



Lateral Placement Characteristics of U-Turning Vehicles: A Statistical Investigation

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Abstract

The present study is carried out to comprehend the lateral placement characteristics of U-turning vehicle by collecting field data from 11 different median openings across India. Videography technique was used for data collection. A distribution fitting toolbox of MATLAB is used to fit the lateral placement data into statistical distribution and it is found that the collected lateral placement data of six test sections agreed to gamma distribution and five test sections were expressed with normal distribution. The lateral placement of U-turning vehicle moves away from the median side when the width of the road increases. Furthermore, from ANOVA test results, it is found that lateral placement of U-turning vehicles differs significantly due to the presence of kerb or shoulder. Subsequently, it is observed that at low hourly approaching through traffic volume (ATTV), the lateral placement of U-turning vehicles is skewed towards the kerbside of the carriageway and as the volume increases, lateral placement shifts towards the median side. Subsequently, mathematical models have been developed for different category of U-turning vehicles with varying ATTV. The developed models will be helpful for estimating conflicting traffic volume at median opening and proper estimation of conflicting traffic volume will result in better estimation of U-turn capacity at median opening. Furthermore, study of lateral placement will also be helpful for proposing a geometrical augmentation at median opening for reducing traffic congestion and for enhancing the level of service and safety.

Keywords Median opening · U-turn · Lateral placement · Distribution fitting · ANOVA · Mixed traffic

Introduction

In the past few decades, India has gone through rapid urbanization, which led to an enormous increase in vehicular traffic. Therefore, to cater the rapidly mounting demand, augmentation of the road network by constructing multi-lane roads is inevitable. The multi-lane roads are usually constructed with a raised median to segregate traffic coming from the opposite direction [1]. Median openings are provided in the raised median to allow the vehicular traffic to take 180° turn and reverse their direction of travel, and merge with the opposing traffic, termed as U-turn. In India, most of these median openings are uncontrolled, without

any signal, sign, or personnel for controlling the vehicular traffic movement [2]. Hence, these median openings operate as uncontrolled intersections facilitating one of the complex traffic maneuvers known as U-turn.

The U-turn maneuver at the median opening is very risky and complex because the U-turning vehicle has to deal with the fast-moving oncoming vehicle from the opposite direction and the vehicle has to take 180° turn and need to merge with the approaching stream [3, 4]. Proper capacity estimation of the median opening is one of the important steps for efficient traffic management and better traffic operation [5, 6]. The estimation of capacity at uncontrolled median opening requires three parameters, namely; conflicting through volume, critical gap, and follow-up time [6]. Among these three parameters, the estimation of conflicting traffic volume in mixed traffic is most challenging pertaining to the peculiarity heterogeneous traffic prevailing in India. In one of the studies in the United States of America for 6-lane road, the conflicting traffic volume was estimated as 2.2 times of approaching traffic volume in each lane [7]. These findings do not hold good under heterogeneous traffic conditions as

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small-size vehicles such as 2 W often squeeze through available small gaps between vehicles, and most of the time move in a disorganized manner [8]. Absence of lane discipline, reversal of priority, and a high degree of heterogeneity make the proper conflicting traffic volume estimation exercise cumbersome under heterogeneous traffic condition.

Therefore, conflicting traffic volume under heterogeneous traffic condition could be estimated properly by studying the lateral position of U-turning vehicle. Furthermore, the lateral positioning of the vehicle is also influenced by various factors like roadway geometry and traffic operation characteristics. Therefore, the lateral placement of U-turning vehicle is one of the important operational characteristics at median openings. The present investigation is undertaken to understand the lateral placement of U-turning vehicle at the uncontrolled median opening in mixed traffic condition. The detailed framework of the present study has been illustrated in Fig. 1.

Literature Survey

Several studies have been carried out to understand the placement characteristics at various traffic facilities. In one of the earliest researches, Bhardwaj et al. [9] studied the position of an outer wheel of vehicles on single, intermediate, and two lanes on an Indian highway. The research team observed that heavy vehicles move closer to the pavement edge when compared to cars and light commercial vehicles. Blab and Litzka [10] studied the lateral distribution of heavy vehicles and also attempted to find out the effect of lateral placement on the design of road pavements. They introduced a factor termed

as Shift factor (SF) which was used to describe the relation between speed and rutting. Dey et al. [11] studied the lateral placement of vehicles at 19 different sections of a two-lane highway in India. From the statistical data, it is indicated that the placement of vehicles may follow a unimodal or a bimodal curve depending upon the percentage of slow- and fast-moving vehicles. To address the issue of bimodality in the placement of vehicles, the research team described two parameters named as placement factor (PF) and skewness range (SR). Stodart and Donell [12] investigated vehicle speed, lateral position of vehicles, visibility of pavement marking and geometry roadway on a two-lane rural highway during controlled night time driving experience. The research team reported that horizontal curve direction, roadside hazard rating, vertical grade, horizontal curve radius, and approach tangent length depend on the vehicle speed and lateral vehicle position; whereas, upstream horizontal curve radius depends only on the speed of the vehicle. Mehar et al. [13] investigated lateral characteristics (like lateral acceleration) of different vehicles on a straight highway. The relation between lateral acceleration and heading angle with longitudinal speed is explored for the three different types of vehicles, named as hatchback car, sedan car, and motorized three-wheeler. Most of the above literature clearly indicates extensive research regarding the placement behavior of vehicles moving straight in different roadway facilities. However, very few literatures are available to understand the placement characteristics of U-turning vehicle at median opening. Mohapatra and Dey [5] studied the lateral placement of vehicles on 13 median openings at the six-lane divided urban road. The result suggested that all the U-turning vehicles have either unimodal or bimodal. Unimodal distribution was described by a normal distribution, whereas bimodal distribution was described separately by two different normal distributions; one for “only 2-W” and another for “all the vehicles excluding 2-W”. They described the issue of bimodality in placement using separation factor ($S(r)$) and placement factor (PF).

