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

Tathagatha Khan[1] and Smruti Sourava Mohapatra[2*]

[1] Research Scholar, Department of Civil Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Dhanbad 826004, India. Email: tathagatha.17dr000429@cve.iitism.ac.in

[2*] Assistant Professor, Department of Civil Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Dhanbad 826004, India. Email: smruti@iitism.ac.in (corresponding author).

*Corresponding author: Smruti Sourava Mohapatra (smruti@iitism.ac.in)

ABSTRACT

Mid-block median openings (MBMO) are provided to take U-turn. U-turn is a complex process, and to make U-turn, the vehicle has to stop at MBMO to find a suitable gap in the approaching through traffic stream, and when a suitable gap is available, it completes its maneuver. Two parameters, namely, service delay (SD) and occupancy time (OT), are crucial operational characteristics of MBMO, which affect the traffic operation significantly. The present study examines the influence of driver's behaviour, and vehicle attribute on SD and OT at 6-lane and 4-lane divided roads. From the 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 decreases with an increase in ATTV. Male drivers were observed to have 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, and loaded vehicles were observed to turn steering slowly concerning the safety of their passenger and goods compared to empty vehicles. The findings of this study will be beneficial in validating simulation results, defining Level of Service, etc., for traffic planners in regulating traffic efficiently.

Keywords: Mid-block median opening (MBMO); Approaching through traffic volume (ATTV); U-turn; Drivers behaviour; Heterogeneous traffic.

INTRODUCTION

India is a country with 1.37 billion population, with a massive amount of vehicular traffic. The enormous amount of vehicular traffic is causing a high level of congestion, especially at intersections in urban roads, and this situation many times 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 have access to the abutting properties by taking U-turn and also to reverse the direction of movement of traffic. These openings are also offered as an alternative for right-turning traffic at downstream or upstream of an intersection.

The maneuver associated with U-turn at mid-block median opening (MBMO) is very 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 MBMO. This merging process creates a conflicting situation between U-turning vehicles and ATT. The duration of conflicting situations depends on the occupancy time (OT) of a U-turning vehicle. Moreover, this merging behavior becomes very involved and chaotic when a sufficient gap is not available to take a U-turn. In this scenario, the U-turning vehicle waits 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 U-turning vehicle gets impatient and tries to merge with the ATT forcefully and creates a risky situation. Moreover, in developed countries, mid-block median opening (MBMO) is controlled by stop or yield signs[5,6]. But in India, almost at all MBMO, these stop and yield signs are absent[7]. Further, even when signs are provided at some locations, drivers don't follow them and habitually disobey the rule of priority[8]. In addition to the problems associated with U-turns, traffic flow patterns in India 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 the homogeneous traffic condition. In homogeneous traffic conditions, separate lanes are provided for different categories of vehicles, whereas in heterogeneous traffic conditions 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-size vehicles often squeeze through any available gap between large-size vehicles and move in a disorganized manner[10]. In these peculiar conditions prevailing in India, the traffic operation at these MBMO 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 pretty clear from the scenario mentioned above that MBMOs are problematic locations and need special attention for proper performance evaluation. Therefore, the operating conditions at these locations necessitate examining the traffic operational characteristics at MBMO in heterogeneous traffic conditions.

Factors influencing operational characteristics

Various operational characteristics, namely traffic volume, speed, delay, gap acceptance, occupancy time, affect the traffic operation at different traffic facilities[,11]. Numerous research has been carried out to recognize 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 onto the major street. From the sensitivity analysis, the authors reported that through vehicle delay ranges from 0.0 to 0.06 sec. Al-Omari and Benekohal[13] developed a new methodology for modeling delay at under saturated two-way stop-controlled intersection. The authors divided the total delay into two parts, namely service delay and queue delay. The research reported that the proposed models 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 the minor road into congested major roads. The authors developed an automated merging system scheme with two primary goals, i.e., the merging vehicle is fluidly permitted to enter the major road, and the main road vehicle was allowed to modify its speed. The relationship between speed-flow and merging behavior 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 intersection, and its accuracy was calibrated by field data. Sil et al.[4] carried out a study on delay at unsignalized median opening. The authors estimated average service delay to vehicles and proposed service delay models based on the microscopic analysis under heterogeneous and unruly traffic conditions. Moreover, the authors reported that the number of conflicting vehicles and opposing through traffic affect service delay. The authors also estimated merging time for different categories of vehicles.

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 Pivic[17] conducted a phone survey on 504 teens (age 16–20) and 409 adults (age 25–45) drivers in the United States of

Alabama to examine a relationship between risk perception, positive affect, and risky driving. The authors reported that male and teen drivers were found to engage themselves in risky driving behavior more frequently than females and adult drivers, respectively. Meng and Weng[18] studied the effects of the environment, vehicle, and driver characteristics on risky driving behavior at work zones. The authors developed a decision tree to graphically display the relationship between risky driving behavior and its influencing factors. The authors 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 are the factors associated with the risky driving behavior at work zones.

It is revealed from the critical literature review that SD and OT are two crucial operational characteristics pertaining to traffic operation at MBMO area. 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 investigated for U-turning vehicles in general and in heterogeneous conditions in particular. Therefore, these available research gaps in currently available literature motivated us to study the influence of drivers' behavior and vehicles' attributes on two operational characteristics, namely SD and OT of U-turning vehicles at MBMO area. These findings will be beneficial for accessing the operation of vehicular traffic, defining the level of service (LOS), and realistic estimation of capacity at MBMO.

Significance of the study

As mentioned earlier, interactions of vehicles at MBMO are considered to be a complicated process because it creates a conflict situation between the slow-moving U-turning vehicle and fast-moving ATT stream. This conflicting situation depends on the amount of time, U-turning vehicle occupies the MBMO area which is termed as OT. Likewise, when a vehicle wishes 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 MBMO until it finds a suitable gap. In this process, the vehicle faces a delay in service before merging, which is termed SD.

HCM (2010)[19] and HCM (2016)[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. But 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, no police personal). Even if priority movement is specified with proper stop and yield signboards, road users violate the priority rule. In the premise of above mention scenarios SD and OT become two important characteristics of traffic operation at unsignalized locations such as MBMO. However, no study is available in open literature about the variations of these two parameters in varying operational characteristics. Therefore, the present study was undertaken to carry out the following objectives:

1. To investigate the influence of approaching through traffic volume (ATTV) on SD and OT for different category of vehicles.
2. To investigate the influence of drivers' and vehicles' attributes on SD and OT at varying ATTV.

