ASSESSMENT OF VEHICULAR PASSENGER OCCUPANCY AND ITS EFFECT ON LOS

Rashmi Ranjan Samal[1], Kundan Samal[1], Sitansu Kumar Das[2], Satya Ranjan Samal[1], Malaya Mohanty[1,*]

[1]Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, School of Civil Engineering, Bhubaneswar, India
[2]Government College of Engineering, Department of Civil Engineering, Keonjhar, India

*E-mail of corresponding author: malaya.mohantyfce@kiit.ac.in

Kundan Samal 0000-0003-2142-0656,
Satya Ranjan Samal 0000-0001-8675-453X,
Sitansu Kumar Das 0000-0003-3472-2792,
Malaya Mohanty 0000-0002-6116-782X

Resume
The expansion of infrastructure in developing countries have led to a surge in car ownership. Although cars offer greater safety, their less passenger occupancy has contributed to reduced level of service (LOS). The present study was aimed to investigate the effect of passenger occupancy of various modes of transport on LOS. Detailed on-field surveys, including video recordings and questionnaires have been used to collect data, which is subsequently analyzed. The study findings suggest that a huge improvement in LOS and congestion can be achieved if public transportation is used more. Even usage of 3Ws and 2Ws can reduce congestion compared to usage of cars. While a person using a bus uses just 0.48 m^2 of the road space, a person using car uses 2.23 m^2 of the road space. The findings of this research are intended to inform traffic engineers and practitioners in developing more balanced traffic management strategies.

Article info
Received 18 November 2025
Accepted 9 March 2026
Online 18 March 2026

Keywords:
Level of Service (LOS)
congestion
passenger occupancy
vehicular occupancy
traffic engineering
transportation management

Available online: https://doi.org/10.26552/com.C.2026.018

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

1 Introduction

Transportation systems are integral part to the economic and social fabric of any society. The efficiency and effectiveness of these systems depend on various factors, including the mode of choice, vehicle occupancy, and the level of service (LOS) provided [1]. The LOS is the service provided to the road users in terms of comfort and safety, which is usually categorized using Volume to Capacity (V/C) ratio. The choice of vehicle mode/category that is preferred by the road users, along with vehicle occupancy and level of service are critical factors that influence the efficiency and sustainability of transportation systems. Understanding these elements helps in planning and implementing strategies to improve mobility, reduce congestion, minimize environmental impacts and sustainability of transportation networks.

The mode of choice refers to the type of a vehicle, which individuals/groups select for their transportation needs. Examples include private cars (4W), public buses (Bus), private motorized two-wheelers (2W), bicycles, or walkers/pedestrians. The choice of transportation mode is influenced by various factors, including individual preferences, socioeconomic status, environmental concerns, and the availability of infrastructure [2-3]. In a developing country like India, the use of different types of vehicles varies significantly among the population. As of recent data [4], the trends in sales of the two-wheelers (2Ws), three-wheelers (3Ws), cars, and buses in India show significant growth and transformation. Motorized 2 Wheelers remain the most common form of personal transportation in India, with approximately 70-75% of households owning at least one [4-6]. On average, public buses are used by around 10-15% of the population for daily commuting [6]. Another very commonly used public mode of transportation in developing countries like India are 3 Wheelers/autorickshaws (3W) [6-8]. They cater to around 5-10% of the urban population, providing a flexible and relatively affordable alternative to buses and personal vehicle. Next are the cars/jeeps, which can be termed as LMVs/4 Wheelers too. In India, the ownership and use of private cars (4W) are

***Figure 1** Snapshots of Video Recordings*

increasing rapidly, but they are still less prevalent as compared to 2W [6-8]. On an average, 7.5% (ranging from 4.4% in rural areas to 13.8% in urban areas) of households are found to be owning private car [7-9]. These statistics highlight the diversity in transportation preferences in India, which is dynamically shifting towards private cars or 4W [10]. However, the occupancy of these vehicles poses a threat to congestion as well as air quality [11-13].

Vehicle occupancy refers to the number of people in a vehicle at a given time [13]. This concept is significant in transportation planning, environmental analysis, and urban development. Understanding vehicle occupancy helps in assessing traffic congestion, fuel efficiency, and pollution levels [14-16]. Indians are heavily dependent on private vehicles as compared to public transportation. Even in private vehicle possession, gradually a shift from 2Ws to cars is being observed. If 100 people commuting to workplace using 2Ws shift towards cars, the space required for 100 cars would be 4-5 times more than for the 2Ws. This shall lead to undesirable delay and congestion on the road. Many studies were devoted to the usage of public transport [16-22], which can improve the effectiveness of traffic flow and improve air quality. Increased areas occupied by private vehicles with less occupants may lead to increased travel times, cause congestion and reduce the level of service (LOS) on road. The LOS of a road describes the quality of service that a roadway facility is providing to its users encompassing aspects such as travel time, frequency, reliability, and user comfort [21]. Although studies have been conducted to evaluate the mode of choice and vehicular occupancy individually by various researchers [6-8], combined effect of both the factors have been rarely studied. Further, studies in developing countries are limited.