The review of the literature reveals that the lateral placement of U-turning vehicle is one of the important operational characteristics. From the critical review of available literatures, it was inferred that the placement behavior of vehicles has been studied to understand the traffic behavior, but the lateral placement of U-turning vehicle has not been explored in depth. Therefore, this study has been undertaken to get insight into the placement characteristics of U-turning vehicles for a better estimation of conflicting traffic volume, which is an intrinsic parameter for capacity estimation.

Study Area

The present study is carried out to understand lateral placement characteristics of U-turning vehicles by collecting field data from 11 uncontrolled median openings of 4-lane

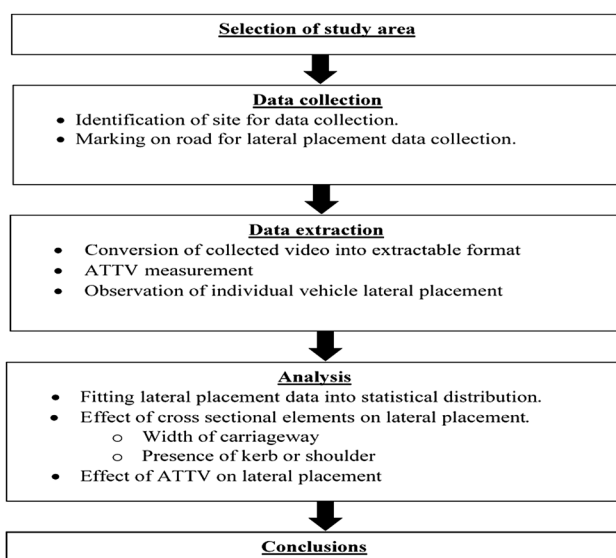


Fig. 1 Framework of the study

divided urban roads across India. The spatial coordinates of the data collection sites were extracted from google earth map. Subsequently, the extracted coordinate was fed to shapefile of Indian map in ArcGIS (version 10.3.1). The resulted output map has been presented as Fig. 2 to illustrate the data collection sites.

The width of the carriageway at the test sections varied from 6.00 to 7.50 m. Among the eleven test sections, six sections have shoulder and the other section has kerb. The

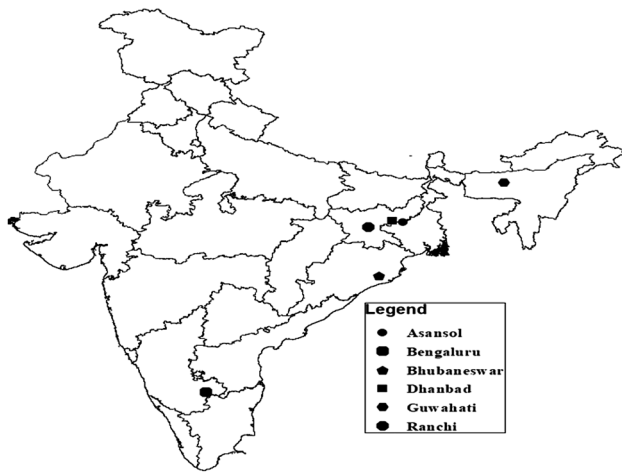


Fig. 2 Location of data collection sites

sites of data collection were chosen in such a way that the influence of curvature, nearby intersection, bus stop, pedestrian movement, on-street parking, and trading activities and other side friction are minimal. The eleven data collection sites were finalized because of their diversified geometric attributes. The details of the road geometry of all the test sections are given in Table 1.

A typical line diagram of a median opening along with the road marking is shown in Fig. 3. In this study, all the vehicles were segregated into four categories, namely: two-wheeler (2 W), three-wheeler (3 W), small car (SC) and big car (BC). Passenger cars were segregated into two categories, namely: small car (SC) and big car (BC) because several models of passenger cars are available in Indian market with varying operating conditions [13]. Cars having total length of 4 m or less are considered as SC (for example: Hyundai Santro, Maruti Wagonr, Tata Indica, Maruti Zen, Maruti Alto, Maruti 800, Nissan Micra, Hyundai i10, Hyundai i20, Maruti Suzuki Swift, Volkswagen polo, etc.) and cars having total length of 4 m or more are considered as BC (for example: Mahindra Scorpio, Tata sumo, Honda Civic, Honda City, Mahindra XUV 500, Hyundai Verna, Honda CRV Toyota Innova, etc.). The SCs generally have an engine less than 1500 cc and the BCs are fitted with engine more than 1500 cc. Some atypical cars like Maruti Swift Dzire, Hyundai Xcent, and Tata Indigo are shaped like sedans but their length is smaller than 4 m and engine capacity is

Table 1 Detailed geometry of all the test sections

Serial number	Section name	City	Kerb/shoulder	A (m)	B (m)	C (m)	Date and duration of data collection
01	S-01	Asansol	Kerb	1.25	6.00	16.20	21 May 2018 8 h
02	S-02	Bangalore	Kerb	1.35	7.50	17.60	7 March 2018 8.2 h
03	S-03	Bangalore	Kerb	1.40	7.50	19.40	9 March 2018 7.4 h
04	S-04	Bhubaneswar	Kerb	1.70	7.50	20.00	20 December 2018 7.6 h
05	S-05	Bhubaneswar	Shoulder	0.90	6.00	19.40	26 December 2018 8 h
06	S-06	Bhubaneswar	Kerb	1.10	6.00	17.50	27 December 2018 7.2 h
07	S-07	Dhanbad	Shoulder	1.20	7.50	17.40	13 July 2018 7 h
08	S-08	Guwahati	Shoulder	1.80	7.50	27.80	21 December 2017 7.5 h
09	S-09	Guwahati	Shoulder	1.00	6.00	20.00	19 December 2017 7 h
10	S-10	Ranchi	Shoulder	1.80	7.50	27.80	10 April 2018 8 h
11	S-11	Ranchi	Shoulder	0.80	7.50	21.40	12 April 2018 8.2 h