TRAFFIC DATA COLLECTION

The current research objectives have been achieved by collecting required traffic data from 14 test sections, which includes seven MBMO in each 6-lane and 4-lane road. The road width was found to vary from 9.5m to 10m and 6m to 7.5m at 6-lane and 4-lane roads. Table 1 presents the 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 A.M. to 5.00 P.M on weekdays, and the data collection 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 a suitable position to get an unobstructed view of the MBMO area for collecting traffic data. Out of three video cameras, ‘video-recorder 1’ was used to record the turning maneuver of U-turning vehicles, ‘video-recorder 2’ was used to record the ATTV, and ‘video-recorder 3’ was used to record the gender of drivers and attributes of vehicles. The turning maneuver of the U-turning vehicle has been divided into two parts. The first part of turning maneuver starts at the time when the U-turning vehicle stops at the mid-block area, tries to find a suitable space between two approaching through vehicles, and start the U-turning process. The second part starts from the time when the U-turning vehicle starts the turning maneuver to the time when the U-turning vehicle completes the turning maneuver and completely merge with the ATT. For the collection of merging time data, a merging line was drawn across the carrigeway 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 required data using a video editing software, namely, 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 rule, the reversal of priority, etc.[21] From the recorded field data, different parameters, namely, SD, OT, ATTV, gender, and characteristics of vehicle taking U-turn (color of number plate, vehicle loading state) were extracted. Fig. 1 represents vehicular operation at MBMO and the detailed data extraction process has been illustrated with the help of Fig. 2.

Fig. 1 Vehicular operation at MBMO: (a) screenshot of data collection site; (b) schematic diagram showing video recorder setup at data collection site

Fig. 2 Schematic diagram representing data extraction process

For the estimation of SD and OT, the identification of an imaginary reference line is one of the challenging steps. The reference line is the 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) see Fig. 2. SD is calculated using equation 1.

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

Similarly, OT is measured from the time (t_2) departure of the front bumper from the reference line (X-X) to the time (t_3) departure of the back bumper of U-turning vehicle from the merging line (Y-Y), and the same is shown in Fig. 2. OT is calculated using equation 2.

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

The extracted data were segregated based on the category of vehicles, and the descriptive statistics have been presented in Fig. 3 in the form of box and whisker diagrams. Fig. 3 suggests that the average SD and OT are lowest for 2W, whereas HV has the highest SD and OT in 6-lane road, and in 4-lane road BC was observed to have the highest SD and OT. It is because 2W drivers have peculiar driving behavior and they try to explore all the possible gaps available in the ATT. But, HV has a bigger physical dimension and hence requires more time to clear the MBMO area.

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 6-lane and 4-lane roads. The wide variation 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, ATTV needs to be estimated from the collected video. In this regard, hourly ATTV was calculated by counting total ATT in 5 minutes, and the same has been converted to hourly ATTV. Oh and Yeo[22] advocated for considering 5-minute volume count instead of 15-minute count for prediction of traffic flow in in one of the studies in California. The author opined 5-minute count to provide better estimation in approaching through traffic volume and the fluctuation in traffic flow is taken care in a improved manner [23]. Analogous approach has been adopted by various research in India for estimation of hourly traffic volume[22,23,24,25]. Furthermore, ATTV was found to vary from 1000 vph to 6500 vph in 6-lane and 500 vph to 3500 vph in 4-lane road. Therefore, the ATTV data have been aggregated with a bin size of 500 vph. Furthermore, to explore the effect of drivers' and vehicles' attributes on SD and OT, driver characteristics (male/female) and vehicle characteristics (personal vehicle/commercial vehicle; loaded/empty) were manually recorded from visual observation of the collected video.

Fig. 3 Box plot for SD and OT for type of vehicles; (a) & (c) 6-lane road; (b) & (d) 4-lane road

ANALYSIS OF FACTORS INFLUENCING OPERATIONAL CHARACTERISTICS

In this section, an effort has been made to examine the influence of various factors comprehensively. ATTV, attributes of drivers and vehicles on operational characteristics of U-turning vehicles are presented in the subsequent subsections.

Influence of ATTV on SD and OT

The average SD is calculated at varying ATTV, and its variation is presented in Fig. 4 (a & b). It can be inferred from the figure that 2W faces the least SD, whereas HV faces the highest SD. SD was found to vary from 2.33sec to 3.14sec for 2W and 2.79sec to 6.44sec for HV in 6-lane roads. Furthermore, 2W and BC are observed to face the least SD and highest SD, respectively, in 4-lane roads. SD is observed to vary from 2.32sec to 4.87sec for 2W and 4.25sec to 9.35sec for BC at 4-lane road. The above observation is because 2W has a smaller physical dimension and unique driving characteristics. Because of its unique driving characteristics and smaller physical dimension, it explores all the available gaps in the ATT stream and completes the U-turning maneuver facing less SD. 3W faces the lowest SD after 2W, because 3W has unusual physical dimensions and the drivers are generally aggressive in nature. Therefore, when the required gap is not available for a longer 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 maneuver. Furthermore, as SC and BC have bigger physical dimensions compared to 2W and 3W, they are found to face more SD. LCV and HV are found to experience the highest SD because of their physical dimension. These vehicles need to wait for suitable available gaps due to the safety concern of the goods carried. From the above observation, it can be concluded that the physical dimension of vehicles plays a vital role in defining the SD faced by U-turning vehicles.

Further, it is also observed that at lower ATTV, vehicles could take U-turn without waiting or even stopping at the median opening and are observed to face lesser SD. But as the ATTV increases, vehicles need to stop and wait at the median opening for a longer time than at lower ATTV for finding a suitable gap between two vehicles in the ATT stream. Due to the reasons mentioned above, U-turning vehicles tend to face more SD at higher ATTV than a lower ATTV. The increasing trend of SD with increasing ATTV is found to be similar in 6-lane and 4-lane roads. Subsequently, mathematical models are developed, and SD is observed to increase exponentially for different types of vehicles. SD increases exponentially as the ATTV increases, because the chance of available gap decreses in the ATT stream. It is certain that 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 longer period of time and faces more delay in service. In this situation the SD experienced by U-turning vehciles increases with increase in ATTV. Table 2 illustrates the developed models to predict SD at varying ATTV.

Fig. 4 Average SD and OT of U-turning vehicles at varying ATTV

Likewise, an effort is made to study the influence of varying ATTV on OT. In this context, the average OT is calculated at varying ATTV, and its variation is presented in Fig. 4 (c &d). From the figure, inference can be drawn that OT of 2W is lowest, which is found to vary from 3.7sec (1000-1500vph) to 2.74sec (6001-6500vph). The OT of 3W is observed to be more than 2W but less than SC and BC owning to the fact that 3W has aggressive driving nature, and also its physical size is comparatively smaller than that of SC and BC. Hence, 3W can clear the MBMO area in lesser time compared to SC and BC. Moreover, due to the longer wheelbase, HV requires more time to clear the MBMO area, and hence highest OT was observed for HV. It was found to vary from 9.66sec to 11.45sec, depending on ATTV.

