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MERGING PROCESS OF U-TURNS AT UNCONTROLLED MEDIAN OPENINGS UNDER MIXED TRAFFIC CONDITIONS

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Abstract. At an uncontrolled median opening, the limited priority situation and the high degree of heterogeneity in traffic stream make the merging manoeuvre of U-turning vehicles very much complex. This study is an attempt to understand this merging manoeuvre. The different types of merging manoeuvres have been identified in the field and accordingly classified into different categories. Depending upon the number of vehicles that can merge all together into the opposing through traffic by accepting a single gap, the merging has been classified into two types: single entry merging and multiple entry merging. On the other hand, based on the situation of priority of movement, the merging process is divided into another two categories: ideal merging and forced merging. More explicitly, the ideal merging is split into free merging and Swift Merging (SM). In addition, the forced entry merging is categorized into Gradual Merging (GM) and Aggressive Merging (AM). Time distance diagrams for different types of merging are presented for their better understanding. Field data collected at seven median openings located on various 6-lane divided urban roads are used to analyse different types of merging in a mixed traffic situation. All vehicles plying on the road are divided into 5 categories such as car, motorized two-wheeler (2-W), motorized three-wheeler (3-W), Sports Utility Vehicle (SUV), and Light Commercial Vehicle (LCV) and the merging behaviour of these categories of vehicles have been studied. The effect of influencing parameters like opposing traffic volume and delay on merging are investigated. Mathematical relations are developed between Merging Time (MT) of a vehicle type and the opposing traffic volume. To address the effect of Service Delay (SD) on the MT of a vehicle, models are proposed between SD and MT for all the five categories of vehicles. The two types of merging; gradual and swift are prominently observed in field. The time required by different categories of vehicles for these two merging at various traffic volume levels are determined. Finally, two-tailed *t*-test is conducted to see if the MT for the two different types of merging is statistically different.

Keywords: merging; median opening; mixed traffic; service delay; opposing traffic.

Introduction

In developing countries like India the heterogeneous road traffic is not segregated by vehicle type and, therefore, all vehicles travel on the same right of way. Smaller sized vehicles often squeeze through any available gap between large size vehicles and move in a haphazard manner (Dey *et al.* 2013). In the absence of lane discipline and wide variation in the size and operating characteristics of different types of vehicles, they are found to move abreast in a lane. Multilane roads are generally constructed with raised median in order to segregate the opposing traffic movements. In the case of urban roads, mid-block access is provided for vehicles to make a U-turn and reach driveways on the opposite side of the road at the essential positions depending on the requirement. A U-turn refers to performing a 180° rotation to reverse the direction of travel. The U-turn movement at a median opening is highly complex and risky compared with turning movements at intersections, firstly because of the presence of the opposing traffic volume and secondly because the turning vehicle has to make a 180° movement and merge with the opposing traffic stream in which it is seeking an acceptable gap. The U-turning vehicle must wait and then turn in the face of oncoming traffic and may need to accelerate rapidly to reach the speed of the traffic stream. If there are many turning vehicles on the approach, then a long queue in the stream cannot be avoided and then queue spillback to block through traffic is possible. This can lead to traffic problems, mainly reduced capacity and level of safety