The present study has been conducted to explore the preferences and behaviors of road users regarding their mode of choice, analyze the vehicle occupancy patterns for different categories of vehicles, and examine how these factors affect the level of service on road. The research provides valuable insights into current transportation trends and identifies potential areas for improvement in transportation systems to reduce congestion, delays, etc., thereby improving LOS on roads.

2 Data collection, extraction and methodology

The objectives of the present study have been attained by the collection of data from various road locations. The present study has been conducted in the city of Bhubaneswar, India on the urban arterials, which are 4-lane divided roads. Bhubaneswar is a Tier - II developing smart city in India. The cities across India have been divided into three categories [22].

- Category X (population of 5 million and above),
- Category Y (population between 0.5 and 5 million), and
- Category Z (population below 0.5 million).

Usually, these are indicated as tier-I, tier-II, and tier-III cities, respectively. The present study has been conducted in a tier - II city considering its varied qualities concerning people, their economic standards, education standard, job status, family type, etc., leading to a much large spectrum of driving behavior. Further, Tier II cities in India are experiencing many developmental changes in recent times [22]. Furthermore, majority of the cities in India belong to the category of tier-II. Thus, to achieve the motive of the research, Bhubaneswar, which is one of the tier-II cities of India and the capital city of Odisha has been chosen as the study area. However, the methodology used in the study can be used at various tier-I and tier-III cities to get the findings for them. Due to difference in demography and living standards, the results will vary, mainly in terms of vehicular composition leading to difference in congestion and LOS levels. Video recordings have been conducted for various road mid-block sections across the city. Few snapshots from various locations are provided in Figure 1.

The collected videos are played on a TV monitor and the classified traffic volume is extracted. In case of 2 Wheelers, the vehicle occupancy is noted from the collected videos. For buses, physical inspection and driver interrogation has been conducted to ascertain the average vehicle occupancy. Similarly, for 3 wheelers and 4 wheelers, the vehicle occupancy is determined based on both, observation from videos and field along with cross-examination from riders. Thereafter, the collected traffic volumes across different times of day are converted to Passenger car Units (PCUs) for further

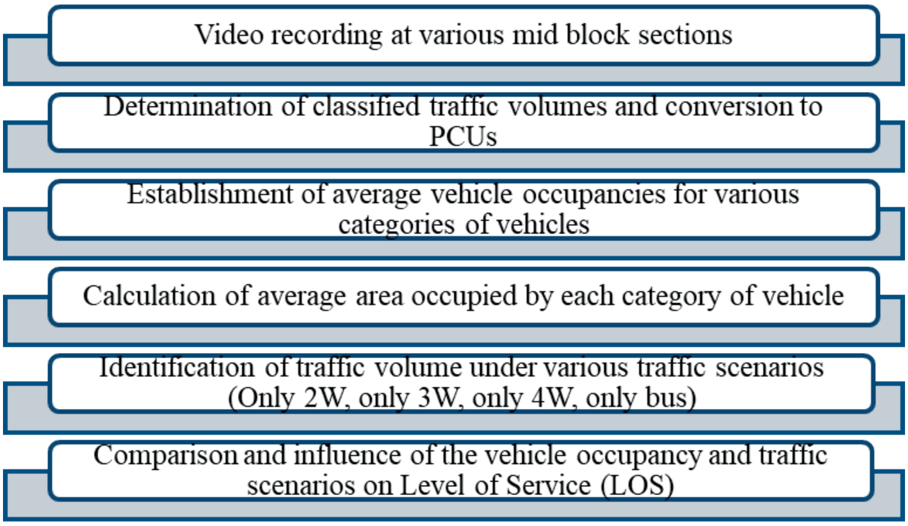


Figure 2 *Flow chart depicting methodology*

Table 1 *Classified vehicle count with percentage composition and PCU*

Time	2W	3W	4W	Buses	Total	Total PCU
8:00-9:00 AM	840	192	210	16	1258	937.6
9:00-10:00 AM	1008	252	264	24	1548	1176
10:00-11:00 AM	1440	260	400	24	2124	1564.8
11:00-12:00 PM	1500	312	620	32	2464	1938.8
12:00-01:00 PM	1600	404	496	36	2536	1959.2
01:00-02:00 PM	980	224	460	12	1676	1337.2
02:00-03:00 PM	1352	240	580	24	2196	1712.8
03:00-04:00 PM	1548	344	720	12	2624	2077.2
04:00-05:00 PM	1592	304	740	16	2652	2084
Total Volume	11860	2532	4490	196	19078	14788
Vehicle Composition (%)	62.1	13.3	23.6	1	100	

Table 2 *Median PCU Units used for the present study*

Vehicles	PCU
Two-Wheeler (2W)	0.50
Four-Wheeler (4W)	1.00
Big Cars/LCV (4W)	1.40
Three-Wheeler (3W)	1.20
Bus	2.20

analyses. Figure 2 shows the methodology that has been used in the present study.