All the values are in meters. A: median width; B: road width; C: median opening width

Fig. 3 Layout of a typical median opening

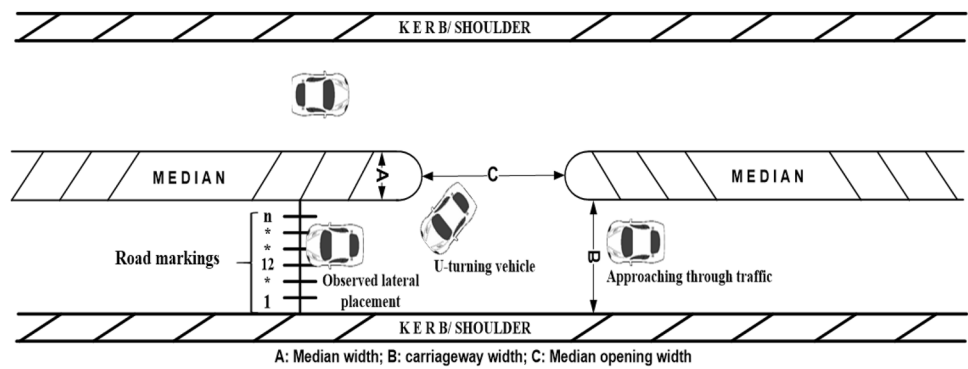


Table 2 Average distance of merging line from median nose

Category of vehicles	Average distance of merging line from median nose (m)
2 W	2.3
3 W	2.4
SC	2.6
BC	2.8

around 1000 cc. Therefore, these cars are considered as SC in the present study.

In this study, the left front wheel was observed for recording lateral placement because the left front wheel traverses the outer path and is more critical than the left rear wheel [5]. In the case of three-wheeler (3 W), the position of the left rear wheel is measured. The entire carriageway width was divided into a segment of 25 cm each by marking with the help of white color paint on the road surface and each segment was numbered continuously from the kerbside of the carriageway to the median side. From the preliminary study, 50 sample data were collected for each category of U-turning vehicles and it was observed that different category of U-turning vehicle completes the U-turn and merges with the approaching through traffic (ATT) at a distance as presented in Table 2. Therefore, the mid-value of the observed distance, i.e., 2.5 m was considered as a suitable distance for road marking to collect the lateral placement data. A similar observation was also reported by Mohapatra and Dey [5] in 6-lane divided urban roads.

Video recording technique was employed to collect the lateral placement data for U-turning vehicles. The video was recorded in such a way that observations were possible for lateral placement of U-turning vehicle. For finding the suitable position to install the camera for collecting traffic data, 10-min video data were collected and the video was played at the data collection site in a laptop and the percentage of drivers getting distracted due to the position of the video camera was observed. If the distraction percentage was observed to be more than 5 percent, then the position

of the video camera was changed and the above procedure was repeated until the distraction percentage was reduced to less than 5 percent. When the distraction percentage was observed to be less than 5 percent, then the authors considered the position of the video camera to be suitable for data collection.

Extraction and Analysis of Data

The recorded video was played on a large display monitor and video image-processing software (Avidemux, version: 2.7.3) was used to extract required data manually from recorded video. The parameters extracted include lateral placement of U-turning vehicle and hourly approaching through traffic volume (ATTV) and U-turning vehicle. The observed ATTV and U-turning traffic composition during peak period have been presented in Tables 3 and 4, respectively.

The lateral placement data were recorded from the kerbside because it was easy to observe the left front wheel of U-turning vehicles. But for the analysis purpose, the lateral placement of U-turning vehicles was presented from the median side of the road to have a common reference point. To present the lateral placement from the median side, the observed lateral placement (i.e., measured from the kerbside of the road) of each and every vehicle is deducted from the road width of the particular road section. For all the eleven test sections, the lateral placement for each category of U-turning vehicles was converted into a frequency distribution table of 25-cm class intervals. The mean and standard deviation were calculated for all the four categories of U-turning vehicles and have been given in Table 5. From the results tabulated in Table 5, it is observed that the mean placement of two-wheeler (2 W) is usually within the lane near the median side. The observed characteristics could be attributed to the small turning radius, small size, and peculiar shape of 2 W. The observed lateral placement of 3 W is found to be the slightly more than 2 W. The observed placement is due to the conical shape of 3 W and aggressive

Table 3 Peak hour traffic volume and composition of ATT at different test sections

Section no.	ATTV (vehicles/h)	Composition of ATT (%)						
		2 W	3 W	SC	BC	LCV	HV	Other
S-1	2412	50.17	12.52	18.28	16.54	–	–	2.49
S-2	3072	40.66	13.77	19.17	24.19	0.55	–	1.66
S-3	3492	41.12	16.04	20.07	20.65	0.6	–	1.52
S-4	2676	48.65	8.64	22.87	17.04	1.08	–	1.72
S-5	3132	48.63	10.85	19.13	19.54	–	–	1.85
S-6	3276	45.45	11.87	23.02	18.41	–	–	1.25
S-7	3254	55.15	4.42	16.91	14.34	4.42	–	4.76
S-8	3228	31.05	9.13	40.64	15.07	–	–	4.11
S-9	3304	32.72	10.14	37.79	14.75	–	–	4.6
S-10	2516	63.69	6.55	18.45	9.52	–	–	1.79
S-11	2844	55.27	16.03	12.66	10.55	0.84	0.45	4.2

Table 4 Peak hour traffic volume and composition of U-turning vehicles at different test sections

