A Study on Characteristics of Vehicular Lateral Position on Rural Highways

Sandeep Singh, Vidya Rajesh, Rajesh Kumar Panda, S. Moses Santhakumar

Abstract

Many pieces of research have concentrated on traffic speed, time headway, space headway, and so on under non-lane-based heterogeneous traffic streams. In contrast, limited studies have been conducted for analyzing and modeling the vehicular lateral position. The lateral position of vehicles plays an equally vital role in the development of microscopic models. Moreover, the vehicle characteristics such as the lateral position and speed are considered independent in the traffic simulation modeling, ignoring their correlation. This study investigates the relationship between the lateral position of vehicles with traffic speed on rural highways. For this purpose, the traffic data related to different vehicles' lateral positions and speed were collected using an infra-red sensor instrument from the National Highways in India. The relationship of vehicles' lateral position with the traffic speeds under different ranges is analyzed to understand their dependence. The study results show that the relationship between vehicles' lateral position is significantly associated with the traffic speed. The study findings help formulate a microscopic simulation model to reproduce accurate maneuvering in the traffic stream, which is useful for analyzing traffic characteristics.

Keywords: Lateral Position; Traffic Speed; Mixed Traffic; Rural Highway; Microscopic Simulation Model.

1. Introduction

Understanding lateral vehicle characteristics of traffic under weak lane discipline is essential to interpret the complexity involved in maintaining a safe transverse position. It is seen that vehicles do not have enough longitudinal and lateral clearances with their surroundings during congestion making it unsafe for maneuvering. The measurements used to assess driver behavior are speed and lateral positions of the vehicles. The study on these parameters is the basis for traffic flow modeling and microscopic simulation analysis. Since these parameters are the key indicators of traffic operation on a rural highway, it is important to study the connections between them jointly rather than separately. Owing to the difficulties in data collection of lateral characteristics of vehicles, lateral vehicle maneuvers are not explicitly modeled and implemented in the simulation models. The minimum lateral distance required is anticipated to increase with the vehicular speed. Because the lateral gap of a specific type of vehicle also depends on the speed of the adjacent vehicle [1]. Further, due to the poor lane discipline in developed countries, such as India, the lateral position of the vehicle requirements under mixed traffic conditions becomes worse and needs to be given equal priority. Only a few studies have been made in the direction of exploring the lateral characteristics of vehicles in the past. The purpose of this analysis is to examine the relationship between the vehicle's lateral position and traffic speed.

2. Literature review

Most of the studies made in developing countries that carry heterogeneous traffic are limited to analyzing the performance of traffic streams using the temporal and longitudinal traffic characteristics. In India, due to the lack of lane behavior, vehicles not only interact longitudinally but also interact laterally with the vehicles around them [2].

* Corresponding author. Tel.: +91 9962219864.
E-mail address: sandeepsingh.nitt@gmail.com
The choice of vehicle speed is also determined by the vehicle's lateral position. The relationship between speed and lateral clearance is linear, and there are lower and higher clearance values at various speeds [3]. Thus, the lateral clearances with respect to speed can be measured using the linear interpolation technique. The gross lateral clearance is aggregated as the clearances of different vehicles, measured on the basis of their class and speed separately [4]. Nagaraj et al. [5] studied longitudinal and lateral clearance of vehicles to build traffic models. The thresholds for various vehicle types were evaluated. The interacting vehicles' interrelation with respect to the lateral gaps and speed was established by Singh et al. [6]. The report determined the maximum and minimum values on two-lane highways for various configurations of vehicle kinds.

