Influence of driver and vehicle attributes on operational characteristics of U-turning vehicles

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Mid-block median openings (MBMOs) are provided to take a U-turn, which is a complex process. To make this movement a vehicle has to stop at the MBMO to find a suitable gap in the approaching through traffic stream. Two parameters, namely, service delay (SD) and occupancy time (OT) are crucial operational characteristics of an MBMO, which significantly affect traffic operation. The present study examines the influence of driver behaviour and vehicle attributes on SD and OT at six-lane and four-lane divided roads. From statistical analysis, SD was observed to be less at low approaching through traffic volume (ATTV) compared to high ATTV, whereas OT was observed to be high at low ATTV, and it decreased with increase in ATTV. Male drivers showed aggressive driving behaviour compared to female drivers, and the same was validated using a two-tailed *t*-test. Moreover, personal vehicles were found to behave defensively compared to commercial vehicles. Also, loaded vehicles were observed to turn their steering slowly being concerned about the safety of their passengers and goods compared to empty vehicles. The findings of this study will be beneficial in validating simulation results, defining level of service, etc. for planners in regulating the traffic efficiently.

Keywords: Approaching through traffic volume, driver behaviour, heterogeneous traffic, mid-block median opening, vehicle attributes.

INDIA is a country with population of a 1.37 billion, and a massive amount of vehicular traffic. Such vehicular traffic is causing a high level of congestion, especially at intersections in urban roads. This situation leads to compromised operating conditions[1]. Therefore, the construction of multilane roads or converting undivided roads into multilane roads is inevitable to improve the operating condition of urban roads. Generally, multilane roads are constructed with a physical barrier in the middle of the carriageway to segregate opposing traffic and avoid a head-on collision[2]. This physical barrier is widely known as the median. In these medians, openings are provided at different locations to take a U-turn and reverse the direction of travel. These openings are also offered as an alternative for right-turning traffic at downstream or upstream of an intersection.

The manoeuvre associated with a U-turn at a mid-block median opening (MBMO) is complicated and highly risky. U-turning vehicles have to negotiate with high speed and volume of approaching through traffic (ATT) and need to find a suitable gap between two fast-moving vehicles for merging with the ATT[3]. Additionally, when a vehicle takes a U-turn and tries to merge with the ATT, it occupies some space for a specified period at an MBMO. This merging process gives rise to a conflicting situation between U-turning vehicles and ATT, the duration of which depends on the occupancy time (OT) of a U-turning vehicle. Moreover, this merging behaviour becomes involved and chaotic when sufficient gap is not available to take a U-turn. In this scenario, the U-turning vehicle has to wait at the median opening and faces a delay. This delay while waiting for the service is termed as service delay (SD)[4]. Subsequently, when U-turning vehicles face SD beyond a certain threshold, the driver of the U-turning vehicle gets impatient and tries to merge with the ATT forcefully and creates a risky situation. Moreover, in developed countries, MBMO is controlled by stop or yield signs[5,6]. However, in India, these stop and yield signs are absent at almost all MBMOs[7]. Further, even when signs are provided at some locations, the drivers do not follow them and habitually disobey the rule of priority[8]. In addition to the problems associated with U-turns, traffic-flow patterns in the country possess some peculiar characteristics, such as heterogeneous traffic conditions and lack of lane discipline, which make the U-turn process more complicated.

Furthermore, the operation of vehicular traffic in heterogeneous traffic conditions is different from that in the homogeneous traffic conditions. In the latter, separate lanes are provided for different categories of vehicles. Whereas in the former all fast- and slow-moving vehicles with varying static and dynamic characteristics share the same right of way because traffic streams are not segregated based on vehicle type[9]. In this prevailing situation, smaller-sized vehicles often squeeze through any available gap between large-sized vehicles and move in a disorganized manner[10]. In these peculiar conditions prevailing in

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India, the traffic operation at these MBMOs often becomes disordered. The compromised traffic operations at these locations result in traffic problems such as reduced capacity, deterioration in the level of service and safety[3]. It is clear from the scenario mentioned above that MBMOs are problematic locations and need special attention for proper performance evaluation. Therefore, the operating conditions at MBMOs necessitate examining the traffic operational characteristics under heterogeneous traffic conditions.

Factors influencing operational characteristics

Various operational characteristics, namely traffic volume, speed, delay, gap acceptance and OT, affect the operation at different traffic facilities[11]. Numerous studies have been carried out on the operational characteristics of various traffic facilities. Bonneson[12] described a model to predict the delay caused to the major street through drivers because of right-turning vehicles coming from the outside traffic lane onto the major street. From sensitivity analysis, he reported that though vehicle delay ranged from 0.0 to 0.06 sec (ref. 12). Al-Omari and Benekohal[13] developed a new methodology for modelling delay at an undersaturated, two-way, stop-controlled intersection. They divided the total delay into two parts, namely SD and queue delay. They reported that the proposed model estimated a more realistic delay than the 1994 Highway Capacity Manual delay model. Milanes *et al.*[14] presented a methodology for seamless merging of traffic from a minor road into congested major roads. They developed an automated merging system scheme with two primary goals, i.e. a merging vehicle is fluidly permitted to enter the major road, and vehicles on the main road vehicle are allowed to modify their speed. The relationship between speed flow and merging behaviour of drivers in the work-zone merging area was studied by Weng and Meng[15]. They developed a merging location model and binary logit model for determining the point where the driver starts considering to merge. Ma *et al.*[16] studied the delay faced and also developed a delay estimation model for major streams under limited priority conditions at unsignalized intersections, and its accuracy was calibrated by field data. Sil *et al.*[4] carried out a study on delay at unsignalized median openings. They estimated average SD to vehicles and proposed models based on microscopic analysis under heterogeneous and unruly traffic conditions. Moreover, they reported that the number of conflicting vehicles and opposing through traffic affect SD. They also estimated merging time for different vehicle categories.

The influence of gender and vehicle characteristics on traffic operation at various traffic facilities has been a topic of interest for many researchers. Rhodes and Pivik[17] conducted a phone survey on 504 young (age 16–20 years) and 409 adult (age 25–45 years) drivers in Alabama, United States of America to examine the relationship between risk perception, positive affect and risky driving. They reported that male and young drivers engaged in risky driving behaviour more frequently than females and adult drivers. Meng and Weng[18] studied the effects of the environment, vehicle and driver characteristics on risky driving behaviour at work zones. They developed a decision tree to graphically display the relationship between risky driving behaviour and its influencing factors. They reported that bad weather, poor road, light conditions, partial/no access control, no traffic control devices, turning left/right and driving in an old vehicle were the factors associated with risky driving behaviour at work zones.