Section no.	U-turning traffic volume: vehicles/h	Composition of U-turning traffic (%)				
		2 W	3 W	SC	BC	Other
S-1	372	49.73	15.32	21.24	8.33	5.38
S-2	744	61.42	6.32	19.22	8.47	4.57
S-3	696	51.58	12.79	16.67	17.38	1.58
S-4	648	45.06	14.2	19.29	18.98	2.47
S-5	684	47.66	13.89	17.4	19.00	2.05
S-6	348	40.51	7.47	26.16	22.41	3.45
S-7	420	51.43	17.14	22.86	5.71	2.86
S-8	612	27.45	11.76	41.18	13.73	5.88
S-9	636	58.50	5.66	22.64	9.43	3.77
S-10	228	36.84	10.53	21.05	26.32	5.26
S-11	252	52.38	9.52	19.05	14.29	4.76

Table 5 Descriptive statistics of lateral placement data of U-turning vehicles at all test sections

Section no.	2 W		3 W		SC		BC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S-1	241.13	70.14	275.73	66.34	306.44	61.67	321.39	54.16
S-2	349.25	98.02	438.19	80.35	483.64	68.90	512.44	58.54
S-3	357.51	101.83	402.03	95.61	481.79	88.54	518.80	86.37
S-4	328.85	99.99	388.93	88.54	463.53	81.80	509.68	66.97
S-5	304.94	113.25	346.01	106.18	377.44	96.22	388.99	88.54
S-6	238.08	74.66	283.48	71.17	309.54	66.12	332.43	59.57
S-7	372.81	164.95	487.24	141.82	513.44	121.25	541.81	96.36
S-8	386.32	142.31	491.77	107.89	521.31	76.88	548.65	89.55
S-9	397.42	102.90	448.50	73.16	475.79	70.69	478.85	60.41
S-10	452.30	131.67	481.99	98.18	514.84	93.72	524.31	88.54
S-11	391.19	115.96	504.17	61.05	553.18	55.59	560.78	60.14

All the values are in centimeters
 SC small car, BC big car

driving of its driver [5, 14]. The bigger dimension of SC and BC with high turning radius compel these vehicles to encroach more carriageway width resulting highest mean lateral placement (towards shoulder/kerb).

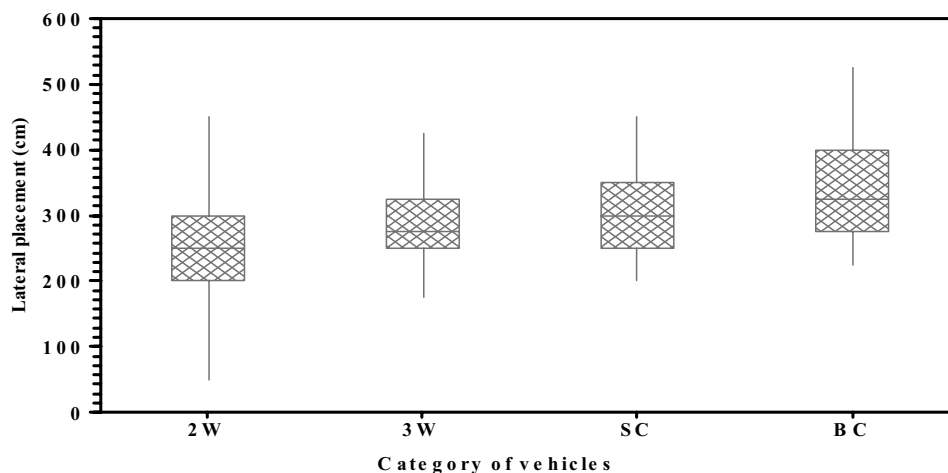
Various statistical parameters pertaining to the lateral placement have been computed and compiled in the form of box plot as shown in Fig. 4. In a boxplot, the input data set is segregated into quartiles. The boxplot demonstrates the minimum value, lower quartile, median, upper quartile, and maximum value. The vertical axis shows the range of the data [15]. The bottom and top of the box represent the 25th and 75th percentile of lateral placement, respectively [16]. The box has been segregated into two parts; the dividing line represents the median of lateral placement. Wide variation in the lateral placement of 2 W can be observed from Fig. 4. This phenomenon is observed for two reasons: (a) the

dimensions and the frontal shape of two-wheelers and (b) the unique driving behavior of 2 W drivers [17].

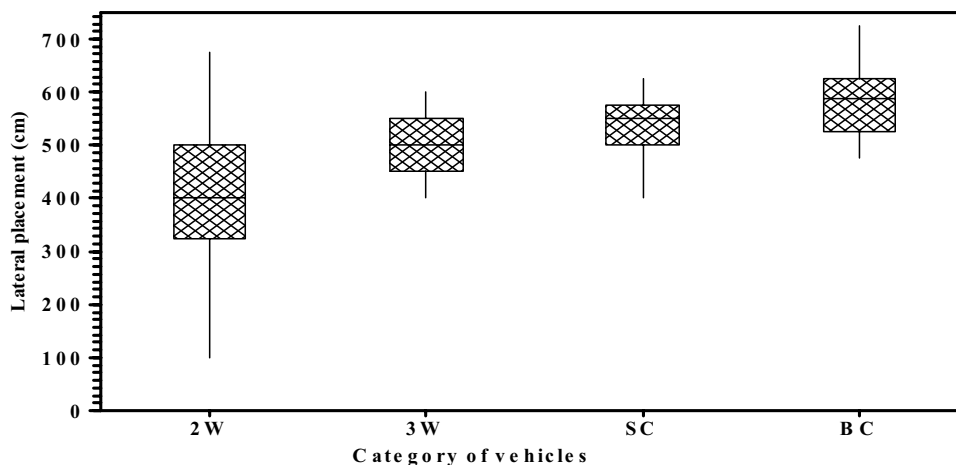
Statistical Distribution

The collected lateral placement data at all the eleven test sections were tried to fit into a statistical distribution. In this effort, distribution fitting toolbox of MATLAB is employed and different distribution, namely: gamma, lognormal, log-logistic, normal and Weibull are examined. Distribution fitting toolbox gives the log-likelihood value and the lowest negative value corresponds to the best fitting for the data [18]. Table 6 presents the details of the parameters of distribution fitted to all the test sections. From the test result, it is seen that data for S-01, S-02, S-03, S-04, and S-06 were