Mallikarjuna [7] noticed a decrease in the vehicles' average gap as area occupancy increased. Brandon and Donnell [8] modeled the speed and lateral vehicle positions considering various single equations systems and methods. These techniques were used to decide whether the vehicle speed and lateral position metrics were endogenously related. Das et al. [9] stated that in the absence of non-lane-based traffic, vehicles frequently look for potential lateral gaps in surrounding traffic. This nature of driving was reported due to the variations in the static and operative features of different types of vehicles. Besides, when driving in various traffic situations, vehicles maintain different gaps, and the vehicle's lateral position often affects the gap [10]. Mahapatra and Maurya [11] studied the lateral and longitudinal performance of vehicles on Indian roads. The study investigated the effect of longitudinal speed on the vehicle yaw rate and found that their values and relationships to longitudinal speed are significantly different for different vehicle types. Chakroborty et al. [12] built acceleration and steering models to calculate the longitudinal and lateral positions. Arasan and Koshy [4] also estimated the longitudinal speed and lateral position. The findings of a study by Gunay [13] have shown that the lateral positions of vehicles within lanes are more disordered on Turkish highways than in developing countries, where a normal distribution in the lateral positions of vehicles can be observed. Singh et al. [14–15] investigated the speed and time headway characteristics at different traffic flow and density levels.

Unlike speed, time headways, time gaps, and lateral clearances, no further studies are made on establishing a relationship between the lateral position of vehicles with the speed of the traffic stream. Understanding that a precise characterization of lateral position is required to assess the follow-up activity correctly under non-lane-based heterogeneous traffic streams, this study focuses on analyzing the characteristic of vehicular lateral positions on straight roads in Indian traffic streams. The present study explores the association of lateral position of vehicles as a function of speed levels in order to evaluate the relationship between them, for which data on traffic speeds have been classified into appropriate ranges. Statistical parameters of the descriptive statistics were used to examine whether or not the change in the magnitude of the speed impacted the vehicular lateral position.

3. Data collection

This research gathered traffic data from Chennai-Trichy National Highway (NH-45) in Tamil Nadu, India. The sections were clear from any other physical obstacles, ensuring the minimum impact of any side friction on the vehicle traffic. The geometric details of the study site are shown in Fig 1.
The latest technological instrument, like the Transportable Infra-Red Traffic Logger (TIRTL), is used for data collection. It is a compact automated infra-red (IR) sensor-based instrument. It can record traffic parameters such as the classified lane-based volume of traffic, physical dimensions of vehicles, speed, time headway, lateral position, etc. It has a transmitter unit (Tx) and a receiver (Rx) located directly on the opposite side of the highway and transverse to the traffic flow. Vehicle speed and the lateral position is obtained from the timing of these beam events. The TIRTL instrument's arrangement across the highway segment for the traffic data acquisition is illustrated in Fig 2.

Fig. 2. Arrangement of TIRTL instrument.

The detailed working principle of the TIRTL instrument and the procedure for capturing various other traffic parameters can be found in the articles by Singh et al. [16–17]. Vehicle data like speed, lateral position, classified vehicle count, and volume were obtained using the TIRTL instrument. The instrument is set up across one direction (towards Trichy) of the four-lane divided highway segment, and traffic data is collected for 18 hours. Nine different vehicle classes were identified to be plying on the highway segment. The traffic composition of the vehicles at the highway segment is illustrated in Fig 3.

Fig. 3. Traffic composition of vehicles.

The ongoing traffic at the study site recorded by TIRTL was 11,066 vehicles during the 18 hours data collection period. The highway section NH-45 is characterized by the highest percentage of CAR with 36%, 2W and MCV accounted for 20% each as the second-highest percentage of vehicles, followed by LCV with 10%, 3W with 5%, HCV and MAV with 3% each, SCV with 2%, and BI (Bi-cycle) with least percentage of the share as only 1%.
The traffic flow variation at the study site is shown in Fig 4. It can be seen that the highest traffic flow is registered during the peak hour between 17:00 hr to 18:00 hr as 857 Veh/hr.

4. Dynamic Passenger Car Unit (DPCU) determination

The estimation of Dynamic Passenger Car Unit (DPCU) is important to transform heterogeneous traffic into equivalent homogeneous traffic. In this research, DPCU is calculated using the speed to area ratio method as shown in Equation (1), suggested by the Indo-HCM (2017) [18].

\[
DPCU = \frac{(V_c/V_i)}{(A_c/A_i)}
\]  

Where,

- \(V_c\) = Average speed of the CAR
- \(V_i\) = Average speed of the \(i^{th}\) subject vehicle type
- \(A_c\) = Area of the CAR
- \(A_i\) = Area of the \(i^{th}\) subject vehicle type