The literature review reveals that SD and OT are two crucial operational characteristics pertaining to traffic operation at an MBMO. Further, it was also found that attributes of drivers and vehicles influence the operational traffic characteristics at different traffic facilities. These aspects of traffic operation and their influencing factors have not been thoroughly studied for U-turning vehicles in general and under heterogeneous conditions in particular. Therefore, the research gaps in the currently available literature motivated us to study the influence of driver behaviour and vehicles attributes on two operational characteristics, namely SD and OT of U-turning vehicles at an MBMO. These findings will be beneficial for accessing the operation of vehicular traffic, defining the level of service (LOS) and realistic estimation of capacity at MBMOs.

Significance of the study

As mentioned earlier, interaction of vehicles at MBMOs is considered to be a complicated process because it creates a conflict situation between the slow-moving, U-turning vehicles and the fast-moving ATT stream. This conflicting situation depends on the amount of time that the U-turning vehicle occupies at the MBMO, i.e. OT. Likewise, when a vehicle needs to take a U-turn, it stops and tries to find a suitable gap in the ATT stream. If the desired gap is not available, the vehicle waits at the MBMO until it finds a suitable gap. In this process, it faces a delay in service before merging, i.e. SD.

HCM[19,20] provided a methodology for determining LOS of U-turning vehicles from major streets based on computed or measured control delay under homogeneous traffic conditions. However, measurement of control delay is not possible under heterogeneous traffic prevailing in developing countries in general and India in particular, because of distinct traffic behaviour. In developing countries, most of the unsignalized intersections are uncontrolled (no stop or yield sign and no police personnel). Even if priority movement is specified with proper stop and yield signboards, road users violate the priority rule.

Table 1. Details of all data collection sites

Section	Location	Type of road	Road width (m)	Median width (m)	Width of median (m)
S-1	Bengaluru	Six-lane road	9.56	2.20	18.00
S-2			9.80	1.35	27.00
S-3			10.00	2.40	21.10
S-4			9.70	1.10	15.50
S-5	Bhubaneswar		9.75	1.3	19.20
S-6			9.4	1.3	19.30
S-7			9.8	1.4	16.60
S-8	Bhubaneswar	Four-lane road	6.3	1.2	18.60
S-9	Dhanbad		7.8	0.6	14.6
S-10			7.5	1.2	17.4
S-11	Guwahati		6.00	1.00	20.00
S-12			7.50	1.10	18.60
S-13	Ranchi		7.50	1.80	27.80
S-14			7.50	0.80	21.40

Thus, SD and OT become two important characteristics of traffic operation at unsignalized locations such as MBMOs. However, to the best of our knowledge no study is available in the open literature about the variations of these two parameters under varying operational characteristics. Therefore, the present study was undertaken with the following objectives: (i) To examine the influence of ATTV on SD and OT for different vehicle categories. (ii) To examine the influence of driver behaviour and vehicles attributes on SD and OT at varying ATTV.

Traffic data collection

The required traffic data were collected from 14 test sections, which include seven MBMOs in each of the six-lane and four-lane roads. The road width was found to vary from 9.5 to 10 m and 6 to 7.5 m at the six-lane and four-lane roads respectively. Table 1 presents details of all the data collection sites. For the present study, video-recording technique was used for collecting traffic data. The traffic data collection was carried out from 8.00 am to 5.00 pm on weekdays, and was avoided during inclement weather. The observed vehicles have been segregated into six categories, namely two-wheeler (2W), three-wheeler (3W), small car (SC), big car (BC), light commercial vehicle (LCV) and heavy vehicle (HV).

Three video recorders were placed at suitable positions to get an unobstructed view of the MBMO for collecting traffic data. Among the video cameras, video-recorder 1 was used to record the turning manoeuvre of U-turning vehicles, video-recorder 2 was used to record ATTV and video-recorder 3 was used to record the gender of drivers and vehicles attributes. The turning manoeuvre of the U-turning vehicles has been divided into two parts. The first part of the turning manoeuvre starts at the time when a U-turning vehicle stops at the MBMO, tries to find a suitable space between two approaching through vehicles and starts the U-turning process. The second part starts from the time when the U-turning vehicle starts the turning manoeuvre to the time when it completes the turning manoeuvre and completely merges with the ATT. For the collection of merging time data, a merging line was drawn across the carriage way at a distance of 2.50 m from the median nose[8].

Field data extraction

The recorded videos were played on a large LED screen to extract the required data using the video editing software Avidemux (2.7.3). In India, manual data extraction is preferred over automatic data extraction due to the distinct features of heterogeneous traffic such as varying static and dynamic characteristics of vehicles, non-adherence to traffic rules, reversal of priority, etc.[21]. From the recorded field data, different parameters, namely SD, OT, ATTV, gender and characteristics of vehicles taking a U-turn (colour of the number plate and vehicle loading state) were extracted. Figure 1 depicts vehicular operation at an MBMO and Figure 2 shows the detailed data extraction process.

For the estimation of SD and OT, identification of an imaginary reference line is one of the challenging steps. The reference line is a virtual line where a U-turning vehicle stops before starting the merging process. SD is measured from the time (t_0) of the arrival of the front bumper at the reference line (*X–X*) to the time (t_1) of departure of the rear bumper of the U-turning vehicle off the reference line (*X–X*; Figure 2). SD is calculated using eq. (1).

$$\mathrm{SD} = t_1 - t_0, \tag{1}$$

Similarly, OT is measured from the time (t_2) of departure of the front bumper from the reference line (*X–X*) to the time (t_3) of departure of the back bumper of the U-turning

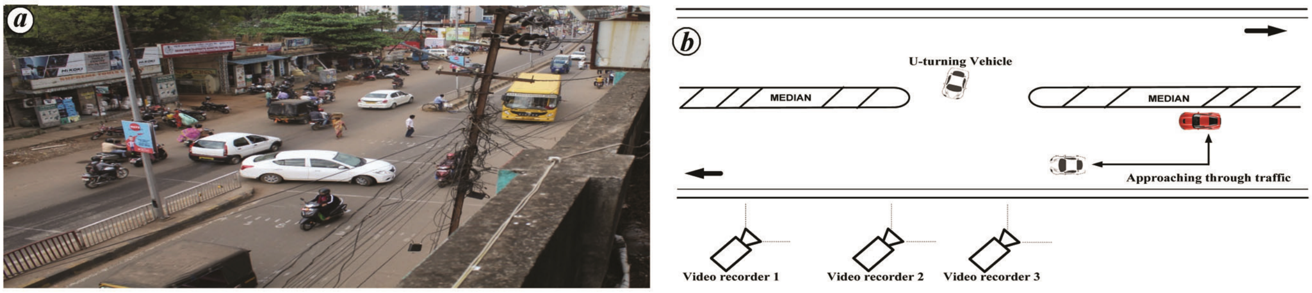

Figure 1. Vehicular operation at mid-block median openings: (***a***) Screenshot of data collection site and (***b***) schematic diagram showing video recorder set-up at the data collection site.