3 Results

Traffic data has been extracted from over 9 hours of recorded video across various traffic volumes on various mid-block sections of Bhubaneswar city. The data comprised of more than 15000 vehicles. The vehicles were first classified into 4 categories as follows.

- Two Wheelers (2W)
- Three Wheelers (3W)
- Cars and jeeps (4W), and
- Buses

Trucks were not considered for the study as their number is small on road and they are used for transport of goods and not passengers. Therefore, they do not serve as a mode choice for road users. Further, 4W comprises both passenger cars and big cars. They have been clubbed in one category as the vehicle occupancy is same in both. Table 1 show cases of the consolidated classified counts of various categories of vehicles over 9 AM to 5 PM period, with percentage composition of each

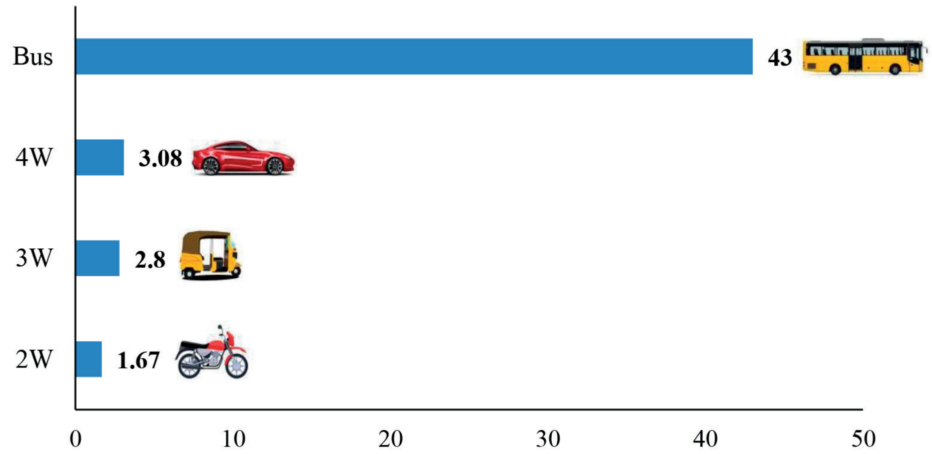


Figure 3 *Average occupancy per vehicle*

Table 31 *Determination of mode choice ratio among road users*

Category of vehicle	Number of vehicles on road (considering 100 vehicles plying on road)	Number of people using them (considering the avg. vehicle occupancy)	Percentage of road users using the specific vehicle category
2W	62	104	40.3
3W	13	37	14.3
4W	24	74	28.7
Bus	1	43	16.7
Total	100	258	

vehicle category. The vehicle counts are converted to PCUs (Passenger Car Units) based on the IRC 106-1990 (Guidelines for capacity of urban roads in plain areas) [23] as shown in Table 2. The PCU for any vehicular category is defined as the equivalent factor as compared to passenger car (which is 1.00), which is determined based on vehicle dimensions and its speed. In the case of 4W, as mentioned earlier, it comprises both passenger and big cars. Therefore, the PCU values for 4W is considered as 1.2 for the study.

As can be seen from Table 1, the average traffic volume on the studied 2-lane one way (one direction of 4-lane divided road) ranged from 938 PCUs to 2084 PCUs on a typical working day. The vehicle composition shows excessive use of private vehicles, both 2W and 4W, while commuting by the road users. Similarly, the 3W too account for 13.3%, which are known for their slow speeds and the public buses account just 1% on the road. However, this does not reflect the number of people using the public and private transport, since the occupancy of all modes is not the same. To understand this, the occupancy of various categories of vehicles have been collected through the field survey and have been extracted from recorded data as well. Figure 3 shows the average vehicle occupancy based on category of vehicles.

As can be observed from Figure 3, the average occupancy of 2W is the smallest and rightfully so, at 1.67, whereas, the 4W (cars and jeeps) even though have a minimum seating capacity of 5, are observed to have an average occupancy of around 3.08. Roughly, it can be stated that if 100 vehicles are plying on road, roughly 62 of them are 2W, 13 vehicles are 3W, 24 are 4Ws, and only 1 vehicle is a bus. From this data, the number of road users using various modes can be determined using their occupancy as stated in Table 3. The conclusion from Table 3 is that around 83% of people are opting for 2W, 3W, or car usage (as pillion/rider, or as driver/passenger), while only 16.7% are opting for bus.