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(Aldian, Taylor 2001). A U-turning vehicle while taking a U-turn need to merge, but not to cross the opposing traffic. In the congested situations, acceptable gaps in main traffic may not be available, and more complex merging phenomena occur. These complex merging phenomena affect the main-road traffic flow in terms of speed, volume, and safety (Kanagaraj *et al.* 2010). Therefore, it is significant to study the merging behavior of U-turning vehicles and to develop some merging models that reflect a real world situation. The study of such merging behavior is very fundamental, challenging, and important in operational and capacity analysis and for devising control measures. The study of merging behaviour is an important component of microscopic traffic simulators for corridor traffic analysis and access management techniques (Kanagaraj *et al.* 2010). Chu *et al.* (2014) studied the speed and position of vehicles during merging on Nagoya urban expressway merging sections and opined that longer acceleration lane length is associated with further merging positions. They proposed normal distribution models for merging positions and speeds of vehicles and found that the merging manoeuvre is significantly affected by the traffic density. Esawey and Sayed (2007) compared the performance and operations of two unconventional intersection schemes, namely: the Crossover Displaced Left-Turn (XDL) and the Upstream Signalized Crossover (USC) intersections. They also compared the performance of the two unconventional intersections against a conventional four-leg intersection in terms of average vehicle delay and potential capacity. Oh and Yeo (2012) estimated the capacity drop in the highway merging sections and found a negative relationship between capacity drop and the number of lanes. They reported that the drop in capacity decreased from 16.33% for 2-lane highway to 8.85% for 5-lane highway. Tageldin *et al.* (2015) demonstrated an automated approach for the extraction of the elements of merging behaviour for right turn movements. Milanes *et al.* (2011) presented a procedure to study the merging behaviour of vehicles approaching from a minor to a major road in congested traffic situations. They developed an automated merging system by utilizing a fuzzy controller to act on the vehicles' longitudinal control – throttle and brake pedals – following the references set by a decision algorithm. Ahammed *et al.* (2008) analysed the traffic behaviour at freeway merge areas by collecting data from 23 merging sites on Highway 417 located within the City of Ottawa, Canada and concluded that merging speed depends on both ramp and Speed-Change Lane (SCL) geometric. They developed statistical models for the prediction of 85th percentile passenger car right lane speed, merging speed, merging distance, and acceleration on the SCL. A safety performance model was also proposed to relate the total number of collisions on the acceleration SCL to the features of the merge area including the merging speed. The response of drivers to road structure and surroundings during merging manoeuvres was studied by Riener *et al.* (2011).They concluded that Ambient Intelligence (AmI) technology has the potential to increase road capacity or average driving speed and furthermore to decrease the panic of drivers while merging. Autey *et al.* (2013) studied the operational performance of four unconventional intersection schemes: the XDL, the USC, the Double Crossover Intersection (DXI) (i.e., half USC), and the Median U-Turn (MUT) by using micro-simulation. Esawey and Sayed (2013) presented an in-depth literature review of existing methods for analysing the operational and the safety performance of unconventional intersection designs. Chu *et al.* (2013) quantified the effects of acceleration lane lengths and traffic conditions on merging manoeuvres at urban expressway entrances. They reported that the merging speeds decrease as traffic conditions become more congested. They compared the initial speed and merging speed of vehicle and concluded that the merging vehicles use the acceleration lane not only for acceleration purpose but also for deceleration purpose. Richl and Sayed (2006) established quantitative relationships between collisions and cross-sectional elements using collision prediction models and collision modification factors. Reliability analysis was done on a series of horizontal curves and they concluded that narrow medians combined with tight horizontal curves did not provide sufficient sight distance. Kondyli and Elefteriadou (2012) investigated the drivers' thinking process and actions during merging or passing through freeway-ramp merging areas. Meng and Weng (2012) studied drivers' merging behaviour in a work zone merging area by using Classification and Regression Tree (CART) approach. Weng and Meng (2011) modelled the speed-flow relationship and merging behaviour in work zone merging areas. They also proposed a merging distance model to find the 85th percentile of the merging distance.

Many research studies have been carried out on the merging behaviour of vehicles under homogeneous traffic conditions. Meng and Weng (2012) used classification and regression tree approach for predicting drivers' merging behaviour in short-term work zone merging areas. Marczak *et al.* (2013) studied the key variables of merging behaviour. Kanagaraj *et al.* (2010) modeled vehicular merging behaviour under heterogeneous traffic conditions by studying the merging manoeuvres microscopically at T-junctions under congested traffic conditions. They developed models for normal and forced merging and validated their findings with field data and suggested that the models could be used to simulate highly congested traffic flow in a realistic manner under heterogeneous traffic conditions. Therefore, insufficient number of reports are available on U-turns under mixed traffic conditions and most of the studies are performed on intersections while the effect of different types of explanatory variables (e.g. service delay, traffic volume, whether the through traffic is affected or not, presence of interruption during merging, number of merging vehicles, etc.) on merging behaviour has not received much attention of researchers. Therefore, these aspects have been considered as the focus of the present study. The objectives of the study are: (a) to identify and study the different types of merging manoeuvres; (b) to assess the influence of Service Delay (SD) and opposing traffic volume on Merging Time (MT) of a U-turning vehicle.