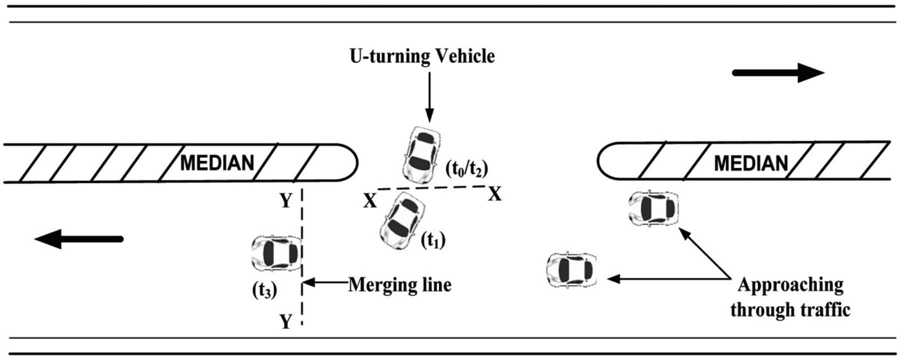

Figure 2. Schematic diagram representing the data extraction process.

vehicle from the merging line (*Y–Y*; Figure 2). OT is calculated using eq. (2).

$$\text{OT} = t_3 - t_2, \tag{2}$$

The extracted data were segregated based on the category of vehicles. Figure 3 presents the descriptive statistics in the form of box and whisker plots. It shows that the average SD and OT were lowest for 2W, whereas HV had the highest SD and OT in six-lane road, while in the four-lane road BC was observed to have the highest SD and OT. This is because 2W drivers have peculiar driving behaviour and they try to explore all the possible gaps available in the ATT. However, HVs have a bigger physical dimension and hence require more time to clear an MBMO. Further, it is also not possible for HVs to explore small gaps owing to their static and dynamic features.

Moreover, significant variations have been observed for the estimated SD and OT six-lane and four-lane roads. This can be attributed to the varying operational characteristics (varying ATTV). Therefore, all the extracted data were segregated based on ATTV. To understand the effect of ATTV on SD and OT, it needs to be estimated from the collected video. In this regard, hourly ATTV was calculated by counting total ATT in 5 min and the same was converted to hourly ATTV. Oh and Yeo[22] advocated for considering 5 min volume count instead of 15 min count for the prediction of traffic flow in one of the studies carried out in California, USA. The authors opined 5 min count provide better estimation of ATTV by taking care of the fluctuation in traffic flow[23]. Analogous approach has been adopted by various research in India for the estimation of hourly traffic volume[22–25]. Furthermore, ATTV was found to vary from 1000 to 6500 vph in six-lane and 500 to 3500 vph in four-lane roads. Therefore, the ATTV data have been aggregated with a bin size of 500 vph. Furthermore, to explore the effect of driver and vehicle attributes on SD and OT, driver characteristics (male/female) and vehicle characteristics (personal/commercial; loaded/empty) were manually recorded from visual observation of the collected video.

Analysis of factors influencing operational characteristics

We examined the influence of various factors like ATTV and attributes of drivers and vehicles on operational characteristics of U-turning vehicles.

Influence of ATTV on SD and OT

The average SD was calculated at varying ATTV, and Figure 4 *a* and *b* shows its variation. It can be inferred

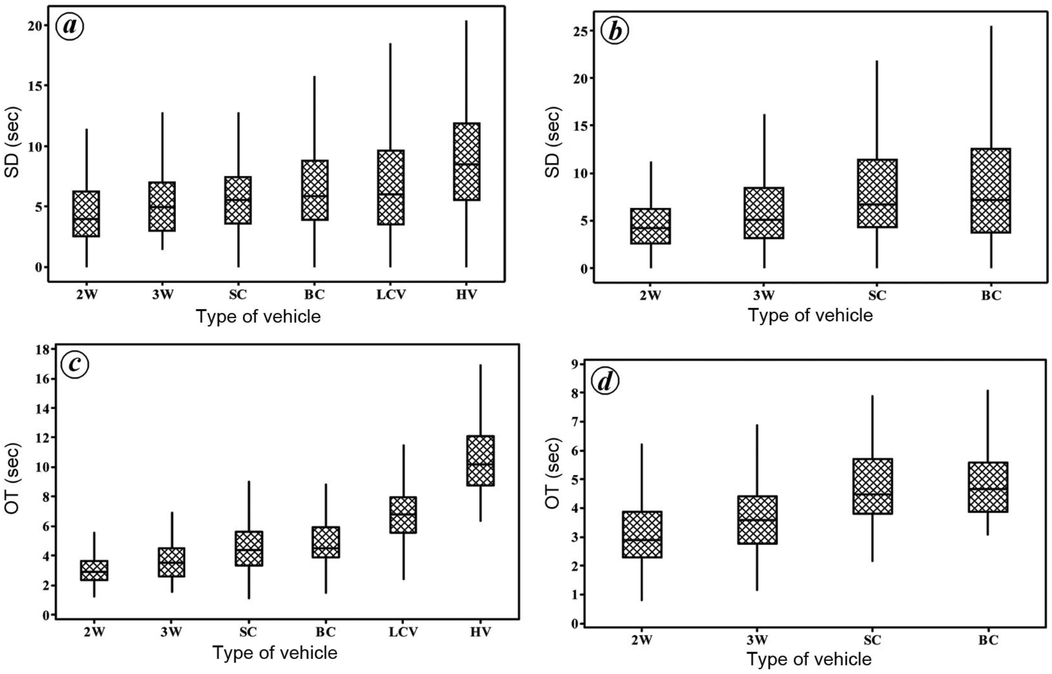

Figure 3. Box plot of service delay (SD) and occupancy time (OT) for vehicle type: (***a***), (***c***) six-lane road and (***b***), (***d***) four-lane road.