From Table 3 can also be noticed that although 62% of trips on roads are made by 2Ws and 23.6% of trips are made by cars and jeeps (4Ws), which accounts for around 86% of trips on roads, however, the people using them comprise only 69%. This showcases that these vehicles might be augmenting traffic congestion leading to increased delays, since they occupy more space on the road, but their occupancy is less. Thus, a smaller number of people are using more space on road, which also varies between 2W, Cars, 3W and Buses. Many articles on social media present this event as a graphic image comparing cars and buses but it is not scientific/technically correct. Moreover, it also varies from category to category. To put a perspective of Indian conditions to the study, at first the top best-selling 2Ws, 3Ws, 4Ws and common buses observed on the road have been considered. The areas occupied by them on the road has been obtained (dimensions of vehicles) and their average has been considered for the said category for the study. Table 4 presents the details.

Average area obtained from Table 4 for different categories have been used in the present study for further

Table 4 *Area covered by commonly sold/observed vehicles of different categories*

Category of vehicle	Area occupied (m^2)	Average area occupied (m^2)
	2W	
Hero Splendor	1.48 (2.00 X 0.74)	1.38
Honda Activa	1.3 (1.833 X 0.697)	
Bajaj Pulsar	1.55 (2.035 X 0.765)	
TVS Jupiter	1.2 (1.834 X 0.650)	
	4W	
Tata Nexon	7.2 (3.995×1.804)	6.87
Maruti Suzuki Swift	6.7 (3.845×1.735)	
Maruti Suzuki Dzire	6.9 (3.995×1.735)	
Tata Punch	6.7 (3.827×1.742)	
	3W	
Bajaj Auto	3.4 (2.635×1.300)	3.67
Piaggio	3.7 (2.700×1.370)	
Atul Auto	3.9 (2.765×1.420)	
	BUS	
Ashok Leyland Sunshine	20.7 (9.415×2.200)	20.8
Mahindra Cruzio Grande Staff	21 (8.950×2.350)	
Eicher Starline	20.7 (9.584×2.164)	

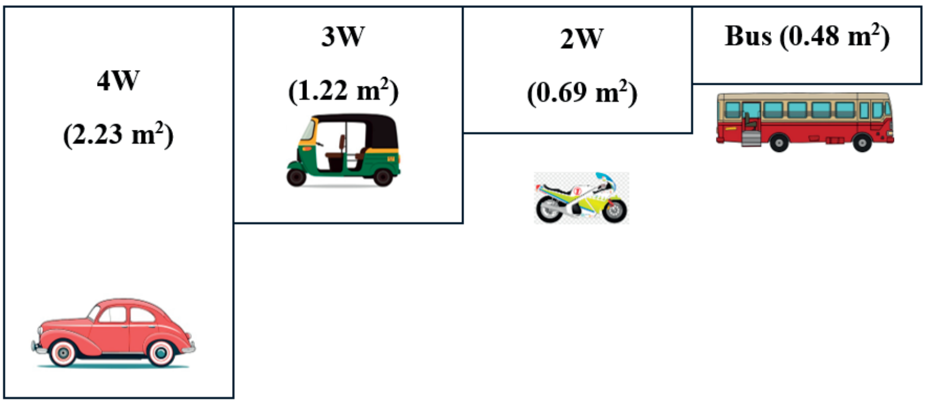


Figure 4 *Area occupied by each road user using a specific category of vehicle*

analysis on assessing the increased congestion on road. Based on the earlier results of vehicle occupancy, the area occupied by each road user using a specific category has been determined and is shown graphically in Figure 4. It clearly shows how people travelling in buses occupy the least space on the road (0.48 m^2) while people travelling in cars take up the highest space on road (2.23 m^2). In other words, the area occupied by around 5 people in a bus, is occupied solely by a car user.

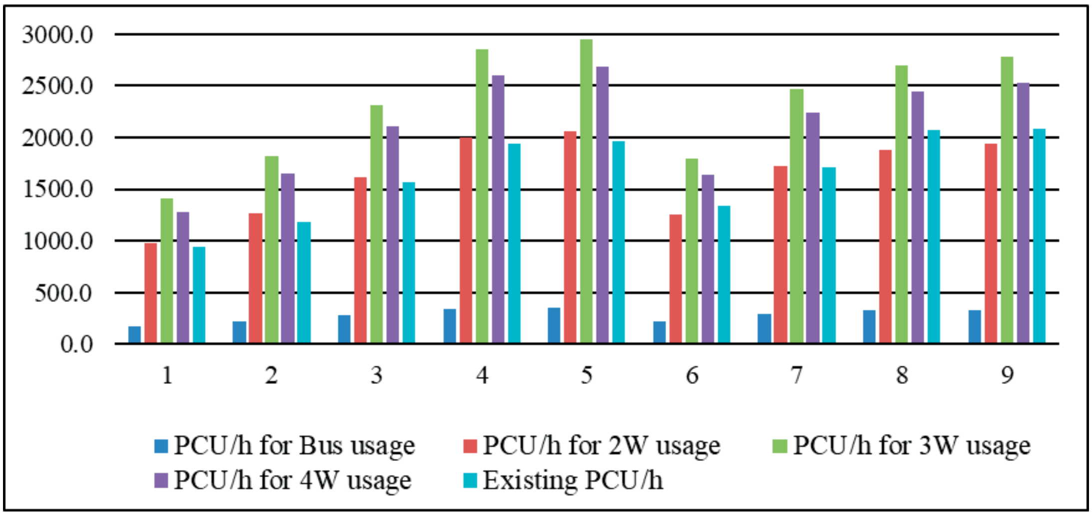
In an ideal scenario, if people start using cars only, it will lead to dangerous levels of traffic congestion. To identify the effect of specific vehicle type on traffic volume, which is a major indicator of the LOS on roads (Indo HCM, 2017; IRC 106-1990), 4 ideal scenarios have been created as follows.