The figure shows that OT has a decreasing trend with increasing ATTV because, at lower ATTV, vehicles tend to take U-turn freely with low speed, making the U-turning vehicle occupy the MBMO area for a longer time. Hence, OT was observed to be more at low ATTV. But as the ATTV increases, U-turning vehicles are forced to wait for a longer time at median opening for finding a suitable gap, which in turn gets frustrated and tries to take U-turn swiftly, which allows the vehicles to clear the MBMO area in less time. Hence the OT is found to be less at higher ATTV. The decreasing trend of OT is found to be similar in both 6-lane and 4-lane roads. Subsequently, mathematical models are developed, and OT is observed to decrease exponentially for different types of vehicles. Table 3 represents the developed models for the prediction of OT at varying ATTV. Subsequently, these developed models presented in Table (2 & 3) can be useful in estimating the SD and OT of different types of U-turning vehicles only by considering the ATTV and simply by avoiding the data collection and extraction process of SD and OT, which is quite a demanding process.

SD and OT Model Validation

The performance of the proposed SD and OT prediction models have been validated from the data of separate sections which were not used for the development of the models. In this study, data from S-7 for 6-lane road and S-14 for 4-lane road has been used for validating the proposed SD and OT models (see Table 1). For the 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 SD and OT were calculated from the collected field data. The ATTV was observed to be in the range of 3500-4000 vph and 2500-3000 vph in 6-lane and 4-lane roads, respectively. Subsequently, mean absolute percentage error (MAPE) was utilized for evaluating the efficacy of the proposed models. MAPE for the present study is estimated from Equation 3.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{SD/OT_m - SD/OT_f}{SD/OT_f}\right| \tag{3}$$

The observed ATTV value of 3750 vph and 2750 vph are used in the models provided in Table 2 and Table 3 for estimating the SD and OT, respectively, for different types of U-turning vehicles. Table 4 presents the SD and OT values estimated from the field and model 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 6-lane road. Further, in 4-lane road maximum error was observed to be 8.81% for 2W and minimum error was observed to be 5.19% for 3W. Likewise, maximum and minimum MAPE for OT was observed to be 9.34% for 2W and 5.21% for HV respectively in 6-lane road. Moreover, in 4-lane road maximum error was observed to be 9.02% for 2W and minimum error was observed to be 5.86% for 3W. From past studies it is evident that a MAPE value less than or equal to 10% is considered to be satisfactory11, 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.

Influence of attribute of drivers on SD and OT

The different driver attributes that can be considered for this analysis are gender, age, state of mind, involvement in secondary activity personality and etc. However, the data regarding drivers' age, state of mind, involvement in secondary activity, and personality could not be extracted from videographic data. Therefore, only the influence of gender has been 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's gender was observed for 2Ws and cars. But, due to compromised visibility, the observation on driver's gender could not be made for car drivers. For this reason, the influence of gender on SD and OT was carried out for 2Ws only.

For examining the gender influence on SD, two-sided t-tests were carried out at varying ATTV by comparing the SD experienced by 2W while taking a U-turn at MBMO. For carrying out the t-test, the followings are the hypotheses. The obtained result for 2W at 1000-1500 vph has been presented in Table 5.

H_0: SD faced by male drivers ≠ SD faced by female drivers

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

The t-test result shows 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 the SD faced by 2W male drivers is statistically different than SD faced by 2W female drivers. The significant difference in SD faced by male-female drivers is due to the reason that when a vehicle wants to take a U-turn, the U-turning vehicle has to stop and wait at MBMO to get an appropriate gap between the two vehicles in ATT. Subsequently, when a U-turning vehicle faces more SD than usual, the U-turning vehicle tends to take more risk and turn aggressively to complete the U-turn. Due to the risk-taking and aggressive driving characteristics of male drivers[26,27], male drivers face less SD and also force the ATT to slow down. In contrast, female drivers wait at the median opening until a suitable gap is available and experience more SD. At all the ATTV, a similar analysis was carried out and observed to give same results for all the ATTV in 6-lane and 4-lane roads indicating that SD experinced by male drivers is statistically different than female drivers.

Likewise, an effort was made to examine the gender influence on OT. For exploring the gender influence on OT, a two-sided t-test was carried out at varying ATTV by reviewing the average OT of 2W while taking U-turn at MBMO in 6-lane and 4-lane roads. For carrying out the t-test, the followings are the hypotheses:

H_0: OT of male drivers ≠ OT of female drivers

H_1: OT of male drivers = OT of female drivers

Table 5 illustrates the t-test result for male-female drivers. From the t-test result, 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 infers that the OT of male drivers is statistically different from the OT of female drivers. The significant difference in OT of male and female drivers is due to the reason that when a vehicle wants to take a U-turn, it occupies specific road space at the MBMO area and creates conflicting situations between U-turning vehicles and ATT. Furthermore, male drivers are observed to take an aggressive turn to complete the U-turn maneuver, which in turn, male drivers occupy the MBMO area 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 the ATTV, a similar analysis was carried out, and it was observed that a t-test has passed in all the ATTV in 6-lane and 4-lane roads, indicating that OT of male drivers is statistically different than female drivers.

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

Fig. 5 Average SD and OT for male and female drivers: (a) 6-lane road; (b) 4-lane road

Influence of attributes of vehicles on SD and OT

In this section, two vehicular characteristics have been explored, namely, the purpose of vehicle use and loading state of vehicle on SD and OT. The details of the results obtained through statistical analyses have been described in subsequent sub-sections.

Influence of purpose of vehicle use on SD and OT

For examining the purpose of vehicle use on SD and OT, SD and OT of commercial and personal vehicle drivers are aggregated at different ATTV. In India, generally, 2W is used for personal use (negligible in the commercial sector). Moreover, 3W, LCV, and HV are used for commercial purposes only. Besides, SC and BC are used for both purposes; hence, considered for examining the influence of purpose of vehicle use on SD and OT.

Two-sided t-tests were carried out at different ATTV by comparing the average SD faced by commercial and personal vehicles at MBMO to examine the influence of vehicle use on SD,. For carrying out the t-test, the followings are the 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 result from Table 6 shows that T_{crt} is more than $T_{stat,}$ indicating acceptance of H_0 and rejection of H_1. Acceptance of H_0 infers that SD faced by personal vehicles is statistically different than commercial vehicles. It is because commercial vehicle drivers are more experienced and skilled, compared to personal vehicle drivers, due to which commercial vehicles can take U-turn swiftly by interrupting the natural flow of ATT. But personal vehicle drivers are less skillful and generally risk avoiders. Therefore, these drivers wait for an appropriate gap for completing the U-turn. At all the ATTV, the same analysis was carried and observed to give identical results at all ATTV in 6-lane and 4-lane roads, indicating that SD faces by commercial vehicle drivers are statistically different from personal vehicle drivers.