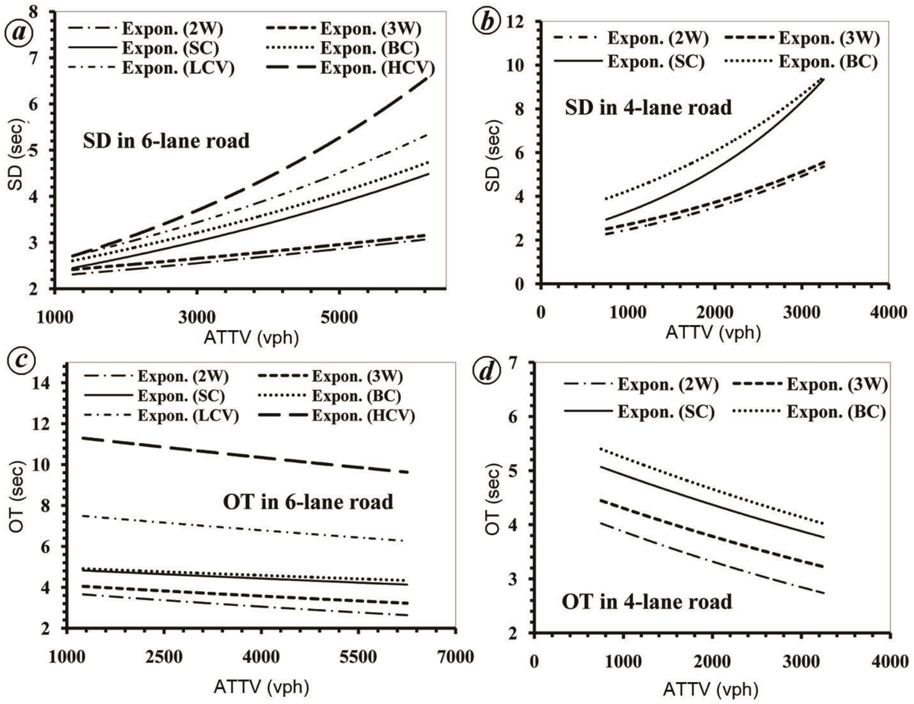

Figure 4. Average SD and OT of *U*-turning vehicles at varying approaching through traffic volume.

from the figure that 2W experiences the least SD, whereas HV experiences the highest SD. SD was found to vary from 2.33 sec to 3.14 sec for 2W and 2.79 sec to 6.44 sec for HV in six-lane roads. Furthermore, 2W and BC were observed to experience the least and highest SD respectively, in four-lane roads. SD was observed to vary from 2.32 sec to 4.87 sec for 2W and 4.25 sec to 9.35 sec for BC in four-lane roads. This is because 2W has a smaller physical dimension and unique driving characteristics. Hence it can explore all the available gaps in the ATT stream and complete the U-turning manoeuvre facing less SD. 3W experiences the lowest SD after 2W, because it

Table 2. Models developed between service delay (SD) and approaching through traffic volume (ATTV)

	Six-lane road		Four-lane road	
Vehicle type	Model	R^2	Model	R^2
2W	$2.15e^{0.00006\text{ATTV}}$	0.96	$1.76e^{0.00034\text{ATTV}}$	0.93
3W	$2.26e^{0.00005\text{ATTV}}$	0.97	$1.98e^{0.00032\text{ATTV}}$	0.94
Small car (SC)	$2.11e^{0.00012\text{ATTV}}$	0.97	$2.08e^{0.00046\text{ATTV}}$	0.97
Big car (BC)	$2.24e^{0.00012\text{ATTV}}$	0.96	$2.99e^{0.00035\text{ATTV}}$	0.94
Light commercial vehicle (LCV)	$2.28e^{0.00014\text{ATTV}}$	0.98	–	–
Heavy vehicle (HV)	$2.17e^{0.00018\text{ATTV}}$	0.96	–	–

Table 3. Model developed between occupancy time (OT) and ATTV

	Six-lane road		Four-lane road	
Vehicle type	Model	R^2	Model	R^2
2W	$3.96e^{-0.00006\text{ATTV}}$	0.90	$4.52e^{-0.00015\text{ATTV}}$	0.95
3W	$4.29e^{-0.00005\text{ATTV}}$	0.92	$4.90e^{-0.00013\text{ATTV}}$	0.98
SC	$5.02e^{-0.00003\text{ATTV}}$	0.97	$5.54e^{-0.00012\text{ATTV}}$	0.93
BC	$5.06e^{-0.00002\text{ATTV}}$	0.93	$5.90e^{-0.00012\text{ATTV}}$	0.92
LCV	$7.84e^{-0.00004\text{ATTV}}$	0.98	–	–
HV	$11.75e^{-0.00003\text{ATTV}}$	0.98	–	–

has unusual physical dimensions and the drivers are generally aggressive in nature. Therefore, when the required gap is not available for a long time, the 3W drivers forcefully enter the conflicting area and force the ATT vehicle to slow down to facilitate the 3W to complete its U-turning manoeuvre. Furthermore, as SC and BC have larger physical dimensions compared to 2W and 3W, they face more SD. LCV and HV experience the highest SD because of their physical dimension. These vehicles need to wait for suitable available gaps due to the safety concerns of the goods carried by them. From the above observations, it can be concluded that the physical dimension of vehicles plays a vital role in defining SD experienced by U-turning vehicles.

It was also observed that at lower ATTV, vehicles could take a U-turn without waiting or even stopping at the MBMO, and experienced less SD. However, with an increase in ATTV vehicles needed to stop and wait at the MBMO for a longer time than at lower ATTV for finding a suitable gap between two vehicles in the ATT stream. Hence, U-turning vehicles tend to experience more SD at higher than lower ATTV. The increasing trend of SD with increasing ATTV was found to be similar in six-lane and four-lane roads. Subsequently, mathematical models were developed and SD was observed to increase exponentially for different vehicle types. It increased exponentially with an increase in ATTV, because the chance of available gap was found to decrease in the ATT stream. If the number of vehicles increases in the ATT stream, the availability of space between two approaching through vehicle decreases. Therefore, as the availability of gap decreases in the ATT stream, the U-turning vehicles are forced to wait for a longer period of time and experience more SD. In this situation the SD experienced by U-turning vehicles increases with increase in ATTV. Table 2 shows the models developed to predict SD at varying ATTV.

We studied the influence of varying ATTV on OT. In this context, the average OT was calculated at varying ATTV, and Figure 4 *c* and *d* shows its variation. From the figure, it can be inferred that OT of 2W is the lowest, and varies from 3.7 sec (1000–1500 vph) to 2.74 sec (6001–6500 vph). OT of 3W is more than 2W, but less than SC and BC owing to the fact that 3W drivers are aggressive in nature, and also that the physical size of 3W is comparatively smaller than that of SC and BC. Hence, 3W can clear the MBMO in less time compared to SC and BC. Moreover, due to the longer wheelbase, HV requires more time to clear the MBMO and hence highest OT is observed for HV. It was found to vary from 9.66 sec to 11.45 sec, depending on ATTV.