- All road users use Bus.
- All road users use 2W.
- All road users use 3W.
- All road users use 4W/Car.

The effect of these ideal scenarios on LOS of the road is compared to the existing traffic scenario with prevailing vehicle proportions. Now, to analyze and compare, traffic counts from field data, as provided in Table 1, have been utilized. For instance, during 10-11 AM, which is one of the peak time periods, a total of 1440-2W, 260-3W, 400-4W, and 24 buses are travelling on the road. Based on average vehicle occupancy, during this time total number of people travelling on the surveyed road can be calculated, which comes out to be 5397 ≅ 5400 (1440*1.67 + 260*2.8 + 400*3.08 + 24*43). Considering the above data, the number of vehicles required if they travel only by 2W, 3W, Car/4W or bus (the 4 ideal scenarios listed earlier) is determined and then converted into PCUs (as per data from Table 2), to

Table 5 Determination of traffic volume under various traffic scenarios

Time (h)	Avg. occupancy	Only Bus		Only 2W		Only 3W		Only 4W		Ex. PCU
		No.	PCU	No.	PCU	No.	PCU	No.	PCU	
8-9	3276	76	167.2	1962	981	1170	1404.0	1064	1276.8	937.6
9-10	4235	98	215.6	2536	1268	1513	1815.6	1375	1650.0	1176
10-11	5397	126	277.2	3232	1616	1928	2313.6	1753	2103.6	1564.8
11-12	6665	155	341.0	3992	1996	2381	2857.2	2164	2596.8	1938.8
12-13	6879	160	352.0	4120	2060	2457	2948.4	2234	2680.8	1959.2
13-14	4197	98	215.6	2514	1257	1499	1798.8	1363	1635.6	1337.2
14-15	5749	134	294.8	3443	1721.5	2054	2464.8	1867	2240.4	1712.8
15-16	6282	146	321.2	3762	1881	2244	2692.8	2040	2448.0	2077.2
16-17	6478	151	332.2	3880	1940	2314	2776.8	2104	2524.8	2084
Avg. Volm.	5462	127	279.4	3272	1636	1952	2342.4	1774	2128.8	1643.1



5(b) *Comparison of existing traffic flow with specific vehicle usage scenarios*

Figure 5 *Graphs displaying traffic flow for specific vehicle usage scenarios and existing traffic volume*

know how the traffic flow can be reduced/increased if a specific category of vehicle is used by road users. These traffic flows are compared to the existing traffic flows (Existing PCU in Table 1) during that time interval. The detailed analysis and comparison of PCUs is shown in Table 5.

It can be observed that the usage of 3W, and Cars increase the PCUs of road as compared to existing traffic, whereas the usage of buses can decrease the PCU. In the context of the present study, the percentage decrease/increase in the traffic volume/accommodation of more/less road user, with the existing traffic volume, with respect to usage of specific category of vehicle is presented in Figures 5 (a) and (b).

5(a) Traffic volume in terms of PCU/h from 8 AM to 5 PM for specific vehicle usage compared to existing traffic flow

As can be seen from the Figure 5, the usage of Bus only, can decrease the traffic flow on roads by 83%, whereas the usage of cars/3W only shall increase the traffic flow by 30-43%. The present study is conducted on a 2-lane one way road where the capacity is 2400 PCU/h based on IRC 106-1990 and Indo-HCM (2017) [23-28]. According to IRC guidelines, for urban roads, the design level of service (LOS) should be C where V/C ratio lies between 0.56-0.70. Indo-HCM (2017) suggests new lane or any other measures if the existing volume regularly exceeds 1680 PCU/h, which is also termed as Design Service Volume (DSV). In the present study, it is observed that although the average existing traffic volume is 1643 PCU/h, however, there are instances like 11 AM - 1 PM and 3 PM - 5 PM where the volume exceeds DSV (Table 5). As can be seen from Table 5, if only buses are used, the LOS can decrease largely on road improving the quality of traffic movement. Table 6 shows the LOS ranges based on Indo-HCM (2017) [26] guidelines, and thereafter Table 7 presents the LOS while using a particular vehicle category under

Table 6 *LOS of Two lane Undivided Urban Roads [26]*

LOS level	V/C ratio
A	< 0.35
B	0.36 - 0.55
C	0.56 - 0.70
D	0.71 - 0.85
E	0.86 - 1.00
F	> 1.00