1. Merging Process

Upon arriving at an uncontrolled median opening, the U-turning vehicles merge with the opposing through traffic. The flow chart for the merging process is given in Fig. 1.

The merging is possible if the available gap is sufficiently high (greater than critical gap) otherwise, the vehicle waits for the next suitable gap. The number of gaps accepted by U-turning vehicles during a unit time will decrease as the opposing through traffic volume increases, resulting in increased waiting time for the U-turning vehicles. Many drivers become indignant due to long waiting and try to merge aggressively by accepting smaller gaps, forcing some of the opposing through vehicles to reduce their speeds. It makes the merging process a complex phenomenon in mixed traffic situation. In the present study, the merging of U-turning vehicles are classified into two types: (a) single entry merging and (b) multiple entry merging, depending upon the number of vehicles moving into the opposing through traffic accepting a single gap. In a single entry merge only one U-turning vehicle moves into a single gap of opposing through traffic, whereas in a multiple entry merge two or more U-turning vehicles merge (i.e. enter) into a single gap of opposing through traffic (Drew

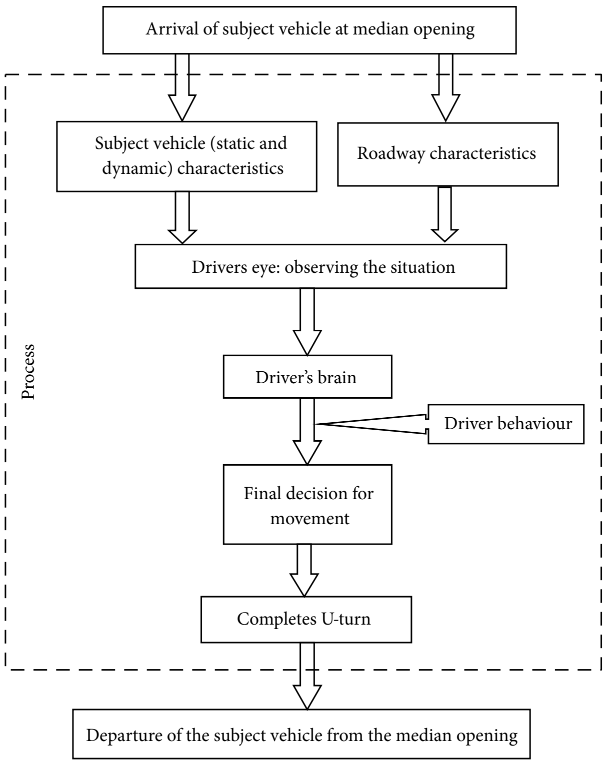

Fig. 1. Flow chart of decision making for U-turning process

1968). The multiple entry merging can be further subdivided into two categories as given below:

- *Parallel merging:* two or more U-turning vehicles merge side by side. This is only possible for small sized vehicles or combination of small and medium sized vehicles. Parallel merging is not possible for heavy vehicles;
- *Streamlined merging:* two or more U-turning vehicles merge following each other. This is generally possible at a low traffic volume where the available gap for merging is sufficiently large.

The U-turning movements have low priority as compared to the opposing through traffic at an uncontrolled median opening. Therefore, it is expected that the U-turning movement will be affected by the opposing through traffic and accordingly the subject vehicle will experience SD before merging. However, in reality it happens that sometimes the opposing traffic need to slow down due to impatient and discourteous behavior of the turning driver and the opposing through vehicles also experience some delay. In this situation the priority of opposing through traffic movement is compromised, which is usually referred to a limited priority situation. Depending on the situation of priority of movement, the merging process is divided into two categories: *ideal merging* and *forced entry merging* and are presented in Fig. 2:

- *Ideal merging:* The merging vehicle is able to enter the opposing through traffic without causing an opposing through vehicle to reduce its speed or change lanes. In this situation, the priority of the movement is respected. The ideal merging can also be subdivided into following two types:
  - *Free merging:* In this case, the U-turning vehicles neither experience any SD (it does not wait before merging) nor influences the movement of opposing through traffic. This type of merging may be called as 'free merging' as this is possible only under free flow condition. The movement of the subject vehicle is totally unaffected by both U-turning vehicles and opposing through traffic. Kyte *et al.* (1991) suggested that when an available gap is more than 12 s, the subject vehicle cannot see the conflicting traffic and therefore, the presence of the conflicting traffic does not influence the manoeuvrity of the vehicle and could be defined as free flow condition. It is further explained in Fig. 3.

    The subject vehicle completes merging if the available gap (the time gap between the rear of the lead vehicle and the front of the following vehicle passing the point of reference) in the opposing through traffic is greater than 12 s. The probability of the i-th driver to accept an available gap t_a is given in equation:

    $$P_{i,free} = P_i(t_a > 12\text{ s}); \quad (1)$$

  - *Swift Merging (SM):* Like free merging, in SM also, the opposing through vehicle neither reduces its speed nor changes the lane, but the U-turning vehicle experiences SD before merging.

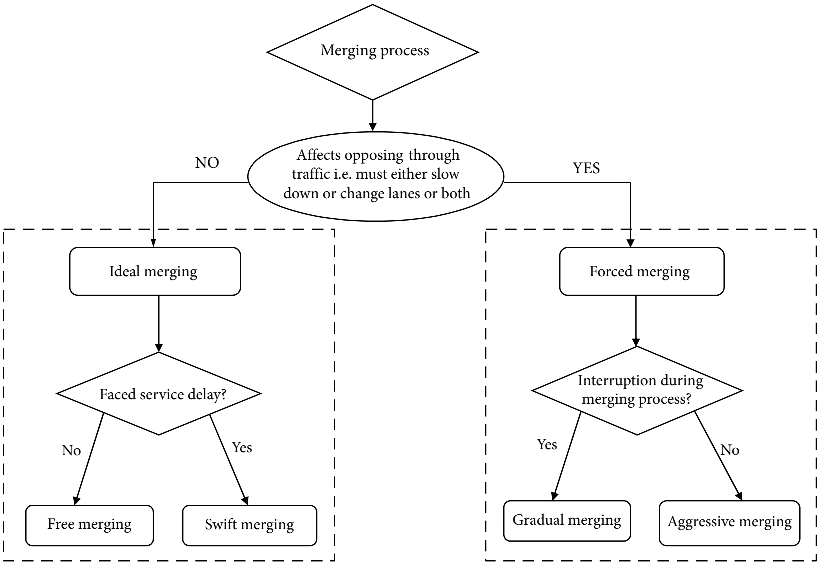

Fig. 2. Different types of merging

The subject vehicle will stop before merging and waits for a suitable gap. As soon as a suitable gap is available to the subject vehicle, the gap will be accepted to complete the merging manoeuvre and the driver will not experience any additional SD as shown in Figs 4–6. In this case, the driver completes merging if the gap is greater than or equal to the drivers critical gap t_c. The probability of the i-th driver to accept an available gap t_a is as given in equation:

$$P_{i,swift} = P_i(t_a > t_c); \tag{2}$$

– *Forced entry merging:* The U-turning vehicles accomplish the merging manoeuvre into the opposing through traffic, so that the opposing through vehicle or vehicles must either slow down or change lane (Drew 1968). The interaction between the subject vehicle and opposing through traffic is relatively high. This happens in a limited priority situation due to the indecent behaviour of a diver to accept a small gap, which would have otherwise been rejected. In this case, the gap is created by slowing down the speed of through vehicle or vehicles and the gap is offered t_o to the subject vehicle to accomplish the manoeuvre. The gap between the lead and lag vehicles widens as the subject vehicle executes a forced merging. This type of merging is subdivided into the following two categories:
  - *Aggressive Merging (AM):* Drivers usually tend to accept shorter gaps by merging aggressively into the opposing through traffic, so that the opposing through the vehicle or vehicles are forced to either slow down or change lane suddenly which may encounter serious and hazardous situations during U-turning manoeuvre. This happens due to the unruly and discourteous behaviour of drivers. The turning vehicles forcefully try to enter the opposing through traffic to avoid delay. In addition, as the duration of waiting time increases beyond a certain limit and the drivers become indignant and aggressive and start accepting smaller gaps. In this case, evasive actions, such as braking or swerving, are taken by the opposing traffic to avoid a collision. As such the gap between the lead and lag vehicles widens rapidly (due to sudden braking of lag vehicle) and the subject vehicle aggressively executes the turning movement. It is shown in Fig. 7 also.

    The probability of the i-th driver to accept an offered gap t_o is as:

$$P_{i,aggeressive} = P_i(t_o > t_c); \tag{3}$$

  - *Gradual Merging (GM):* The subject vehicle waits for the service at the median opening and thereafter starts rolling with a very low speed and gradually enters the opposing traffic stream and completes the merging process (Fig. 8). In the GM, the subject vehicle either stops for a moment or slows down within the conflicting zone. In both the cases, the subject vehicle is bound to experience some additional delay during the merging process. The opposing vehicles generally change their lane in addition to slowing down their speed.
    The probability of the i-th driver to accept an offered gap t_o is:

$$P_{i,gradual} = P_i(t_o \geq t_c)\ (1 - P_i(t_a \geq t_c)). \tag{4}$$

From the above discussion, it is apparent that a merge must be either single entry or multiple entry, free or swift, and gradual or aggressive. However, in reality, a given merge might be described as parallel swift, stream lined swift, parallel gradual, etc. The time distance diagrams for different types of merging process are presented in Figs 3–8.