Figure 4 *c* and *d* shows that OT has a decreasing trend with increasing ATTV because at lower ATTV, vehicles tend to take the U-turn freely at low speed, making the U-turning vehicle occupy the MBMO for a longer time. Hence, OT was observed to be more at low ATTV. However, with an increase in ATTV, the U-turning vehicles are forced to wait for a longer time at the MBMO to find a suitable gap, the drivers get frustrated and try to take a U-turn swiftly, which allows the vehicle to clear the MBMO in less time. Hence OT is found to be less at higher ATTV. The decreasing trend of OT is found to be similar in both six-lane and four-lane roads. Mathematical models were developed and OT was observed to decrease exponentially for different types of vehicles. Table 3 shows the models developed for prediction of OT at varying ATTV. The developed models presented in Tables 2 and 3 can be useful in estimating SD and OT of different types of U-turning vehicles only by considering the ATTV, and avoiding the data collection and extraction process of SD and OT, which is a demanding process.

SD and OT model validation

The performance of the proposed SD and OT prediction models was validated using data collected from separate sections which were not used for the development of the models. In this study, data from S-7 for six-lane road and S-14 for four-lane road have been used for validating the proposed SD and OT models (Table 1). For validation purpose, around 50 samples of SD, OT and ATTV data were extracted from already recorded videos systematically. SD, OT and ATTV were estimated by similar methodology as explained earlier. The average values SD and OT were calculated from the collected field data. ATTV was observed to be in the range 3500–4000 and 2500–3000 vph for six-lane and four-lane roads respectively. Mean absolute percentage error (MAPE) was utilized for evaluating the efficacy of the proposed models. MAPE for the present study was estimated from eq. (3).

$$\mathrm{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{\mathrm{SD}_m \text{ or } \mathrm{OT}_m - \mathrm{SD}_f \text{ or } \mathrm{OT}_f}{\mathrm{SD}_f \text{ or } \mathrm{OT}_f}\right|, \tag{3}$$

The observed ATTV values of 3750 and 2750 vph were used in the models provided in Tables 2 and 3 for estimating SD and OT respectively, for different types of U-turning vehicles. Table 4 presents the SD and OT values estimated from the field and models and computed MAPE values. The maximum and minimum MAPE for SD was observed to be 9.74% for 2W and 4.55% for HV respectively, in six-lane road. In four-lane road, maximum error was observed to be 8.81% for 2W and minimum error was 5.19% for 3W. Likewise, maximum and minimum MAPE for OT was 9.34% for 2W and 5.21% for HV respectively, in six-lane road. In four-lane road, maximum error was 9.02% for 2W and minimum error was 5.86% for 3W. From past studies it is evident that a MAPE value less than or equal to 10% is considered to be satisfactory[11,25]. As the obtained MAPE values are less than 10%, it can be inferred that the proposed models have the ability to provide reasonable SD and OT for different types of U-turning vehicles at varying ATTV.

Table 4. Model validation

Vehicle type	Six-lane (3500–4000 vph)			Four-lane (2500–3000 vph)		
	$\mathrm{SD_f}$	$\mathrm{SD_m}$	MAPE	$\mathrm{SD_f}$	$\mathrm{SD_m}$	MAPE
2W	2.98	2.69	9.74	4.12	4.48	8.81
3W	2.89	2.73	5.67	4.53	4.77	5.19
SC	3.08	3.31	7.32	6.89	7.37	7.04
BC	3.26	3.51	7.56	7.30	7.83	7.33
LCV	3.65	3.85	5.38	–	–	–
HV	4.07	4.26	4.55	–	–	–
	$\mathrm{OT_f}$	$\mathrm{OT_m}$	MAPE	$\mathrm{OT_f}$	$\mathrm{OT_m}$	MAPE
2W	2.89	3.16	9.34	2.74	2.99	9.02
3W	3.36	3.56	6.08	3.24	3.43	5.86
SC	4.17	4.49	7.55	3.71	3.98	7.15
BC	4.37	4.69	7.26	3.96	4.24	7.05
LCV	6.39	6.75	5.59	–	–	–
HV	9.98	10.5	5.21	–	–	–

$\mathrm{SD_f}$, Service delay observed from field; $\mathrm{SD_m}$, Service delay observed from model; MAPE, Mean absolute percentage error; $\mathrm{OT_f}$, Occupancy time observed from field; $\mathrm{OT_m}$, Occupancy time observed from model.

Influence of driver attributes on SD and OT

The different driver attributes that can be considered for this analysis are gender, age, state of mind, involvement in secondary activities, personality, etc. However, data on these attributes could not be extracted from the video recordings. Therefore, only the influence of gender was studied for different types of vehicles. Furthermore, it was observed that in India, almost all drivers of 3W, LCV and HV are male, and the number of female drivers is negligible. Therefore, in the Indian context, the variance in driver gender was observed for 2Ws and cars. Due to compromised visibility, observations on gender could not be made for car drivers. Thus, the influence of gender on SD and OT was studied only for 2Ws.

For examining the gender influence on SD, two-sided *t*-tests were carried out at varying ATTV by comparing SD experienced by 2W while taking a U-turn at an MBMO. For carrying out the *t*-test, we used the following hypotheses.

H_0: SD faced by male drivers $\neq$ SD faced by female drivers.

H_1: SD faced by male drivers = SD faced by female drivers.

Table 5 presents the results obtained for 2W at 1000–1500 vph. The *t*-test results show that T_{crt} is more than T_{stat}; it suggests acceptance of H_0 and rejection of H_1. Acceptance of null hypothesis infers that SD experienced by 2W male drivers is statistically different than that experienced by 2W female drivers. The significant difference in SD faced by male–female drivers is due to the fact that when a vehicle needs to take a U-turn, it has to stop and wait at the MBMO for an appropriate gap between two vehicles in ATT. Subsequently, when a U-turning vehicle experiences more SD than usual, the driver tends to take greater risk and drive aggressively to complete the U-turn. Due to the risk-taking and aggressive driving characteristics of male drivers, they experience less SD and also force the ATT to slow down[26,27]. In contrast, female drivers wait at the MBMO until a suitable gap is available and experience more SD. At all ATTV, similar analysis was carried out and observed to give the same results for six-lane and four-lane roads, indicating that SD experienced by male drivers is statistically different than female drivers.