Likewise, an extensive effort was made to examine the influence of OT on commercial and personal vehicles. In this regard, a two-sided t-test was carried at different ATTV by reviewing the average OT of commercial and personal vehicles while taking U-turn in 6-lane and 4-lane roads. For carrying out the t-test, the followings are the hypotheses:

H_0: OT of commercial vehicle ≠ OT of personal vehicle

H_1: OT of commercial vehicle = OT of personal vehicle

From the t-test result in Table 6, T_{crt} is more than Tstat, indicating acceptance of H_0 and rejection of H_1. Acceptance of H_0 infers that the OT of personal vehicles is statistically different than OT of commercial vehicles. The explanation for this observation has been explained earlier for describing the results obtained for SD. Furthermore, the same analysis was carried for all ATTV, and identical results at all ATTV in 6-lane and 4-lane roads were obtained. This indicates that OT of commercial vehicles is statistically different than personal vehicles.

Furthermore, the analysis was extended to evaluate the effect of ATTV on SD and OT for commercial and personal vehicles. From Fig. 6, it can also be observed that SD and OT for commercial and personal vehicles increases and decreases, respectively, with increases in ATTV. The detailed description for the observations has been explained already in previous sections.

Fig. 6 Average SD and OT for commercial and personal vehicles: (a) & (c) 6-lane road; (b) & (d) 4-lane road

Influence of loading state of vehicle on SD and OT

For examining the influence of the loading state of vehicle, 2W without pillion and with a pillion is considered as empty and loaded vehicles, respectively. Likewise, 3W, LCV, and HV without load and with load are considered empty and loaded vehicles, respectively. SC and BC were not considered due to the reason mention in earlier sections.

For examining the influence of loading state of vehicle on SD, a two-sided t-test was carried out for analyzing the loading state of vehicle at different ATTV by reviewing the average SD faced by empty and loaded vehicles in 6-lane and 4-lane roads. For carrying out the t-test, the followings are the 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

From the t-test result shown in Table 7, T_{crt} is found to be more than T_{stat}. This observation indicates acceptance of H_0 and rejection of H_1. Acceptance of H_0 infers that SD faced by empty vehicles are statistically different than SD faced by loaded vehicles because loaded vehicles stop and wait at MBMO until a suitable gap is available, because for loaded vehicles, the safety of their goods and passengers are crucial concerns. Whereas, empty vehicle tries to enter the MBMO area forcefully by compelling ATT to reduce its speed and allow the vehicle to take U-turn. At all the

ATTV, the same analysis was carried out and observed that t-test has passed in all the ATTV in 6-lane and 4-lane roads, indicating that SD faced by empty vehicle is statistically different from a loaded vehicle.

Likewise, an extensive effort was made to examine the influence of the loading state of vehicle on OT. In this regard, two-sided t-tesst were carried out at different ATTV by comparing the average OT of empty and loaded vehicles in 6-lane and 4-lane roads. For carrying out the t-test, the followings are the hypotheses:

H_0: OT of empty vehicle ≠ OT of loaded vehicle

H_1: OT of empty vehicle = OT of loaded vehicle

From the t-test result shown in Table 7, T_{crt} is found to be more than T_{stat}. This observation indicates acceptance of H_0 and rejection of H_1. Acceptance of H_0 infers that the OT of empty vehicles is statistically different than OT of loaded vehicles. The explanation for this observation has been explained earlier for describing the results obtained for SD. At all ATTV, a similar analysis was carried out and observed that t-test has passed in all the ATTV in 6-lane and 4-lane road, indicating that OT of the empty vehicle is statistically different from the loaded vehicle.

Subsequently, the analysis was extended to evaluate the effect of ATTV on SD and OT for empty and loaded vehicles. From Fig. 7, it can be observed that as the ATTV increases, the SD and OT faced by empty and loaded vehicle also increases and decreases, respectively. The reason for this observation has been explained earlier without considering the loading state of the vehicle. Hence it was observed that SD and OT of 2W, 3W, LCV, and HV increases and decreases respectively, with an increase in ATTV. Additionally, it was also observed that SD and OT of loaded vehicles were found to be more than empty vehicles.

Fig. 7 Average SD and OT for empty and loaded vehicles: (a), (c), (e) & (f) 6-lane road; (b) & (d) 4-lane road

SUMMARY AND CONCLUSIONS

MBMO is a location where vehicles take U-turn. It is a complex maneuver because the 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 MBMO and faces SD. Moreover, while a vehicle takes a U-turn, it occupies some space at the MBMO area and creates a conflicting situation with the ATT. The OT of the U-turning vehicle determines the time of conflicting situations between the U-turning vehicle and ATT at MBMO. Therefore, the authors have made an effort to examine 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, an effort was made to examine the influence of ATTV, driver's gender, and vehicle attributes (purpose of vehicle use, loading state of vehicle) on SD and OT. A rigorous analysis revealed that U-turning vehicles experience less SD at low ATTV compared to at high ATTV. Further, OT of vehicles taking U-turn was observed to be more at low ATTV, and it was also observed to decrease with an increase in ATTV. Moreover, operational characteristics, the attribute of drivers and vehicles on SD and OT was studied by various statistical tests. From the investigation, male drivers were observed to experience less SD than female drivers. Commercial vehicles experience less SD than personal vehicles, and loaded vehicles experience more SD than empty U-turning vehicles. Likewise, it has also been observed that male U-turning drivers have less OT when compared to female U-turning drivers, personal U-turning vehicle has more OT compared to commercial U-turning vehicle, and empty U-turning vehicle has less OT compared to loaded U-turning vehicles.

To speak about the limitation of the study, the driver's age, involvement in secondary activity by the driver, the physiological condition of the driver, pavement condition, etc., can also influence the SD and OT of vehicles taking U-turn at MBMO. But these variables have not been explored in the present study due to the unavailability of 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 set-up.