The CAR has been chosen as the standard type of vehicle for the DPCU estimate. Table 1 shows the average speed, dimensions, and DPCU values.

| Vehicle category | Average speed (Kmph) | Vehicle length (m) | Vehicle width (m) | Vehicle area (m²) | DPCU |
|------------------|----------------------|--------------------|-------------------|-------------------|------|
| 2W               | 50                   | 1.61               | 0.62              | 1.00              | 0.3  |
| 3W               | 73                   | 3.18               | 1.30              | 4.13              | 0.8  |
| CAR              | 80                   | 3.70               | 1.45              | 5.37              | 1.0  |
| SCV              | 55                   | 4.50               | 1.48              | 6.66              | 1.8  |
| LCV              | 65                   | 5.80               | 1.82              | 10.56             | 2.4  |
| MCV              | 60                   | 7.35               | 2.35              | 17.27             | 4.3  |
| HCV              | 56                   | 8.15               | 2.44              | 19.89             | 5.3  |
| MAV              | 49                   | 9.86               | 2.24              | 22.09             | 6.7  |
| BI               | 20                   | 1.45               | 0.32              | 0.46              | 0.3  |
The above-estimated DPCU values are used for converting the heterogeneous traffic flow of vehicles to homogenous traffic flow of vehicles, i.e., from vehicles per hour (Veh/hr) to DPCU/hr. The traffic flow in DPCU/hr at the study site is shown in Fig 5.

![Fig. 5. Traffic flow variation in DPCU/hr.](image)

The average traffic flow was found to be 1084 DPCU/hr. Fig. 5 that the highest traffic flow in DPCU/hr is recorded during mid-nighttime between 03:00 hr to 04:00 hr as 1584 Veh/hr. This is due to the higher number of MCVs, HCVs, and MAVs when compared to other vehicles. These vehicle categories have higher DPCU values compared to the DPCU value of a CAR.

5. Analysis of the lateral position of vehicles with respect to traffic speed

The dynamic characteristics of vehicles occupying the high-speed lane and low-speed lane affect the traffic parameters [19]. One such important traffic parameter is the lateral position (LP) of the vehicle. The LP of a vehicle is defined as the closest position of the vehicle from the edge of the median when the vehicle is in motion. The lateral position analysis of the vehicles shows differences in distance keeping between the various types of vehicles in the carriageway.

The frequency of the lateral position of vehicles is illustrated in Fig 6. Most vehicles occupy the middle of the roadway (between 3 m to 6 m of the carriageway width) for their maneuverability because they tend to maintain a safer lateral position with the other interacting vehicle.

![Fig. 6. Frequency of the lateral position occupied by vehicles.](image)
The frequency for the speed of vehicles is shown in Fig 7. Most vehicles operate at higher speeds between 80 Kmph and 90 Kmph due to their propensity to be maneuverable in free-flow conditions.

![Fig. 7. Frequency of the speed of vehicles.](image)

The scatter plots between speed and LP show how the LP changes with respect to speed. An increase in the LP of the vehicle increases the speed of the vehicle. Fig. 8 shows a rise in vehicle speed as the vehicle moves into the middle of the lane. It is also observed that the overall speed and lateral position relationship follows a second-degree polynomial relation with a moderate coefficient of determination ($R^2$) value of 0.6518.

$$Speed = 2.5937 \times (LP)^2 + 29.131 \times (LP) - 2.681$$  \hspace{1cm} (2)

Further, the observed speeds were classified into suitable intervals of 25 kmph to perform the descriptive statistics on the vehicular lateral position concerning the different speed levels. The speed levels were assumed as 0-25 kmph, 25-50 kmph, 50-75 kmph, 75-100 kmph, and 100-125 kmph. The summary of the descriptive statistical results for the vehicular lateral position at different speed levels is given in Table 2.
Table 2. Descriptive statistical results for the lateral position of vehicles at different speed levels.

