engineer in planning, designing and the effective implementation to traffic engineering measures on a roadway system, especially urban undivided road in CBD area. The capacity and traffic volume decides the performance of any roadway network.

The calculated average speed and traffic volume in PCU/hr. at every 5-minute interval is carried out and corresponding density is formulated by using their relationship. Figure-4, Figure-5, and Figure-6 shows the fundamental relationships between Speed-Density, Speed-Flow and Flow-Density respectively to achieve the capacity of the roadway. Figure-4 indicates the lower density at higher speed and as the density increases the speed decreases due to congestion occurs on the carriage way.

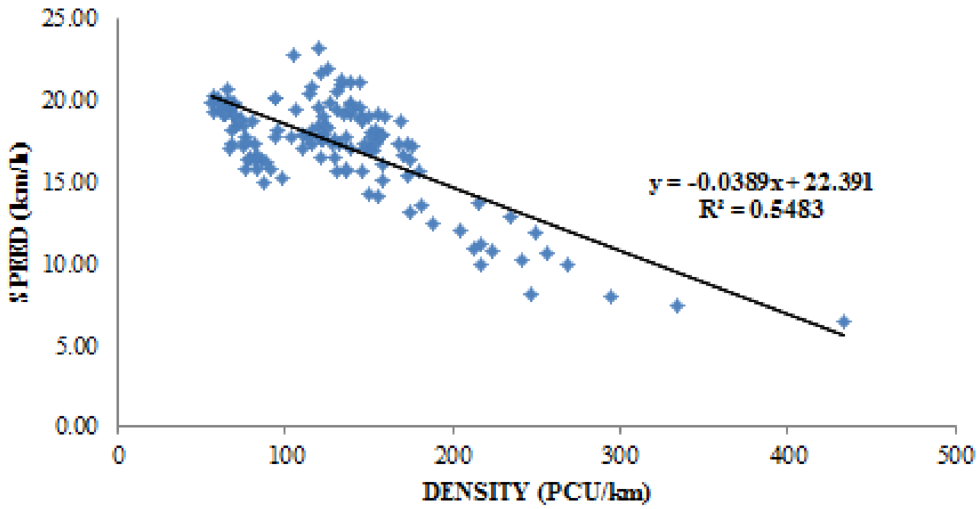

Figure-4 Speed – Density Relationship for M.G. Road

Figure-5 show the graph between speed and flow, which is obtained revised speed and revised flow data with the help of linear equation generated for the regression. It shows the highly congested regions. The overall capacity is 3298 PCU/hr is also estimated with the help of this graph.

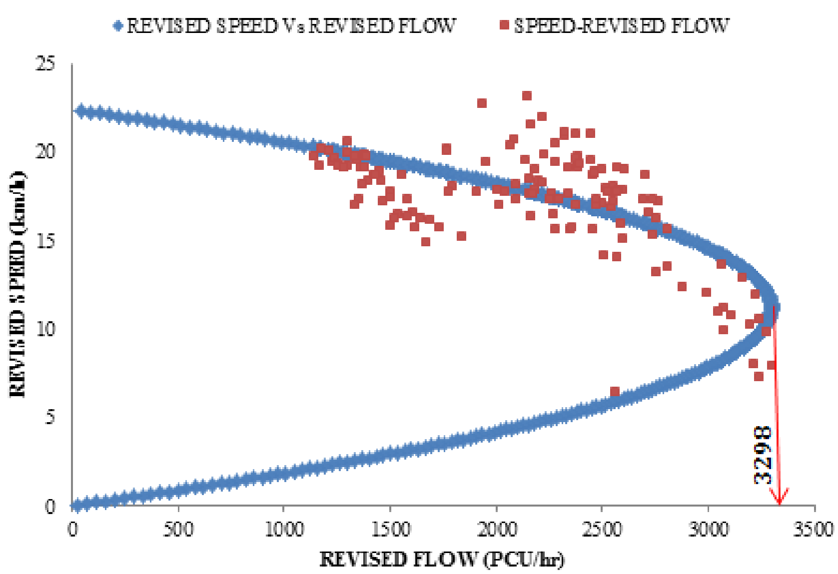

Figure-5 Speed – Flow Relationship for M.G. Road

Figure-6 shows the flow-density graph, which indicates the linearly varying relationship between these two parameters. It is clearly seen that as the flow increases, the density also increases with the increase in the traffic stream.