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Table 1. Details of all data collection site

Section name	Location	Type of road	X (m)	Y (m)	Z (m)
S-1	Bangalore	6-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	4-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

x: road width; y: median width; z: width of median

Table 2 Developed models between SD and ATTV

	6-lane road		4-lane road	
Vehicle type	**Models**	**R^2**	**Models**	**R^2**
2W	$2.15e^{0.00006ATTV}$	0.96	$1.76e^{0.00034ATTV}$	0.93
3W	$2.26e^{0.00005ATTV}$	0.97	$1.98e^{0.00032ATTV}$	0.94
SC	$2.11e^{0.00012ATTV}$	0.97	$2.08e^{0.00046ATTV}$	0.97
BC	$2.24e^{0.00012ATTV}$	0.96	$2.99e^{0.00035ATTV}$	0.94
LCV	$2.28e^{0.00014ATTV}$	0.98	--	--
HV	$2.17e^{0.00018ATTV}$	0.96	--	--

Table 3 Developed models between OT and ATTV

	6-lane road		4-lane road	
Vehicle type	Models	R^2	Models	R^2
2W	$3.96e^{-0.00006ATTV}$	0.90	$4.52e^{-0.00015ATTV}$	0.95
3W	$4.29e^{-0.00005ATTV}$	0.92	$4.90e^{-0.00013ATTV}$	0.98
SC	$5.02e^{-0.00003ATTV}$	0.97	$5.54e^{-0.00012ATTV}$	0.93
BC	$5.06e^{-0.00002ATTV}$	0.93	$5.90e^{-0.00012ATTV}$	0.92
LCV	$7.84e^{-0.00004ATTV}$	0.98	--	--
HV	$11.75e^{-0.00003ATTV}$	0.98	--	--

Table 4 Model Validation

Vehicle Type	6-lane (3500-4000vph)			4-lane (2500-3000vph)		
	SD_f	**SD_m**	**MAPE**	**SD_f**	**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	--	--	--
	OT_f	**OT_m**	**MAPE**	**OT_f**	**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	--	--	--

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

U-turning vehicle	Type of attribute	Type of road	Male			Female			T-statistics		F-statistics	
			μ (sec)	**σ**	**N**	**μ (sec)**	**σ**	**N**	T_{stat}	T_{crt}	F_{stat}	F_{crt}
2W	**SD**	**6-lane**	2.21	2.67	306	2.36	2.27	49	0.43	1.98	1.38	1.48
		4-lane	2.29	3.32	161	2.56	3.01	54	0.55	1.98	1.21	1.48
	OT	**6-lane**	3.59	1.32	306	3.81	1.13	49	1.26	1.98	1.36	1.48
		4-lane	3.73	1.66	161	4.07	1.88	54	1.18	1.98	1.29	1.42

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

U-turning vehicle	Type of attribute	Type of road	Personal purpose			Commercial purpose			T-statistics		F-statistics	
			μ (sec)	σ	N	μ (sec)	σ	N	T_{stat}	T_{crt}	F_{stat}	F_{crt}
SC	SD	6-lane	2.54	3.12	171	2.38	3.19	176	0.47	1.98	1.05	1.29
BC	SD	6-lane	2.56	2.84	147	2.42	2.79	205	0.45	1.98	1.03	1.28
SC	SD	4-lane	3.61	3.84	120	3.41	3.39	60	0.36	1.98	1.28	1.47
BC	SD	4-lane	4.55	5.48	70	4.38	5.12	122	0.22	1.98	1.15	1.41
SC	OT	6-lane	4.97	1.76	171	4.75	1.93	176	1.12	1.98	1.21	1.29
BC	OT	6-lane	5.35	1.68	147	4.99	1.89	205	1.88	1.98	1.26	1.29
SC	OT	4-lane	5.03	1.46	120	4.86	1.55	60	0.72	1.98	1.13	1.43
BC	OT	4-lane	5.64	2.29	70	5.00	2.32	122	1.83	1.98	1.03	1.44

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

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**	**6-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		**4-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	**6-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		4-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

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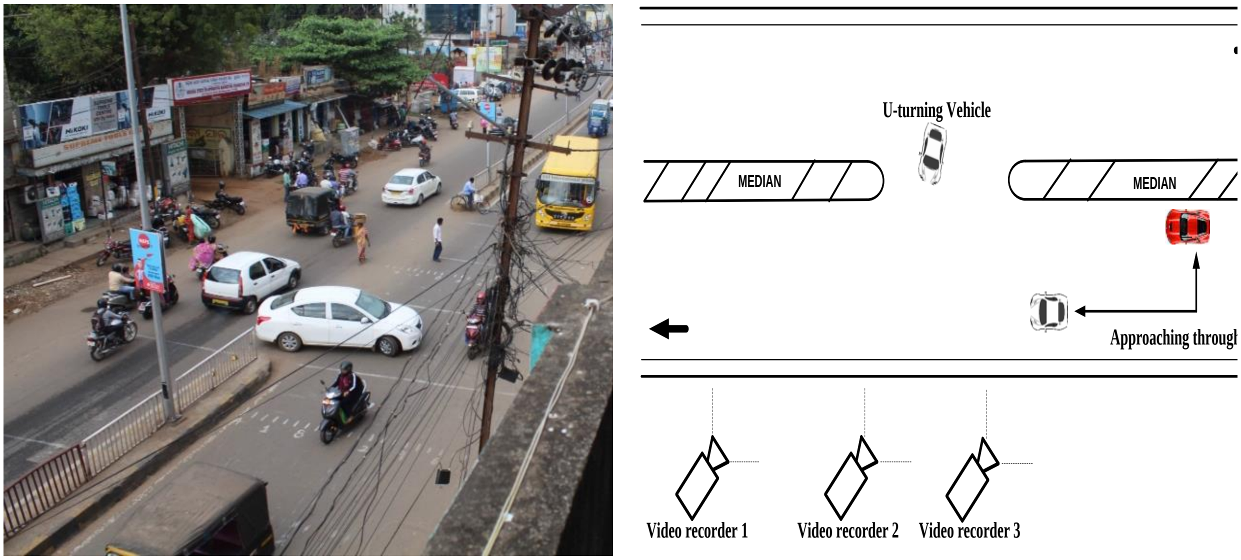


(a) **(b)**

Fig. 1 Vehicular operation at MBMO: (a) screenshot of data collection site; (b) schematic diagram showing video recorder setup at data collection site