Fig. 4 Lateral placement of U-turning vehicles: a S-01, b S-11



(a) Section 1



(b) Section 11

Table 6 Parameters for lateral placement distribution

Serial number	Section name	Distribution fitted	Mean (μ)	SD (σ)	Alpha (α)	Beta (β)
01	S-1	Normal	327.27	73.14	–	–
02	S-2	Normal	331.51	109.22	–	–
03	S-3	Normal	346.49	113.05	–	–
04	S-4	Normal	350.87	111.01	–	–
05	S-5	Gamma	–	–	5.62	46.76
06	S-6	Normal	319.75	80.26	–	–
07	S-7	Gamma	–	–	4.69	47.74
08	S-8	Gamma	–	–	4.54	58.63
09	S-9	Gamma	–	–	2.98	49.85
10	S-10	Gamma	–	–	4.93	55.09
11	S-11	Gamma	–	–	6.04	49.85

fitted to normal distribution and gamma distribution is fitted for the other 6 test section considered in this study.

Further to ascertain the reliability of the distribution fitting operation, goodness of fit is tested by Chi-square test. The lateral placement frequency curve for S-01 and S-11 is

shown in Fig. 5a, b, respectively. The theoretical frequency was calculated using the normal distribution equation for S-01. The calculated and critical values of S-01 for Chi-square test were 27.01 and 28.86 at 18 degrees of freedom and at 95% confidence level. As the calculated value is less

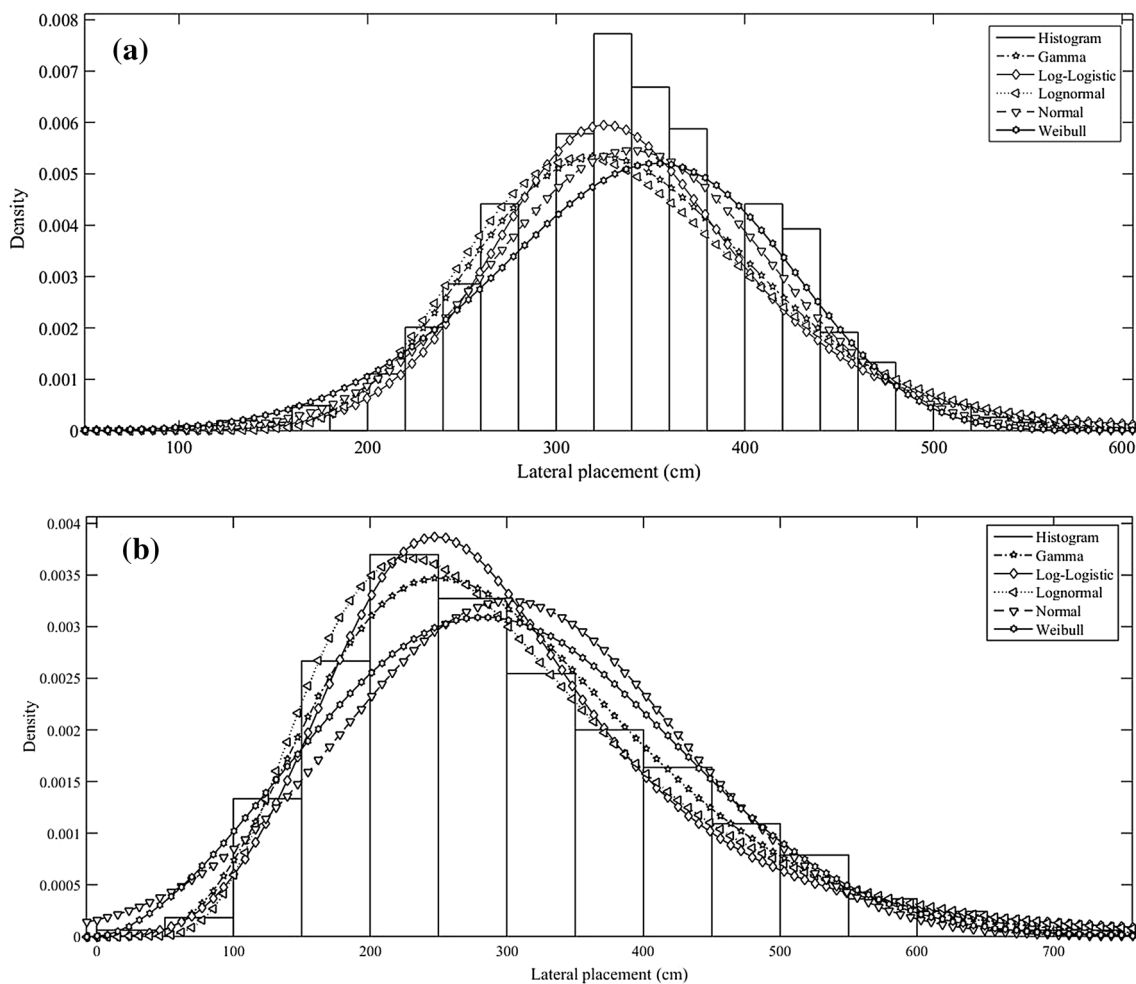


Fig. 5 Lateral placement distribution curve for U-turning vehicles: **a** S-01, **b** S-11

than the critical value, it is inferred that the data correspond to normal distribution. For S-11, gamma distribution equation was used to calculate the theoretical frequency. The calculated and critical values of S-11 for Chi-square test are 8.01 and 30.14 at 19 degrees of freedom and at 95% confidence level. As the calculated value is less than the critical value, it is inferred that the data follow gamma distribution.