Table 7 *Determination of LOS under various traffic scenarios*

Time (h)	Only Bus		Only 2W		Only 3W		Only 4W		Actual PCU	Actual V/C (LOS)
	PCU	V/C (LOS)	PCU	V/C (LOS)	PCU	V/C (LOS)	PCU	V/C (LOS)		
8-9	167.2	0.07 (A)	981	0.41 (B)	1404.0	0.59 (C)	1276.8	0.53 (B)	937.6	0.39 (B)
9-10	215.6	0.09 (A)	1268	0.53 (B)	1815.6	0.76 (D)	1650.0	0.69 (C)	1176	0.49 (B)
10-11	277.2	0.12 (A)	1616	0.67 (C)	2313.6	0.96 (E)	2103.6	0.88 (E)	1564.8	0.65 (C)
11-12	341.0	0.14 (A)	1996	0.83 (D)	2857.2	1.19 (F)	2596.8	1.08 (F)	1938.8	0.81 (D)
12-13	352.0	0.15 (A)	2060	0.86 (E)	2948.4	1.23 (F)	2680.8	1.12 (F)	1959.2	0.82 (D)
13-14	215.6	0.09 (A)	1257	0.52 (B)	1798.8	0.75 (D)	1635.6	0.68 (C)	1337.2	0.56 (C)
14-15	294.8	0.12 (A)	1721.5	0.72 (D)	2464.8	1.03 (F)	2240.4	0.93 (E)	1712.8	0.71 (D)
15-16	321.2	0.13 (A)	1881	0.78 (D)	2692.8	1.12 (F)	2448.0	1.02 (F)	2077.2	0.87 (E)
16-17	332.2	0.14 (A)	1940	0.81 (D)	2776.8	1.16 (F)	2524.8	1.05 (F)	2084	0.87 (E)
Avg. volm.	279.4	0.12 (A)	1636	0.68 (C)	2342.4	0.98 (E)	2128.8	0.89 (E)	1643.1	0.68 (C)

particular traffic scenarios. Table 7 is an extension to Table 5.

In Table 7, it can be observed that LOS A is achieved only when buses are used for transport by all the road users. Similarly, even usage of only 2Ws will keep the LOS levels to mostly B/C. However, more usage of 3W and cars can lead to congestion and deteriorate the quality of traffic flow as compared to the actual traffic conditions on the road. Similarly, more usage of bus can help to alleviate the traffic congestion and improve the driving conditions. Previous studies by various authors [29-31] have examined changes in traffic conditions using historical data from cities such as Bhopal and Delhi, and have highlighted the challenges, and strategies associated with achieving sustainable urban mobility in India. The findings from the present study provides further insights into this issue by proposing strategic solutions to address the growing problem of traffic congestion in Indian cities, which has resulted in reduced LOS and increased congestion.

4 Conclusion

The traffic congestion is a major issue in many of the developing countries including India. Many studies are being conducted to tackle the issue. However, one of the most pertinent issues of mode use or vehicle passenger occupancy is less discussed and studied. In the present study was investigated the reduction of LOS on the road due to stubbornness of road users to use a particular category of a vehicle. Traffic survey was conducted on assessing the impact of different vehicle categories (Bus, Car, 3 Wheeler, and 2 Wheeler) on traffic volume and road capacity on various road stretches in Bhubaneswar. By analyzing existing traffic conditions and evaluating ideal scenarios where only one type of vehicle dominates the road, the study has yielded critical insights into the road space usage, traffic volume, and the overall quality of traffic flow.

The current analysis indicates that the existing traffic conditions, characterized by a diverse mix of vehicle types, result in moderate congestion. Although the Passenger Car Unit (PCU) values suggest that the traffic movement is generally manageable, there are noticeable signs of congestion during the peak hours. It was an insightful finding that the buses, which contribute just 1% of total vehicular categories for passenger transport, carry 16% of total road users. However, 2Ws, which comprise around 64% of total road traffic only carry 43% of total road users. Similarly, it was underwhelming to see that only 30% (16% buses, 14% 3Ws) of total passengers prefer public transport. A major portion, around 25-30% of people use private cars even for short distances. A key observation is the substantial difference in space efficiency among various vehicle categories. Buses, despite being fewer in number, utilize the road space most effectively on a per-person basis because of their high occupancy (0.48 m^2 per person). In contrast, cars are the least efficient mode, as they occupy the greatest road space per passenger (2.23 m^2 per person nearly 5 times of a person using bus), offering comfort but contributing heavily to congestion. Although the road users travelling in two-wheelers (2W) also occupy less space per capita (0.69 m^2), however, based on safety and risk factors, buses are safer. When all the road users depend solely on buses, the total PCU drops significantly, leading to smoother traffic flow and an improved Level of Service (LOS A with V/C consistently around 0.10). Conversely, a car-only scenario dramatically increases PCUs, resulting in severe congestion with LOS levels hovering around E and F for most of the time period. The 3 Wheeler scenario leads to higher PCUs compared to buses, yet remains less detrimental than cars, producing moderate traffic conditions. Similarly, 2 Wheelers show better space efficiency than cars and 3 Wheelers but still do not match the congestion-reducing potential of buses. Overall, the LOS assessment shows that the bus-dominated traffic performs the best due to efficient road space use and high occupancy, car-only conditions perform the worst owing to high space consumption and low occupancy, while the 2 Wheeler and 3 Wheeler scenarios offer moderate performance falling between these two extremes.