We examined the influence of gender on OT. For this, a two-sided *t*-test was carried out at varying ATTV by reviewing the average OT of a 2W while taking a U-turn

Table 5. Results of *t*-test of SD and OT for male–female drivers (1000–1500 vph)

U-turning vehicle	Type of attribute	Type of road	Male μ (sec)	Male σ	Male N	Female μ (sec)	Female σ	Female N	T_{stat}	T_{crt}	F_{stat}	F_{crt}
2W	SD	Six-lane	2.21	2.67	306	2.36	2.27	49	0.43	1.98	1.38	1.48
		Four-lane	2.29	3.32	161	2.56	3.01	54	0.55	1.98	1.21	1.48
	OT	Six-lane	3.59	1.32	306	3.81	1.13	49	1.26	1.98	1.36	1.48
		Four-lane	3.73	1.66	161	4.07	1.88	54	1.18	1.98	1.29	1.42

μ, Mean, σ, standard deviation; N, total number of sample; T_{stat}, T-statistics; T_{crt}, T-critical; F_{stat}, F-statistics; F_{crt}, F-critical.

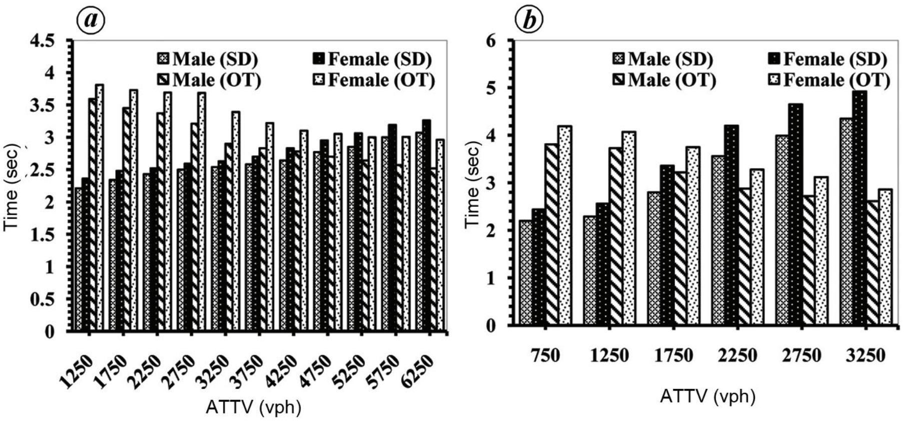

Figure 5. Average SD and OT for male and female drivers: (***a***) six-lane road and (***b***) four-lane road.

at an MBMO in six-lane and four-lane roads. For carrying out the *t*-test, we used the following hypotheses:

H_0: OT of male drivers ≠ OT of female drivers.

H_1: OT of male drivers = OT of female drivers.

Table 5 shows the *t*-test results for male–female drivers. T_{crt} is found to be more than T_{stat}; it infers acceptance of H_0 and rejection of H_1. Acceptance of H_0 indicates that the OT of male drivers is statistically different from that of female drivers. The significant difference in OT of male and female drivers is due to the fact that when a vehicle needs to take a U-turn, it occupies specific road space at the MBMO and creates conflicting situations between U-turning vehicles and ATT. Furthermore, male drivers were observed to take an aggressive turn to complete the manoeuvre; thus they occupy MBMO for less time compared to female drivers. On the other hand, female drivers are defensive and require more time to clear the conflicting area than male drivers[28]. At all ATTV, similar analysis was carried out. From the test result identical results were obtained for six-lane and four-lane roads, indicating that OT of male drivers is statistically different compared to female drivers.

Furthermore, the analysis was extended to evaluate the effect of ATTV on SD and OT for male and female drivers. From Figure 5, it is evident that SD and OT of male and female drivers increases and decreases respectively, with increases in ATTV. A detailed discussion for the increase and decrease in SD and OT with varying ATTV irrespective of gender has been provided earlier. Similar results were observed for both genders. Further, SD and OT of male drivers were less than those of female drivers because, as mentioned earlier, male drivers are aggressive compared to female drives[28,29]. Hence, the aggressive driving characteristics of male drivers make it possible for them to clear the MBMO in less time than female drivers.

Influence of vehicle attributes on SD and OT

Next we explored the purpose of vehicle use and loading state of vehicle on SD and OT. Details of the results obtained through statistical analyses are described below.

Influence of purpose of vehicle use on SD and OT: For this, SD and OT of commercial and personal vehicle drivers were aggregated at different ATTV. In India, generally, 2W is for personal use (negligible in the commercial sector), while 3W, LCV and HV are used for commercial purposes only. SC and BC are used for both purposes and hence were considered in this study.

Two-sided *t*-tests were carried out at different ATTV by comparing the average SD experienced by commercial and personal vehicles at the MBMO to examine the influence

Table 6. Results of *t*-test of SD and OT for commercial and personal vehicles (1000–1500 vph)

U-turning vehicle	Type of attribute	Type of road	Personal purpose μ (sec)	σ	N	Commercial purpose μ (sec)	σ	N	*T*-statistics T_{stat}	T_{crt}	*F*-statistics F_{stat}	F_{crt}
SC	SD	Six-lane	2.54	3.12	171	2.38	3.19	176	0.47	1.98	1.05	1.29
BC			2.56	2.84	147	2.42	2.79	205	0.45	1.98	1.03	1.28
SC		Four-lane	3.61	3.84	120	3.41	3.39	60	0.36	1.98	1.28	1.47
BC			4.55	5.48	70	4.38	5.12	122	0.22	1.98	1.15	1.41
SC	OT	Six-lane	4.97	1.76	171	4.75	1.93	176	1.12	1.98	1.21	1.29
BC			5.35	1.68	147	4.99	1.89	205	1.88	1.98	1.26	1.29
SC		Four-lane	5.03	1.46	120	4.86	1.55	60	0.72	1.98	1.13	1.43
BC			5.64	2.29	70	5.00	2.32	122	1.83	1.98	1.03	1.44

of vehicle use on SD. For carrying out the *t*-test, we used the following hypotheses:

H_0: SD faced by commercial vehicle ≠ SD faced by personal vehicle.

H_1: SD faced by commercial vehicle = SD faced by personal vehicle.

The *t*-test results from Table 6 shows that T_{crt} is more than T_{stat}, thus accepting H_0 and rejecting H_1. Acceptance of H_0 indicates that SD faced by personal vehicles is statistically different than commercial vehicles. This is because commercial vehicle drivers are more experienced and skilled, compared to personal vehicle drivers, due to which commercial vehicles can take U-turns swiftly by interrupting the natural flow of ATT. Personal vehicle drivers are less skillful and generally risk-avoiders. Therefore, they wait for an appropriate gap for completing the U-turn. At all ATTV, the same analysis was carried out and observed to give identical results for six-lane and four-lane roads, indicating that SD experienced by commercial vehicle drivers is statistically different from that of personal vehicle drivers.