Effect of Cross-Sectional Elements on Lateral Placement of U-Turning Vehicles

Statistical investigations are carried out to ascertain the effect of cross-sectional elements on the lateral placement of U-turning vehicle. Cross-sectional element includes road margins, width of carriageway, cross slope of the carriageway, kerbs, cross slope, etc. In this investigation, the effect of carriageway width, presence of kerb or shoulder is explored by ANOVA.

Width of Carriageway

In this section, the effect of width of carriageway on lateral placement of U-turning vehicles was studied. To evaluate the effect of width of carriageway on lateral placement of U-turning vehicle, sections with similar road margins are compared. For example, test sections S-09 and S-10 have shoulder as road margin and width of carriageway of the two sections are 6 m and 7.5 m, respectively. Likewise, test sections S-01 and S-03 have kerb as road margin and width of carriageway of the two sections are 6 m and 7.5 m, respectively. The mean lateral placement of all four sections with different carriageway width has been presented in Fig. 6. The dissimilarity in the lateral placement for all the categories of U-turning vehicle can be observed from the histogram.

Therefore, ANOVA is carried out on the observed lateral placement of different categories of U-turning vehicle. The results of the analysis have been presented in Table 7. From the table, it can be seen that the average lateral placement of all four categories of vehicles varies with the width of the carriageway. As the road width increases, the placement of U-turning vehicle also moves away from the median side.

Furthermore, the *P* value from ANOVA test suggests that the lateral placement of U-turning vehicles is significantly affected by the road width. Similar analysis was carried out between S-01 and S-02, S-01 and S-04, S-02 and S-06, S-03 and S-06 and S-04 and S-06 having kerb as their road margins; whereas S-05 and S-07, S-05 and S-08, S-05 and S-10, S-05 and S-11, S-07 and S-09, S-08 and S-09, S-09 and S10 and S-09 and S-11 were having shoulder as their road margins. From the ANOVA test between these sections, the result suggests that there is a significant difference between the lateral placements due to the difference in width of the carriageway. Hence, from the analysis, it is concluded that the carriageway width plays a significant role in the lateral placement of U-turning vehicle.

Presence of Kerb or Shoulder

In this section, the effect of presence of kerb or shoulder on lateral placement of U-turning vehicles was studied. To evaluate the effect of presence of kerb or shoulder on lateral placement of U-turning vehicle, sections with similar carriageway width are compared. For example, test sections S-02 and S-05 have 7.5-m carriageway width and road margins of the two sections are kerb and shoulder, respectively. Likewise, test sections S-05 and S-06 have 6-m carriageway width and road margins of the two sections are kerb and shoulder, respectively. The mean lateral placement of all four

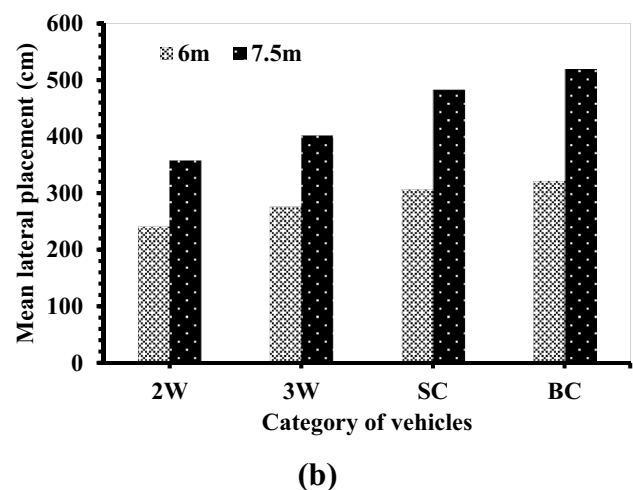
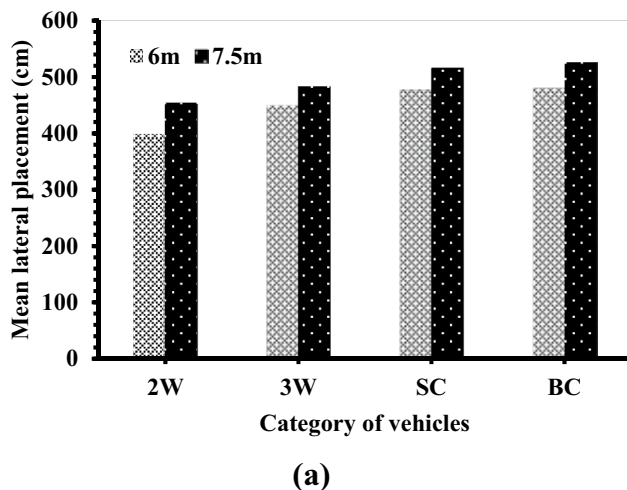


Fig. 6 Mean lateral placement, a S-09 and S-10; b S-01 and S-03

Table 7 ANOVA test results of test sections having similar road margins but differ in carriageway width

Section name	Category of vehicles	Carriageway width	Kerb/shoulder	Mean	SD	P value	F value	F critical value
S-09	2 W	6.0 m	Shoulder	397.42	102.90	0.000	190.72	3.86
S-10		7.5 m		452.30	131.67			
S-09	3 W	6.0 m		448.50	73.16	0.000	51.99	3.95
S-10		7.5 m		481.99	98.18			
S-09	SC	6.0 m		475.79	70.69	0.000	44.49	3.90
S-10		7.5 m		514.84	93.72			
S-09	BC	6.0 m		478.85	60.41	0.000	29.76	3.90
S-10		7.5 m		524.31	88.54			
S-01	2 W	6.0 m	Kerb	241.13	70.14	0.000	69.18	3.84
S-03		7.5 m		357.51	101.83			
S-01	3 W	6.0 m		275.73	66.34	0.000	11.74	3.85
S-03		7.5 m		402.03	95.61			
S-01	SC	6.0 m		306.44	61.67	0.000	27.59	3.85
S-03		7.5 m		481.79	88.54			
S-01	BC	6.0 m		321.39	54.16	0.000	21.00	3.85
S-03		7.5 m		518.80	86.37			

sections with different road margins has been presented in Fig. 7.