The study conclusion is that increasing the bus usage is the most effective way to alleviate traffic congestion and improve traffic flow. On the other hand, unchecked growth in the use of cars and 3 Wheelers will exacerbate congestion, reducing the efficiency and safety of the road infrastructure. To optimize traffic flow and LOS, policy recommendations should focus on encouraging public transportation (especially buses) and limiting the over-reliance on private vehicles like cars and 3 Wheelers. This can be done by reducing the prices of bus fares, and introducing dedicated bus lanes along with increasing the number of buses based on demand on various routes. Along with that, dedicated parking spaces for private cars and strict ban on on-road parking shall decrease usage of the private car.

The present study was concentrated only in a single city Bhubaneswar focusing only on urban major arterial roads. Therefore, the results of the present study might not be applicable to rural areas or metropolis directly; however, the same methodology can be applied to get the results for rural areas and metropolis. Future studies could incorporate the real-time traffic simulation tools and advanced modelling techniques to better predict the long-term effects of shifting vehicle usage patterns. Integration of emerging mobility options, such as electric buses, shared mobility services, and non-motorized transport, can also be explored to understand their impact on congestion and LOS. Additionally, assessing the influence of policy interventions, such as dedicated bus lanes, congestion pricing, and improved last-mile connectivity, can provide deeper insights for sustainable traffic management.

Acknowledgment

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

Conflicts of interest

The authors hereby 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] VUCHIC, V. R. *Urban transit systems and technology*. Hoboken, NJ: John Wiley and Sons, 2007. ISBN 978-0-471-75823-5.
[2] KADIYALI, L. R. *Traffic engineering and transport planning*. New Delhi: Khanna Publishers, 1999. ISBN 978-8174092205.
[3] CERVERO, R. Built environments and mode choice: Toward a normative framework. *Transportation Research Part D: Transport and Environment* [online]. 2002, **7**(4), p. 265-284. ISSN 1361-9209, eISSN 1879-2340. Available from: https://doi.org/10.1016/S1361-9209(01)00024-4
[4] India automotive market report FY 2023 - Bain and Company [online]. 2023. Available from: https://www.bain.com
[5] PINNA, M., SORRENTINO, A., BASSI, M. Transportation modal choices and trends in emerging markets: the case of India. *Transport Policy* [online]. 2014, **31**, p. 10-20. ISSN 0967-070X, eISSN 1879-310X. Available from: https://doi.org/10.1016/j.tranpol.2013.11.007
[6] SAXENA, A. Challenges and prospects of three-wheelers in India's public transport system. *Indian Journal of Transport Management* [online]. 2019, **43**(6), p. 312-325. ISSN 0972-5695.

[7] CHOUDHARY, R., VASUDEVAN, V. Study of vehicle ownership for urban and rural households in India. *Journal of Transport Geography* [online]. 2017, **58**, p. 52-58. ISSN 0966-6923, eISSN 1873-1236. Available from: https://doi.org/10.1016/j.jtrangeo.2016.11.006

[8] SHIRGAOKAR, M. Expanding cities and vehicle use in India: differing impacts of built environment factors on scooter and car use in Mumbai. *Urban Studies* [online]. 2016, **53**(15), p. 3296-3316. ISSN 0042-0980, eISSN 1360-063X. Available from: https://doi.org/10.1177/0042098015608050

[9] Ministry of Health and Family Welfare. National Family Health Survey (NFHS-5) 2019-2021: India reports. Government of India, 2021.

[10] REDDY, B. S., BALACHANDRA, P. Urban mobility: a comparative analysis of megacities of India. *Transport Policy* [online]. 2012, **21**, p. 152-164. ISSN 0967-070X, eISSN 1879-310X. Available from: https://doi.org/10.1016/j.tranpol.2012.02.002

[11] ABDULRAZZAQ, L. R., ABDULKAREEM, M. N., YAZID, M. R. M., BORHAN, M. N., MAHDI, M. S. Traffic congestion: shift from private car to public transportation. *Civil Engineering Journal* [online]. 2020, **6**(8), p. 1547-1554. ISSN 2676-6957, eISSN 2476-3055. Available from: https://doi.org/10.28991/cej-2020-03091566

[12] GUZMAN, L. A., OVIEDO, D., ARELLANA, J., CANTILLO-GARCIA, V. Buying a car and the street: transport justice and urban space distribution. *Transportation Research Part D: Transport and Environment* [online]. 2021, **95**, 102860. ISSN 1361-9209, eISSN 1879-2340. Available from: https://doi.org/10.1016/j.trd.2021.102860

[13] HARTMANN TOLIC, I., NYARKO, E. K., CEDER, A. Optimization of public transport services to minimize passengers' waiting times and maximize vehicles' occupancy ratios. *Electronics* [online]. 2020, **9**(2), 360. eISSN 2079-9292. Available from: https://doi.org/10.3390/electronics9020360

[14] CHANDRA, S., GANGOPADHYAY, S., VELMURUGAN, S., RAVINDER, K. Indian highway capacity manual (Indo-HCM). New Delhi: CSIR-CRRI, 2017.