| Statistical Parameter | 0-25 | 25-50 | 50-75 | 75-100 | 100-125 |
|-----------------------|------|-------|-------|--------|---------|
| Sample size           | 138  | 894   | 923   | 837    | 601     |
| Minimum               | 0.5  | 1.4   | 1.9   | 2.3    | 2.4     |
| Maximum               | 1.5  | 2.6   | 3.8   | 4.9    | 5.2     |
| Range                 | 1.0  | 1.2   | 1.9   | 2.6    | 2.8     |
| Mean                  | 1.2  | 2.1   | 3.5   | 4.4    | 4.8     |
| Median                | 1.1  | 1.7   | 2.8   | 3.6    | 4.2     |
| Mode                  | 1.0  | 2.1   | 2.6   | 3.5    | 4.0     |
| Standard deviation    | 0.76 | 1.12  | 2.60  | 3.40   | 3.61    |
| Standard error        | 0.06 | 0.04  | 0.09  | 0.12   | 0.14    |
| Coefficient of variation | 0.63 | 0.52 | 0.74 | 0.77 | 0.75 |
| Skewness              | 0.35 | 0.28  | 0.82  | 0.66   | 0.94    |
| Kurtosis              | 0.41 | 0.55  | 0.83  | 0.87   | 0.90    |
| 15th percentile       | 0.6  | 1.5   | 2.3   | 2.7    | 2.9     |
| 85th percentile       | 1.4  | 2.4   | 3.6   | 4.6    | 5.0     |

At the lowest speed of range between 0-25 kmph, the minimum and maximum lateral position maintained by all vehicle types on the highway section was observed to be 0.5 m to 1.5 m, respectively. At the highest speed of range between 100-125 kmph, the minimum and maximum lateral position maintained by all vehicle types on the highway section was observed to be 2.4 m to 5.2 m, respectively. The mean lateral position of vehicles at the lowest speed range is 1.2 m, and at the highest speed range is 4.8 m.

Table 2 results show that as the speed level increases, the average lateral position maintained by the vehicles is also increasing. The increasing trend shows that, as the speed of the vehicles on the highway increases, the vehicles keep a long distance from the side of the road edge for safe driving conditions in order to avoid traffic fatalities.

The skewness and kurtosis for the lateral position of vehicles at different speed levels lie in the range of 0.35 to 0.94 and 0.41 to 0.90, respectively. Generally speaking, the skewness and kurtosis of the lateral vehicle orientation increase as traffic speed increases. The nature of skewness is positive, indicating the unsymmetrical distribution of the dataset. While the nature of kurtosis is also positive, indicating that the tail of the distribution is thicker and the central region of the distribution is thinner compared to the normal distribution. The 15th and 85th percentile lateral position variation show an increasing trend with respect to the increase in traffic speed. The vehicles maintain a larger distance from the edge of the roadway. This may be due to the drivers' tendency to move away from the edge of the highway for safety purposes.

6. Results and Conclusions

In this study, the speed relations of the highway traffic were analyzed in order to investigate the nature of the association of vehicular lateral position. The data examined from the field study revealed that there exists a great dependency between the lateral position of vehicles and speed. It was also found that, in different states of traffic speed, the vehicular lateral position corresponds depending on the traffic condition.

This study explored the lateral characteristics of traffic considering the heterogeneity existing in the Indian highway traffic conditions. The study found that microscopic traffic variables such as lateral position, speed are correlated, and the correlation trend tends to vary under different traffic conditions. Furthermore, the descriptive statistical parameters of the lateral position of vehicles are studied to understand the characteristics of the lateral position of vehicles at various speed ranges. It is observed that the influence of the vehicular lateral position takes a new form under different traffic speed ranges. The findings presented in this paper provide a unique insight into the new type of lateral characteristics of vehicles that can be used effectively in microscopic traffic simulation modeling of highways.
7. Limitations and future scope of the study

In the present study, the analysis is done only for one selected section of a highway facility. This study can be further extended to several similar sections. A more extended period of traffic data can be collected and considered for studying the lateral vehicle characteristics under varying speed, flow, and density levels.