We examined the influence of OT on commercial and personal vehicles. A two-sided *t*-test was carried at different ATTV by reviewing the average OT of commercial and personal vehicles while taking a U-turn in six-lane and four-lane roads. For carrying out the *t*-test, we used the following hypotheses:

H_0: OT of commercial vehicle ≠ OT of personal vehicle.

H_1: OT of commercial vehicle =OT of personal vehicle.

The *t*-test results in Table 6 show that T_{crt} is more than T_{stat}, thus accepting H_0 and rejecting H_1. Acceptance of H_0 indicates that OT of personal vehicles is statistically different from that of commercial vehicles. The explanation for this has been provided earlier while describing the results obtained for SD. Furthermore, the same analysis was carried for all ATTV, and identical results were obtained for six-lane and four-lane roads. This indicates that OT of commercial vehicles is statistically different from that of personal vehicles.

The analysis was extended to evaluate the effect of ATTV on SD and OT for commercial and personal vehicles. From Figure 6, it can also be observed that SD and OT for commercial and personal vehicles increase and decrease respectively, with increase in ATTV. A detailed description on these observations has been provided earlier in the study.

Influence of loading state of vehicles on SD and OT: For this 2W without and with pillion was considered as empty and loaded vehicle respectively. Likewise, 3W, LCV and HV without and with load were considered empty and loaded vehicles respectively. SC and BC were not considered due to the reasons mentioned earlier in the study.

A two-sided *t*-test was carried out for analysing the loading state of vehicles at different ATTV by reviewing the average SD experienced by empty and loaded vehicles in the six-lane and four-lane roads. For carrying out the *t*-test, we used the following hypotheses:

H_0: SD faced by empty vehicle ≠ SD faced by loaded vehicle.

H_1: SD faced by empty vehicle = SD faced by loaded vehicle.

The *t*-test results in Table 7 show that T_{crt} is more than T_{stat}. This indicates acceptance of H_0 and rejection of H_1. Acceptance of H_0 implies that SD experienced by empty vehicles is statistically different than that experienced. This is by loaded vehicles, because loaded vehicles stop and wait at an MBMO until a suitable gap is available, due to safety concerns regarding the goods and passengers. Whereas an empty vehicles tries to enter the MBMO forcefully by compelling ATT to reduce its speed and allow the vehicle to take a U-turn. At all ATTV, similar analysis was carried out. From the test result identical results were obtained for six-lane and four-lane roads, indicating that SD experienced by empty vehicle is statistically different from that experienced by loaded vehicles.

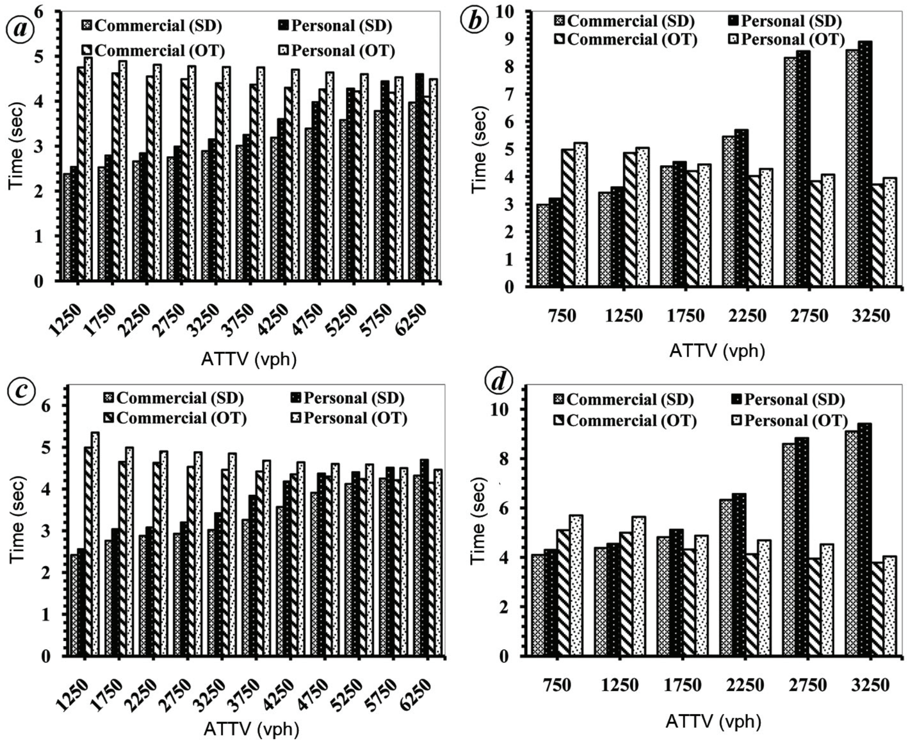

Figure 6. Average SD and OT for commercial and personal vehicles: (***a***), (***c***) six-lane road and (***b***), (***d***) four-lane road.

Table 7. Results of *t*-test of SD and OT for empty and loaded vehicles (1000–1500 vph)

U-turning vehicle	Type of attribute	Type of road	Empty			Loaded			*T*-statistics		*F*-statistics	
			μ (sec)	σ	N	μ (sec)	σ	N	T_{stat}	T_{crt}	F_{stat}	F_{crt}
2W	SD	Six-lane	2.26	2.96	236	2.34	2.61	78	0.22	1.98	1.28	1.38
3W			2.34	3.16	45	2.42	2.77	33	0.12	1.99	1.30	1.75
LCV			2.52	3.01	107	2.69	2.93	33	0.30	1.98	1.05	1.66
HV			2.72	4.50	31	2.86	4.24	35	0.14	1.99	1.13	1.80
2W		Four-lane	2.26	3.97	204	2.54	3.49	81	0.58	1.98	1.30	1.38
3W			2.65	3.03	32	2.82	2.42	39	0.25	1.99	1.56	1.75
2W	OT	Six-lane	3.64	1.50	236	3.76	1.37	78	0.65	1.98	1.18	1.38
3W			3.98	1.41	45	4.18	1.16	33	0.65	1.99	1.49	1.75
LCV			7.38	1.81	107	7.53	1.67	33	0.46	1.98	1.17	1.66
HV			11.33	2.90	31	11.46	3.38	35	0.17	1.99	1.35	1.82
2W		Four-lane	3.77	1.48	204	3.95	1.30	81	1.02	1.98	1.30	1.38
3W			4.16	1.80	32	4.33	1.51	39	0.42	1.99	1.43	1.75

We examined the influence of loading state of a vehicle, on OT. The two-sided *t*-tests were carried out at different ATTV by comparing the average OT of empty and loaded vehicles in six-lane and four-lane roads. For carrying out the *t*-test, we used the following hypotheses:

H_0: OT of empty vehicle ≠ OT of loaded vehicle.