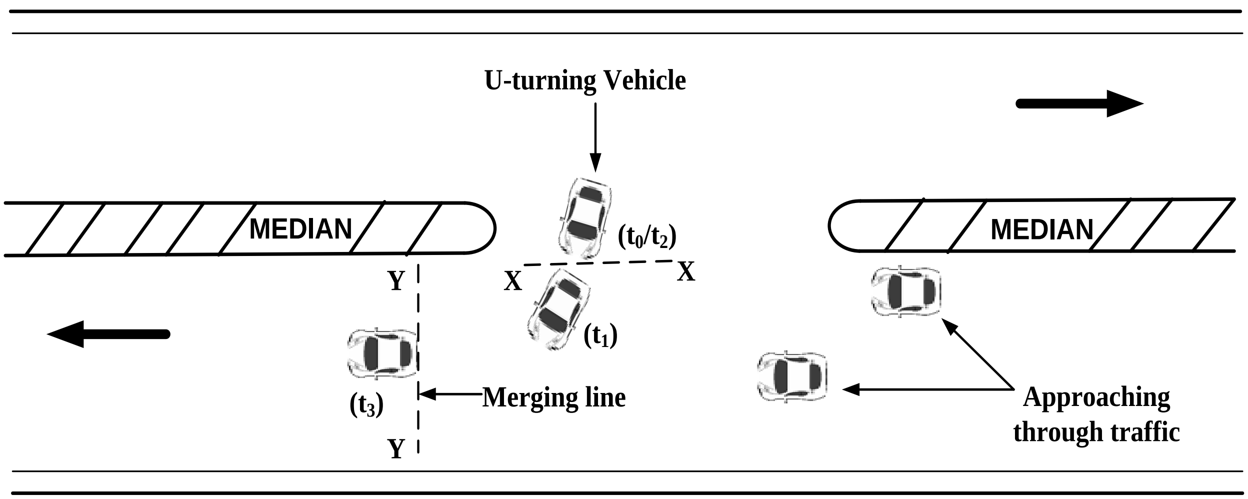
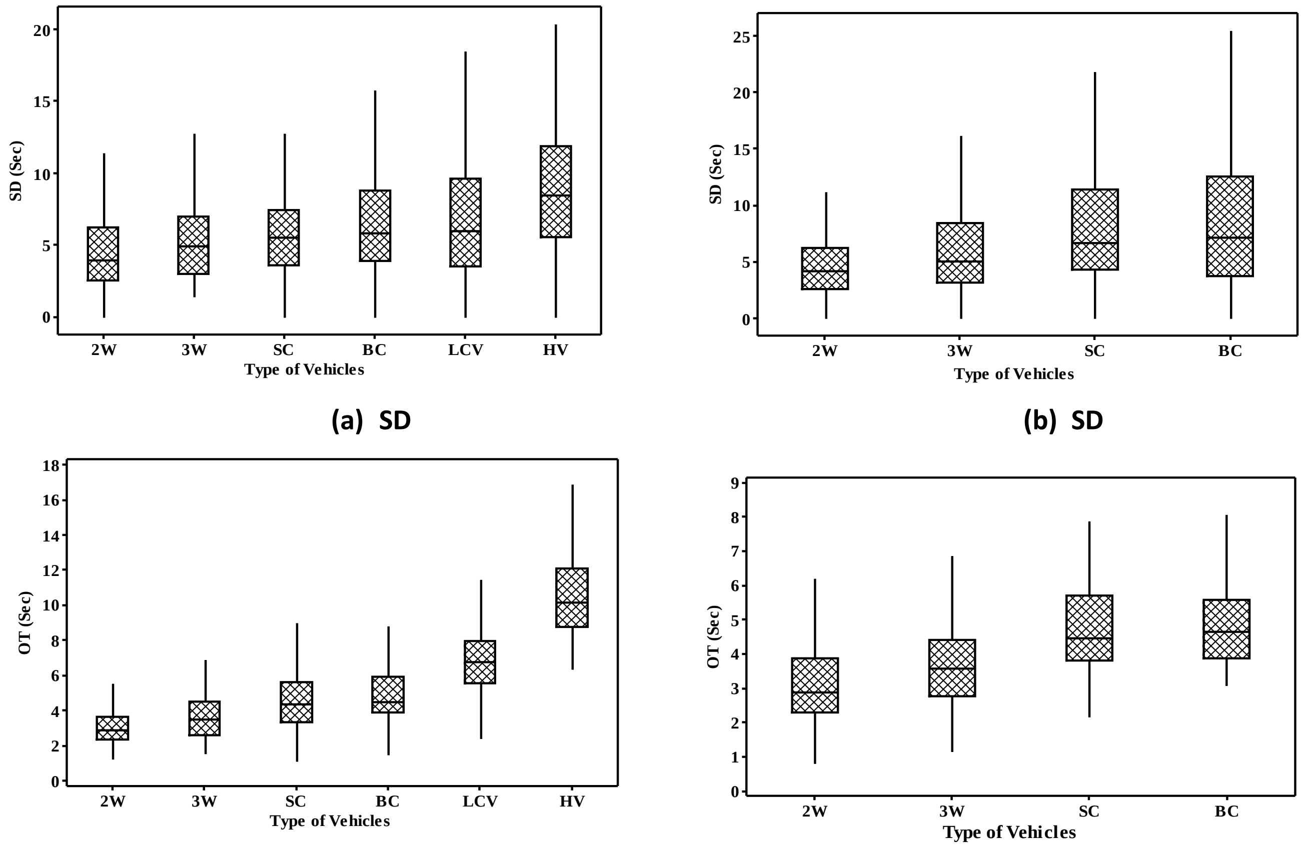


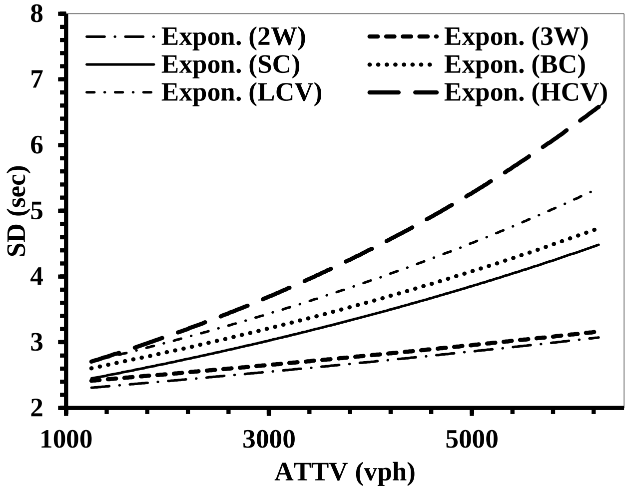
Fig. 2 Schematic diagram representing data extraction process