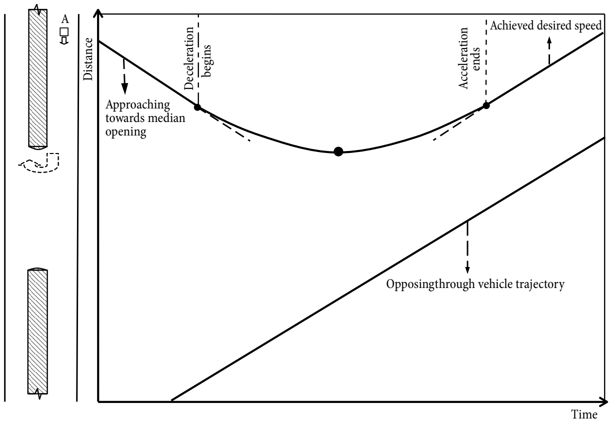

Fig. 3. Time–distance diagram for free merging

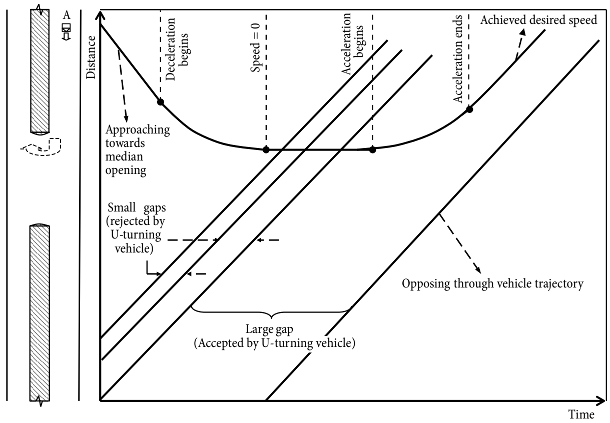

Fig. 4. Time–distance diagram for SM

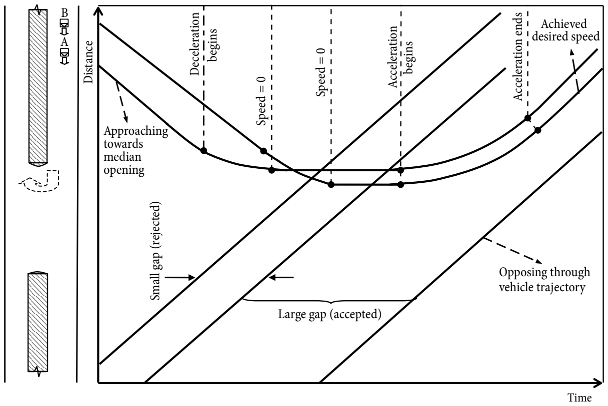

Fig. 5. Time–distance diagram for parallel SM

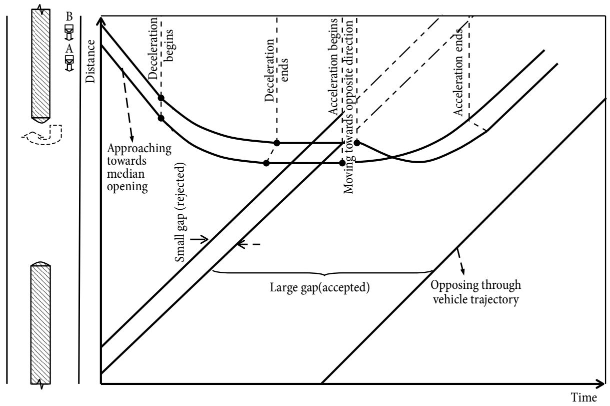

Fig. 6. Time–distance diagram for stream lined SM

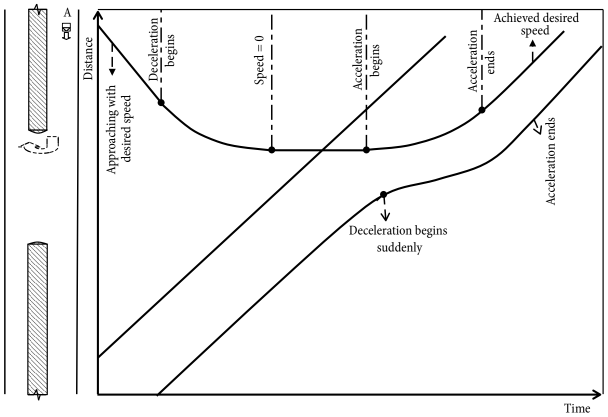

Fig. 7. Time–distance diagram for AM

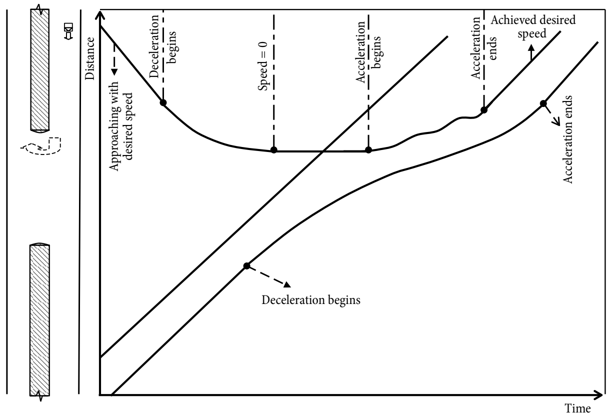

Fig. 8. Time–distance diagram for GM

2. Data Collection and Extraction

The disaggregate data for the merging process was collected at seven different locations of median openings on multilane divided urban roads in Bhubaneswar city of India. The locations were chosen in such a way that the test sites were free from the effect of any upstream and downstream junction, side friction, pedestrian movements, curvature or bus stop. All the roads are six-lane divided roads having one side width of 9.5 m to 10.0 m with raised kerb. Video recording technique was adopted to collect the data and the recorded film was played in the laboratory several times to obtain the realized MT, approaching traffic volume and the SD experienced by each subject vehicle (U-turning). Data for SD and MT were collected for approximately 15 hours for all sites on various weekdays at different traffic volume levels. The resulting data set included 1498 observations for five different categories of vehicles classified as two-wheeler (2-W), three-wheeler (3-W), Sports Utility Vehicle (SUV), car, and Light Commercial Vehicle (LCV). Heavy vehicles