[15] GUENSLER, H. *Conformity policy: air quality impact assessment for local transportation projects*. California: Institute of Transportation Studies, 1998.

[16] PUCHER, J., KORATTYSWAROOPAM, N., ITTYERAH, N. The crisis of public transport in India: overwhelming needs but limited resources. *Journal of Public Transportation* [online]. 2004, **7**(4), p. 1-20. eISSN 2375-0901. Available from: https://doi.org/10.5038/2375-0901.7.4.1

[17] KUMAR, M., ANAND, V., SRIVASTAVA, A. Public transport service quality and passenger satisfaction: a case of UPSRTC, Agra, India. *Pacific Business Review International*. 2016, **8**(11), p. 82-92. eISSN 0974-438X.

[18] SHAH, J., ADHVARYU, B. Public transport accessibility levels for Ahmedabad, India. *Journal of Public Transportation* [online]. 2016, **19**(3), p. 19-35. eISSN 2375-0901. Available from: https://doi.org/10.5038/2375-0901.19.3.2

[19] TIWARI, G., JAIN, D., RAO, K. R. Impact of public transport and non-motorized transport infrastructure on travel mode shares, energy, emissions and safety: case of Indian cities. *Transportation Research Part D: Transport and Environment* [online]. 2016, **44**, p. 277-291. ISSN 1361-9209, eISSN 1879-2340. Available from: https://doi.org/10.1016/j.trd.2015.11.004

[20] KHAROLA, P. S., TIWARI, G., MOHAN, D. Traffic safety and city public transport system: Case study of Bengaluru, India. *Journal of Public Transportation* [online]. 2010, **13**(4), p. 63-91. eISSN 2375-0901. Available from: https://doi.org/10.5038/2375-0901.13.4.4

[21] PANDEY, A., BISWAS, S. Assessment of level of service on urban roads: a revisit to past studies. *Advances in Transportation Studies*. 2022, **57**, p. 49-70. ISSN 1824-5463.

[22] MIR, S. H., KUMAR, D. Traffic congestion in tier-I and tier-II cities by executing Intelligent Traffic System. *International Journal of Progressive Research in Science and Engineering*. 2020, **1**(3), p. 12-17. eISSN 2582-7898.

[23] Indian Roads Congress (IRC). IRC:106-1990 - Guidelines for the design of roadways for mixed traffic. New Delhi: IRC, 2010.

[24] Ministry of Road Transport and Highways (MoRTH). Annual report 2019-2020. New Delhi: Government of India, 2020.

[25] Transport Research Wing (MoRTH). Indian highway capacity manual (IHCM). New Delhi: Government of India, 2011.

[26] Transport Research Wing (MoRTH). Manual on road traffic studies. New Delhi: Government of India, 2011.

[27] AITHAL, B., RAMACHANDRA, T. V. (Eds.). *Urban growth patterns in India: spatial analysis for sustainable development* [online]. CRC Press, 2020. ISBN 9780429275319. Available from: https://doi.org/10.1201/9780429275319

[28] TANWAR, R., AGARWAL, P. K. Investigating the factors determining service quality in Bhopal's multimodal public transport system: a factor analysis. *Case Studies on Transport Policy* [online]. 2025, **19**, 101317. ISSN 0967-070X, eISSN 1879-310X. Available from: https://doi.org/10.1016/j.cstp.2024.101317

[29] TANWAR, R., AGARWAL, P. K. Multimodal integration in India: opportunities, challenges, and strategies for sustainable urban mobility. *Multimodal Transportation* [online]. 2025, **4**(2), 100210. eISSN 2772-5863. Available from: https://doi.org/10.1016/j.multra.2025.100210

[30] SHARMA, A., SINGH, S. N., SERRATOS, M. M., SAHU, D., STREZOV, V. Urban energy transition in smart cities: a comprehensive review of sustainability and innovation. *Sustainable Futures* [online]. 2025, **10**, 100940. eISSN 2666-1888. Available from: https://doi.org/10.1016/j.sftr.2025.100940

[31] KAPOOR, A. Changes in ecosystem service values due to urbanization in the national Capital Region of India (2005-2025). *Discover Cities* [online]. 2026, **3**(1), 16. eISSN 3004-8311. Available from: https://doi.org/10.1007/s44327-026-00196-1