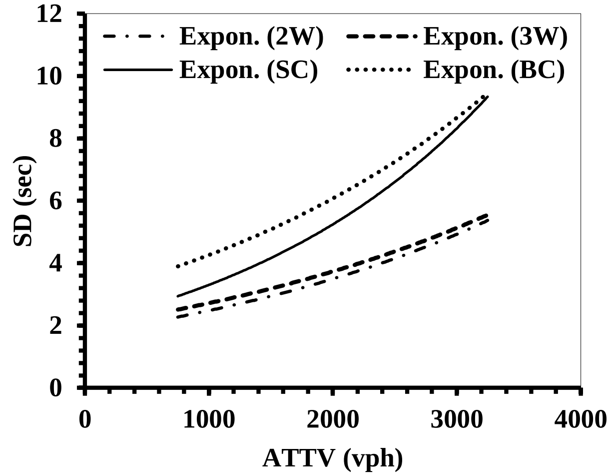
(a) SD (b) SD

(c) OT (d) OT

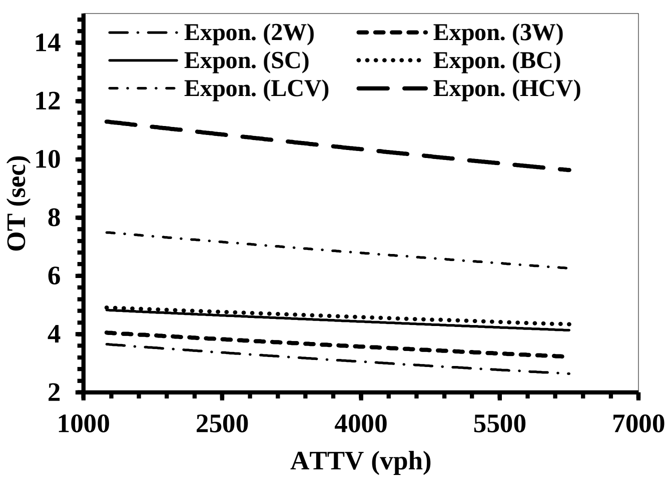
Fig. 3 Box plot for SD and OT for type of vehicles; (a) & (c) 6-lane road; (b) & (d) 4-lane Road



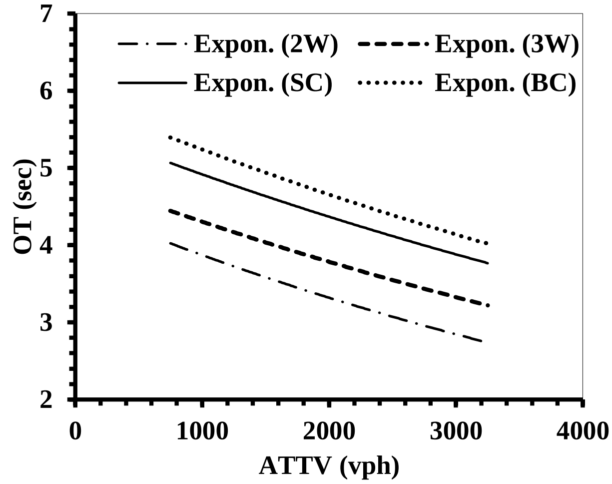
(a) SD in 6-lane road



(b) SD in 4-lane road



(c) OT in 6-lane road



(d) OT in 4-lane road

Fig. 4 Average SD and OT of U-turning vehicles at varying ATTV

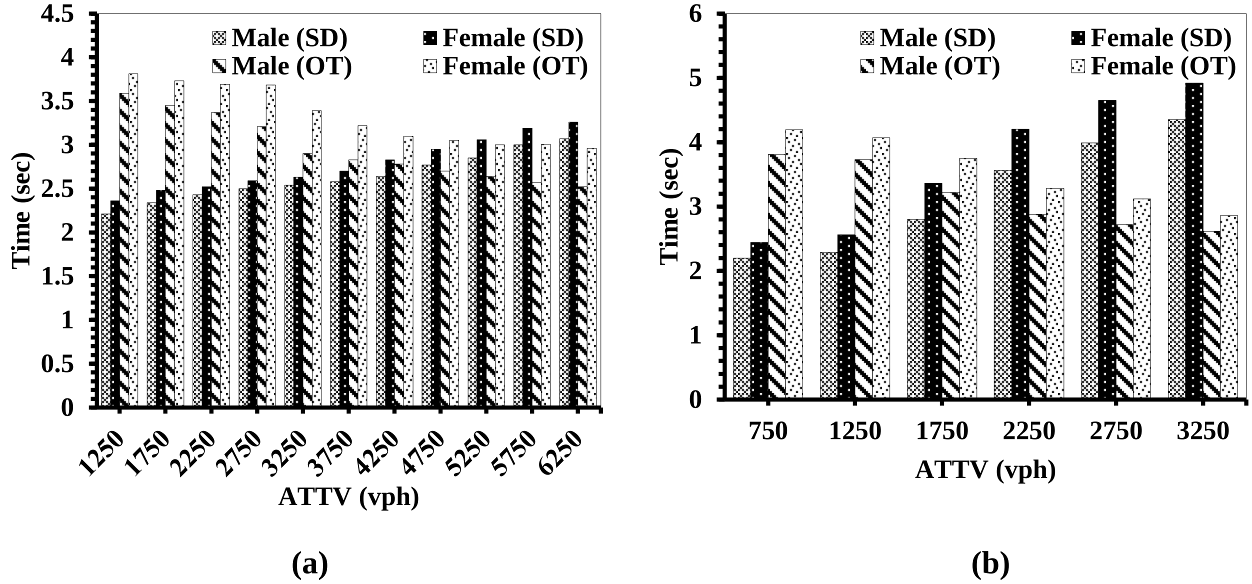


Fig. 5 Average SD and OT for male and female drivers: (a) 6-lane road; (b) 4-lane road