References

[1] C. Mallikarjuna, T. Budde, and D. Pal, Analysis of the lateral gap maintaining behavior of vehicles in heterogeneous traffic stream, Proc. Soc. Behav. Sci., vol. 104, pp. 370–379, 2013.
[2] G. Mahapatra, and A. K. Maurya, Study on lateral placement and speed of vehicles under mixed traffic condition, Proceeding of Conference of Eastern Asia Society for transportation Studies, 2015.
[3] K. P. Isaac, Studies on mixed traffic flow characteristics under varying composition, Ph.D. thesis, Bangalore University, Bangalore, India, 1995.
[4] V. T. Arasan, and R. Z. Koshy, Methodology for modeling highly heterogeneous traffic flow, J. Transp. Eng., vol. 131 (7), pp. 544–551, 2005.
[5] B. N. Nagaraj, K. J. George, and P. K. John, A study of linear and lateral placement of vehicles in mixed traffic environment through video-recording, Highway. Res. Bulletin, Indian Roads Congress, New Delhi, India, vol. 42, pp. 105–136, 1990.
[6] B. Singh, Simulation and animation of heterogeneous traffic on urban roads, Ph.D. Thesis, Indian Institute of Technology Kanpur, India, 1999.
[7] C. Mallikarjuna, Analysis, and modelling of heterogeneous traffic, Ph.D. thesis, Indian Institute of Technology Delhi, India, 2007.
[8] P. S. Brandon, and E. T. Donnell, Speed and lateral vehicle position models from controlled nighttime driving experiment J. Transp. Eng., vol. 134 (11), 2008.
[9] S. Das, A. K. Maurya, and A. K. Budhkar, Dynamic data collection of staggered-following behavior in non-lane-based traffic streams, SN Applied Sciences, 2019.
[10] D. Pal, and C. Mallikarjuna, Cellular automata cell structure for modeling heterogeneous traffic, European Transport – Trasporti. Europei., vol. 45, pp. 50–63, 2010.
[11] G. Mahapatra, and A. K. Maurya, Study of vehicles lateral movement in non-lane discipline traffic stream on a straight road, Proc. Soc. Behav. Sci., vol. 104, pp. 352–359, 2013.
[12] P. Chakraborty, S. Agrawal, and K. Vasiitha, Microscopic modeling of driver behavior in uninterrupted traffic flow, J. Transp. Eng., vol. 130 (4), pp. 438–451, 2004.
[13] B. Gunay, An investigation of lane utilisation on Turkish highways, Proceedings of the Institution of Civil Engineers - Transport, vol. 157 (1), pp. 43–49, 2004.
[14] S. Singh, A. Kumar, M. Niyas, and S. M. Santhakumar, Multivariate analysis of freeways speed and time headway under mixed traffic streams, 2020 International Conference on COMmunication Systems & NETworkS (COMSNETS), Bengaluru, India, pp. 116–121, 2020. https://doi.org/10.1109/COMSNETS48256.2020.9027497
[15] S. Singh, B. K. Shukla, and S. M. Santhakumar, Infra-red sensor-based technology for collecting speed and headway data on highways under mixed traffic conditions, 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, pp. 607–611, 2020. https://doi.org/10.1109/SPIN48934.2020.9070829
[16] S. Singh, B. K. Shukla, and S. M. Santhakumar, A study on lane-based capacity of four-lane rural highways with heterogeneous traffic, Int. J. Res. An. Rev., vol. 5 (4), pp. 274–283, 2018.
[17] S. Singh, B. K. Shukla, and S. M. Santhakumar, An empirical investigation of lateral placement of vehicles on multi-lane highways using infra-red sensor data, Int. J. Res. An. Rev., vol. 5 (4), pp. 1185–1189, 2018.
[18] Indian Highway Capacity Manual (Indo-HCM: 2017), CSIR-Central Road Research Institute (CRRI), New Delhi, India.
[19] S. Singh, R. K. Panda, D. K. Saw, and S. M. Santhakumar, Effect of heavy transport vehicles on speed-flow characteristics of mixed traffic on multi lane divided intercity highways, Resilience and Sustainable Transportation Systems. In: Proceedings of the 13th Asia Pacific Transportation Development Conference (ASCE), Shanghai, China, pp. 176–185, 2020. https://doi.org/10.1061/9780784492902.021