H_1: OT of empty vehicle = OT of loaded vehicle.

The *t*-test results in Table 7 show that T_{crt} is more than T_{stat}. This observation indicates acceptance of H_0 and rejection of H_1. Acceptance of H_0 implies that OT of empty vehicles is statistically different than OT of loaded vehicles. The explanation for this observation has been given earlier while describing the results obtained for SD. As mentioned earlier, similar analysis was carried out. The *t*-test results indicated that OT of an empty vehicle is statistically different from that of a loaded vehicle.

Subsequently, the analysis was extended to evaluate the effect of ATTV on SD and OT for empty and loaded vehicles. From Figure 7, it can be observed that as ATTV increases, SD and OT experienced by empty and loaded vehicles also increase and decrease respectively. The reason for this has been explained earlier without considering the loading state of the vehicle. It was observed that

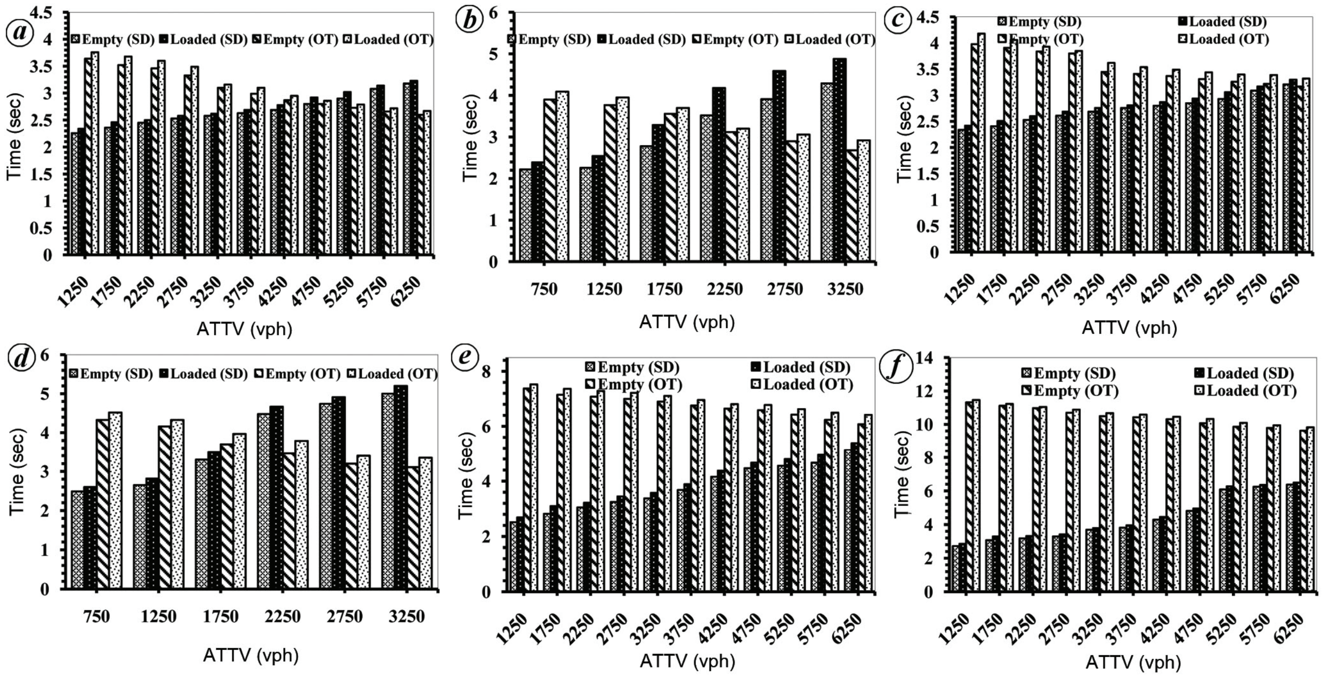

Figure 7. Average SD and OT for empty and loaded vehicles: (*a*), (*c*), (*e*), (*f*) six-lane road and (*b*), (*d*) four-lane road.

SD and OT of 2W, 3W, LCV and HV increased and decreased respectively, with increase in ATTV. It was also observed that SD and OT of loaded vehicles were more than those of empty vehicles.

Summary and conclusion

MBMO is a location where vehicles take a U-turn. It is a complex manoeuvre because a U-turning vehicle needs to find a suitable gap between fast-moving vehicles in the ATT stream. If an appropriate gap is not available, then the U-turning vehicle has to wait at the MBMO and experiences SD. Moreover, while a vehicle takes a U-turn, it occupies some space at the MBMO and creates a conflicting situation with ATT. OT of a U-turning vehicle determines the time of conflicting situations between the U-turning vehicle and ATT at the MBMO. Therefore, we examined the influence of operational characteristics (ATTV, various attributes of drivers and vehicles) on SD and OT of U-turning vehicles.

To achieve the objectives of the present study, we examined the influence of ATTV, driver gender and vehicle attributes (purpose of vehicle use, loading state of vehicle) on SD and OT. A rigorous analysis revealed that U-turning vehicles experienced less SD at low ATTV than at high ATTV. Further, OT of vehicles taking a U-turn was more at low ATTV, and it was observed to decrease with increase in ATTV. The operational characteristics, attributes of drivers and vehicles on SD and OT were studied using various statistical tests. Male drivers were observed to experience less SD than female drivers. Commercial vehicles experienced less SD than personal vehicles, and loaded vehicles experienced more SD than empty U-turning vehicles. It was also observed that male U-turning drivers experienced less OT when compared to female U-turning drivers, personal U-turning vehicles experienced more OT compared to commercial U-turning vehicles and empty U-turning vehicle experienced less OT compared to loaded U-turning vehicles.

With regard to the limitations of this study, driver age, involvement in secondary activities by the driver, physiological condition of the driver, pavement condition, etc. can also influence the SD and OT of vehicles taking U-turn at MBMO. However, these variables have not been explored in the present study due to unavailability of the required field data. Therefore, these aspects are proposed as the future scope of the present study. The influence of other driver characteristics (age, mobile usage, etc.) and vehicle attributes (age of the vehicle, tyre condition, etc.) on various operational aspects can be explored by utilizing advanced data collection techniques.

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