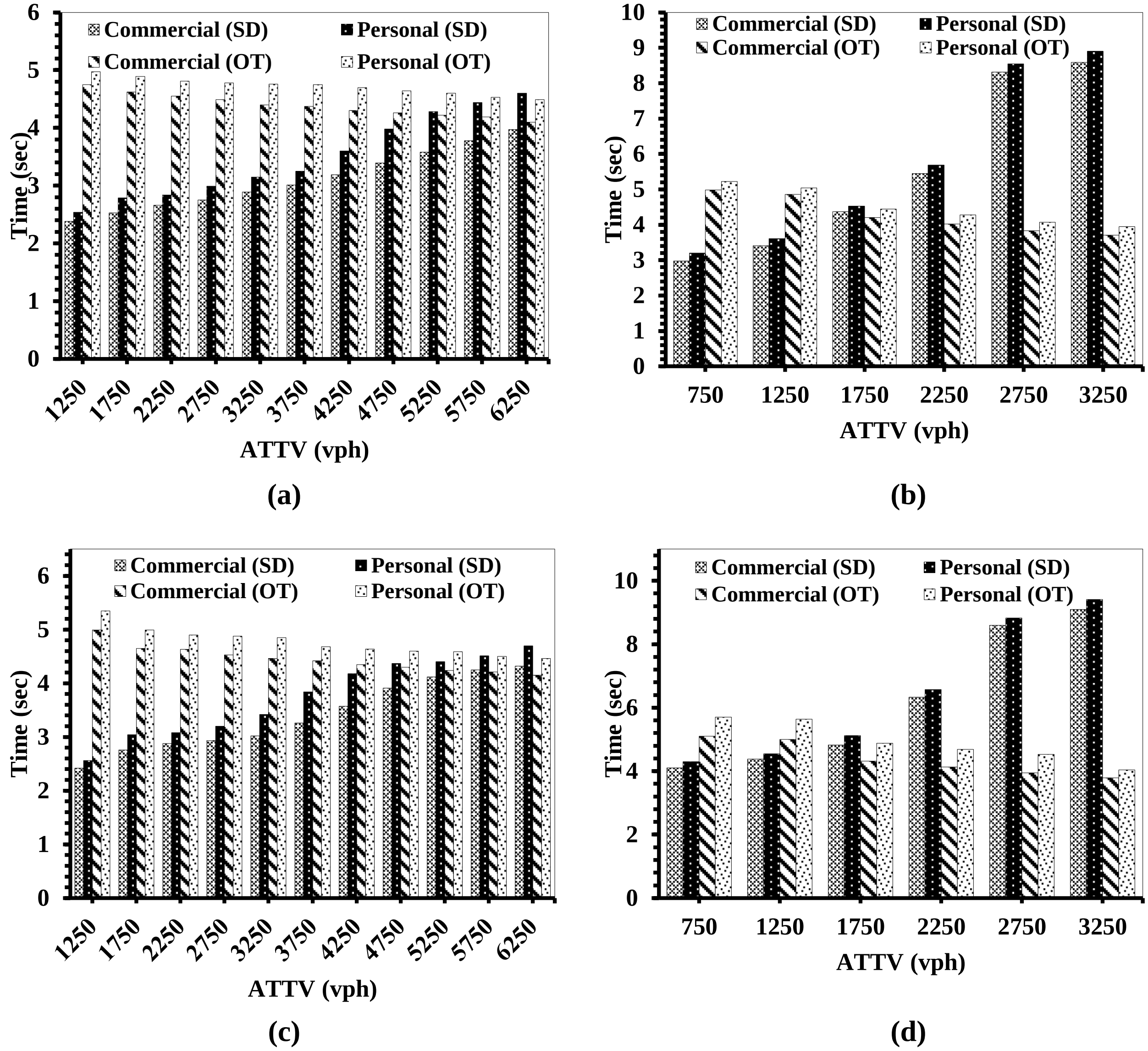


Fig. 6 Average SD and OT for commercial and personal vehicles: (b) & (c) 6-lane road; (b) & (d) 4-lane road

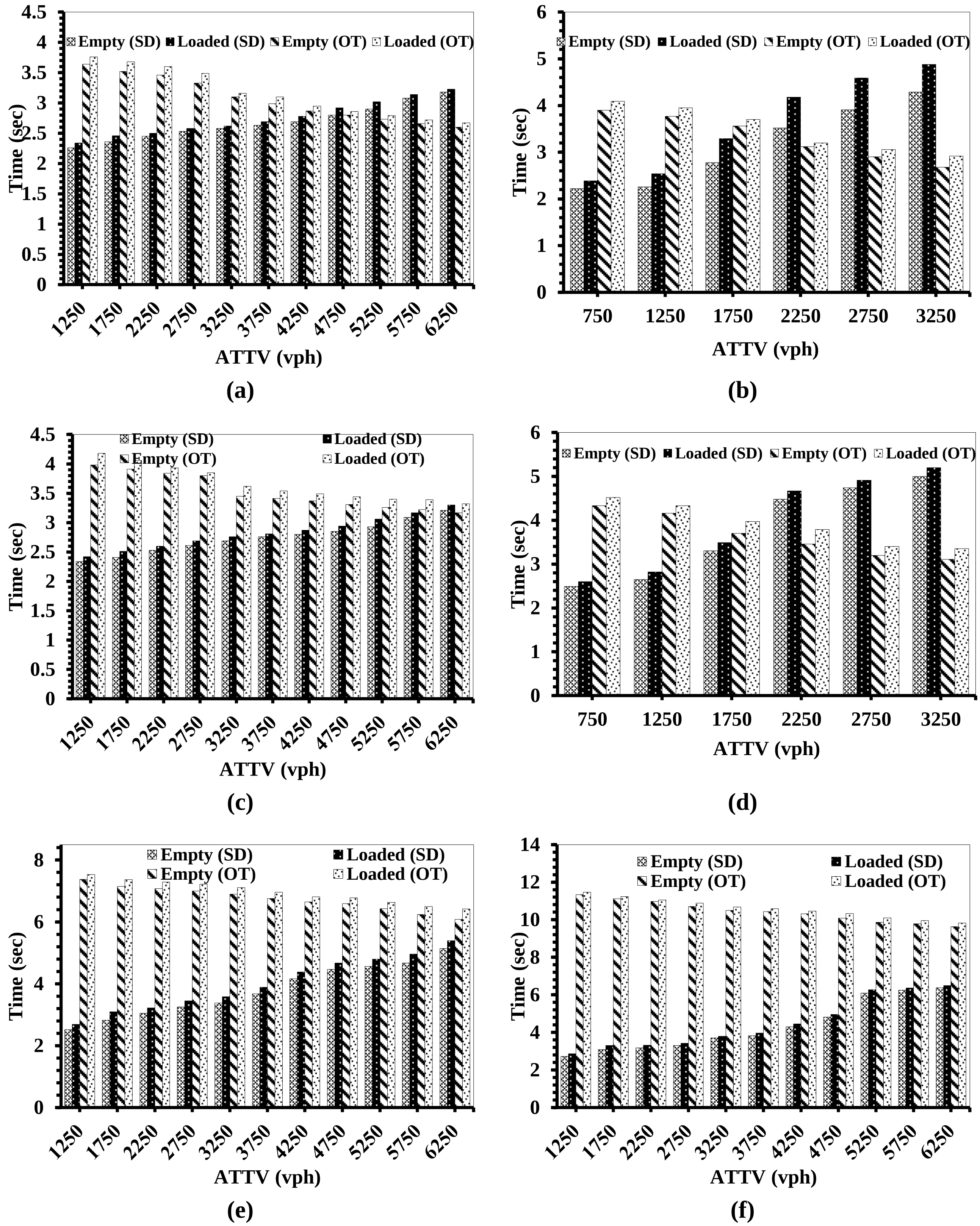


Fig. 7 Average SD and OT for empty and loaded vehicles:
(a), (c), (e) & (f) 6-lane road; (b) & (d) 4-lane road