The dissimilarity in the lateral placement for all the categories of U-turning vehicle can be observed from the histogram. Therefore, ANOVA test is carried out on the observed lateral placement of different categories of U-turning vehicle. The results of the analysis have been presented in Table 8. From the table, it can be seen that the average lateral placement of all four categories of vehicles varies with the presence of a different type of road margins (kerb or shoulder). The lateral placement was observed towards the median side due to the presence of kerb, whereas the lateral placement was observed to skew towards the shoulder side

due to the presence of shoulder. Furthermore, the P-value from ANOVA suggests that the lateral placement of U-turning vehicles is significantly affected by the presence of different type of road margins. Similar analysis was carried out between S-01 and S-02, S-01 and S-04, S-02 and S-06, S-03 and S-06 and S-04 and S-06 having kerb as their road margins; whereas S-05 and S-07, S-05 and S-08, S-05 and S-10, S-05 and S-11, S-07 and S-09, S-08 and S-09, S-09 and S-10 and S-09 and S-11 were having shoulder as their road margins. From the ANOVA test, the result suggests that there is a significant difference between the lateral placement of U-turning vehicles due to the presence of different type of road margins (kerb or shoulder). Hence, from the analysis,

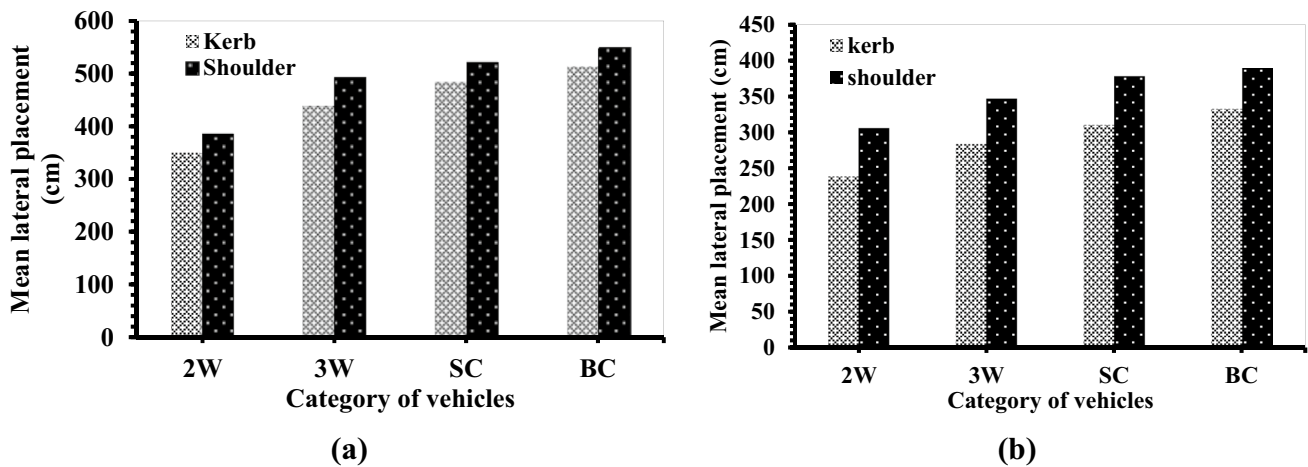


Fig. 7 Mean lateral placement, a S-02 and S-08; b S-05 and S-06

Table 8 ANOVA test results of test sections having same carriageway width but different road margin

Section name	Category of vehicles	Carriageway width	kerb/shoulder	Mean	SD	P value	F value	F critical value
S-02	2 W	7.50 m	Kerb	349.25	98.02	0.020	4.83	3.84
S-08			Shoulder	386.32	142.31			
S-02	3 W		Kerb	438.19	80.35	0.003	8.49	3.86
S-08			Shoulder	491.77	107.89			
S-02	SC		Kerb	483.64	68.90	0.000	36.73	3.85
S-08			Shoulder	521.31	76.88			
S-02	BC		Kerb	512.44	58.54	0.003	8.86	3.85
S-08			shoulder	548.65	89.55			
S-06	2 W	6.0 m	Kerb	238.08	74.66	0.000	102.56	3.85
S-05			Shoulder	304.94	113.25			
S-06	3 W		Kerb	283.48	71.17	0.000	213.06	3.86
S-05			Shoulder	346.01	106.18			
S-06	SC		Kerb	309.54	66.12	0.000	15.68	3.86
S-05			Shoulder	377.44	96.22			
S-06	BC		Kerb	332.43	59.57	0.000	22.10	3.86
S-05			Shoulder	388.99	88.54			

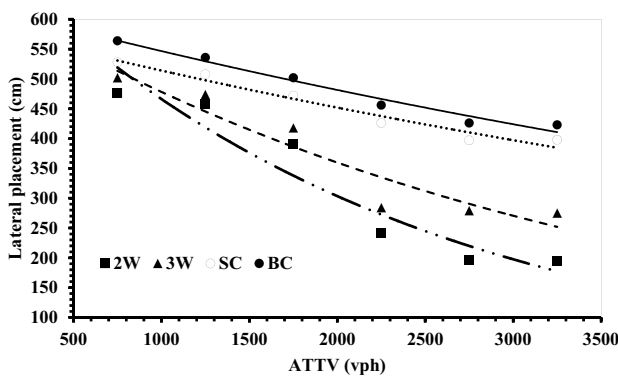


Fig. 8 Lateral placement at varying ATTV

it is concluded that the road margins play a significant role in the lateral placement of U-turning vehicle.