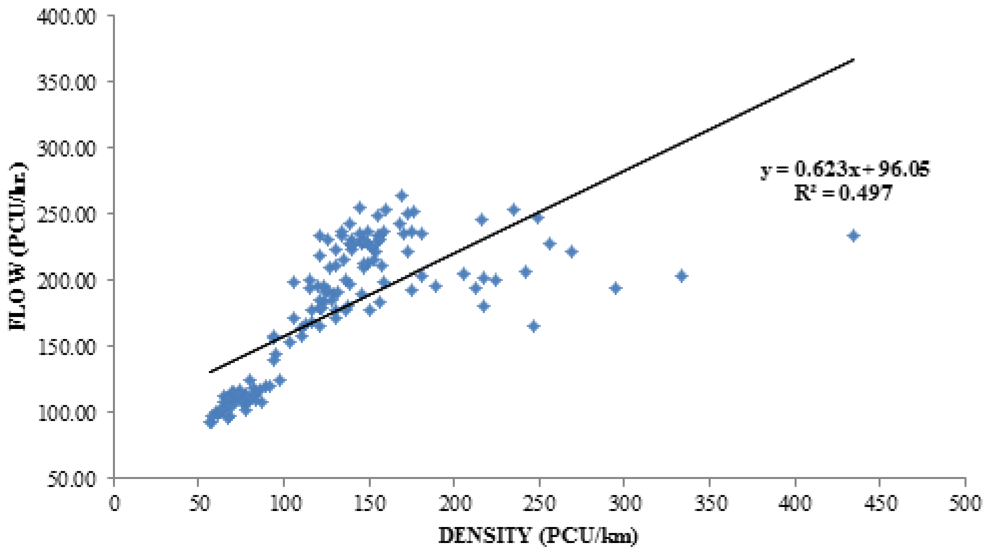

Figure-6 Flow – Density Relationship for M.G. Road

6. RESULTS & CONCLUSIONS

The analysis is based on the data collected on an urban undivided road having effective carriage way width of 11.7 m. with on-street parking permitted on either side at alternate day considering all categories of vehicles commonly found in a CBD urban area. The dynamic PCU values are determined by Chandra's method based on speed and area ratio and these new PCU values are quite different from the values given in IRC: 106-1990. The vehicle composition of two-wheeler and three-wheeler are **66 %** and **22 %** respectively which have corresponding dynamic PCU values as 0.19 and 0.79. The vehicle composition and PCU values are significant in traffic stream and have influence on traffic flow parameters (such as speed, flow and density) affecting the overall capacity of the roadway system in CBD area. Due to increase in composition of these two categories of vehicles, the speed is decreasing and the PCU values decreases. So that the use of dynamic PCU should be applicable for the capacity estimation instead of using static PCU given in IRC: 106-1990 for such a busy road lying under CBD areas. The capacity of 11.7 m wide undivided road estimates 3298 PCU/hr bidirectional which is slightly higher than the value of 3000 PCU/hr suggested in IRC: 106-1990 considering four lane undivided arterial road category. The speed equation derived from the speed-density relationship is that the speed is equal to the constant value 22.39 minus 0.038 times the density ($R^2 = 0.548$). The level of service of this road is E, as the peak hour factor is 0.94 which indicates unstable flow with congestion and intolerable delay. The service volumes (3172 PCU/hr) are also reaches at the maximum capacity (3298 PCU/hr) of the undivided road. The average traffic stream speed is about **18.83 km/hr** for heterogeneous bidirectional flow.

From the above computed results, it can be concluded that, a typical congested traffic scenario studied in this paper is present in most of the undivided urban roads of CBD area of major cities of India in heterogeneous traffic condition. Hence the results may be used to take traffic management measures in the CBD area to improve prevailing level of service and to improve the capacity of undivided carriageway. Selected traffic management measures can be change in configuration of parking, total or partial restriction of parking and effective enforcement measures to prohibit encroachment.

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