Effect of ATTV on Lateral Placement

After evaluating the geometrical attributes on lateral placement of U-turning vehicle, the effect of operational characteristics such as ATTV on lateral placement of U-turning vehicles was evaluated. The variation of lateral placement with varying ATTV is shown in Fig. 8. The aggregated lateral placement data for each category of U-turning vehicles have been segregated into groups on the basis of ATTV. The ATTV was determined on the basis of 5-min video count because researchers have reported that 5 min of vehicle count provides the realistic estimation of hourly traffic volume in heterogeneous traffic

flow condition [19]. From the exercise, the ATTV was observed to vary from 500 vph to 3500 vph. Subsequently, the traffic volumes are classified into 6 groups with a bin size of 500 vph. Afterward, the lateral placement of a particular category of U-turning vehicle corresponding to a particular ATTV range was aggregated. The mean and standard deviation of each category of U-turning vehicle corresponding to the ATTV were estimated. It was observed that at low traffic volume, the lateral placement of U-turning vehicles is skewed towards the kerbside of the carriageway. Gradually, as the traffic volume increases, the lateral placement shifts away from the kerbside to the median side. The possible explanation for this observation could be due to the reason that with an increase in ATTV, the U-turning vehicles are forced to wait for longer period of time than they generally wait at the median opening before taking U-turn. Hence, due to the longer waiting period, the U-turning vehicle drivers get impatient and try to complete the U-turn swiftly utilizing less width of carriageway than usual. Hence, due to swift merging, ATTV has to reduce their speed and allow the U-turning vehicle to complete their U-turn. After investigating the effect of ATTV on lateral placement, the authors have suggested mathematical models for different categories of U-turning vehicles. The developed model has been presented in Table 9. The disparity of lateral placement of U-turning traffic volume with varying ATTV is an important phenomenon because these findings will significantly affect the estimated conflicting traffic volume. Subsequently, a better estimation of conflicting traffic volume will result in the realistic computation of U-turn capacity.

Table 9 Proposed models for different category of U-turning vehicles at varying ATTV

Category of vehicles	Models	R ²
2 W	716.58 e ^{-0.00043ATTV}	0.92
3 W	635.97 e ^{-0.00028ATTV}	0.88
SC	584.83 e ^{-0.00013ATTV}	0.95
BC	620.88 e ^{-0.00013ATTV}	0.97

Table 10 Model validation

Category of vehicle	Lateral placement		Difference in percentage
	Proposed model	Field observation	
2 W	346.17	316.00	9.55
3 W	395.99	369.00	7.31
SC	469.35	440.50	6.55
BC	498.28	482.00	3.38

Validation of the Proposed Models

For validating the proposed model, field data were collected from a different test section which was not used for developing the models. From the collected field data, two parameters were extracted namely, lateral placement of U-turning vehicle and ATTV. A random sample of 50 data for each category of U-turning vehicles was extracted for validating the proposed model. Table 10 shows the lateral placement values obtained from the proposed model and filed observation. From Table 10, it can be observed that lateral placement obtained from field data is in close agreement with the result obtained from the proposed model. Moreover, it can also be observed that the maximum and minimum errors in estimating the lateral placement values are 9.55% and 3.38%, respectively. Therefore, it can be concluded that the proposed models are efficient enough to predict the lateral placement of different categories of U-turning vehicles in 4-lane divided urban road.

Conclusions

The U-turning vehicle encroaches upon the lane width in the opposite direction and creates a possibility of conflict with the ATT and congestion at the median opening area. The capacity of U-turn is dependent on the amount of conflicting traffic, which depends upon the type of vehicle making the U-turn. The capacity estimation needs three intrinsic parameters, namely: conflicting traffic volume, critical gap and follow-up time. Out of these there parameters, the calculation of conflicting traffic volume is challenging pertaining the peculiar characteristic of mixed traffic in developing

courtiers in general and in India as particular. The conflicting traffic volume can be estimated properly by studying the lateral placement of U-turning vehicles. Therefore, a statistical investigation of lateral placement characteristics of U-turning vehicle has been carried out in this study by collecting lateral placement data from 11 uncontrolled median openings of 4-lane divided urban roads across India. The frequency distribution plot for lateral placement was plotted for all categories of U-turning vehicles at all the test sections. It was observed that the size of vehicles has a significant effect on the lateral placement of U-turning vehicles. A distribution fitting toolbox of MATLAB was employed to examine the distribution of lateral placement data. The inferences made from the exercise were further analyzed by Chi-square test. A coherence was observed between the results of distribution fitting toolbox and Chi-square test. Furthermore, ANOVA test has been carried out to evaluate the effects of cross-sectional elements on the lateral placement characteristic of vehicle. The ANOVA test result showed that the width of the carriageway and presence of kerb or shoulder have significant effects on the lateral placement of U-turning vehicles. The effect of varying ATTV on lateral placement has been explored and it was observed that at low ATTV, the lateral placement is skewed towards the kerbside, but as the ATTV increases, the lateral placement shifts towards the median side. Subsequently, separate models to predict the lateral placement for different categories of U-turning vehicle have been proposed. The proposed model will be helpful for estimating the lateral placement of U-turning vehicles only by knowing the ATTV, without carrying the placement study. The accuracy of the proposed model was checked by comparing the lateral placement obtained from field data and the placement estimated from the model. The maximum percentage difference was found to be 9.55%. The current study on lateral placement of U-turning vehicle will give an insight into the merging behavior of U-turning vehicle and will be useful in correct estimation of conflicting traffic volume. Correct estimation of conflicting traffic volume will be beneficial for realistic estimation of capacity of U-turns at median openings in mixed traffic condition. Furthermore, this investigation holds significance to improve the geometry of the road at median openings which will mitigate the congestion and will enhance the operating condition as well as the safety at uncontrolled median openings on multilane divided roads.

This study not only possesses lots of future scope for extension but also has practical implications in planning, operation, and design of uncontrolled median openings of not only India but also in other parts of the world possessing varying attributes of traffic operation. The researchers have not considered the relationship between speed of U-turning vehicles and lateral placement. Moreover, various geometrical attributes such as turning radius of U-turning vehicles,

width of median opening and visibility of ATT were also not considered. Therefore, these attributes could be explored in future research.

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