Table 1. Traffic composition at different sections

Section #	Approaching traffic volume [vph]	U-turning traffic volume [vph]							
		2-W	3-W	car	SUV	LCV	HV	other	total
1	4416	492	213	153	36	24	6	18	942
2	4380	552	72	170	80	30	12	8	924
3	5876	647	72	103	30	12	6	12	882
4	5521	178	23	15	4	2	–	–	222
5	5858	108	12	36	3	1	–	–	160
6	4857	139	20	43	14	5	2	1	224
7	4736	700	343	287	92	94	23	66	1605

were not considered in this study, as their proportion was less than 1% in traffic composition. The observed hourly traffic volume (vehicles per hour) and compositions at different study sections are given in Table 1.

The recorded film was played on a TV monitor to extract the data with an accuracy of 0.04 s. Video image-processing software was used to extract the data from the recorded video. The software extracts video image into frames in which 1 s of video data were converted into 25 frames. The photographic presentation of data extraction for MT and SD is shown in Fig. 9.

The front bumper of the U-turning Vehicle arrives at reference line (t_0 – service delay starts)

The rear bumper of the U-turning vehicle departs from reference line (t_d – end of service delay or initiation of merging)

The rear bumper of the U-turning vehicle passes over the merging line (t_m – end of merging)

Fig. 9. Measurement of SD and MT in the field

The identification of the reference line for the measurement of SD at uncontrolled median openings is very important. Al-Omari and Benekohal (1997) measured SD as the time from the instant t_0 when the front bumper of the subject vehicle arrived at the reference line to the moment t_d the rear bumper passed over the reference line. In the case of U-turns at uncontrolled median openings, the vehicles encroach the lane adjacent to the median and thus interfere with the through traffic movements (TRB 2004). From the preliminary observations of videos, it was noticed that about 80% of the U-turning vehicles stopped at a point encroaching almost one third width of the median lane in the opposite direction. This virtual point was marked on the video and considered as the reference point for the measurement of arrival and departure time of a vehicle. Thus, SD of a U-turning vehicle was measured from the time t_0 the front bumper arrived at the reference line to the time t_d the rear bumper passed over the reference line:

$$SD = t_d - t_0. \tag{5}$$

Similarly, the MT was measured from the time t_d the rear bumper passed over the reference line to the time t_m the rear bumper passed over the merging line:

$$MT = t_m - t_d. \tag{6}$$

From a preliminary study in the field, it was found that the position of the merging line varies with the category of the vehicle. The merging line was defined as a virtual bar downstream the nose of the median opening where the turning vehicle completely merges with through traffic coming from the opposing direction. Again, this merging line is not uniform for all the categories of vehicles and the average values as observed in the field are given in Table 2. In this microscopic study, the merging line was identified individually for each and every merging process and accordingly the MT was recorded.

Table 2. Distance of merging line for different categories of vehicles

Category of vehicle	Distance of merging line downstream the median nose [m]
2-W	2.0
3-W	2.5
SUV, car	3.0
LCV	3.3

3. Analysis of Data

The microscopic analysis of SD was done with a large amount of data for each category of vehicle at 7 different median openings on 6-lane divided urban roads.

The SD statistics for different vehicle categories are given in Table 3. As may be seen, the SD is minimum for 2-W and the maximum for LCV. The effect of opposing through traffic volume on SD to individual category of vehicles was also studied. The SD for each category of vehicle was estimated from the collected data at different opposing traffic volumes [vph] and the results are shown in Fig. 10. It is obvious that the presence of high opposing traffic volume would inflict for SD.

The merging manoeuvres are also studied and the MT of different types of vehicles at various levels of opposing traffic volume is presented in Table 4.

Table 3. SD statistics for different categories of vehicles

Category of vehicle	Mean μ [s]	Standard deviation σ [s]
2-W	6.78	5.00
3-W	6.91	6.00
SUV	7.74	5.21
Car	9.44	7.99
LCV	11.53	7.75

Table 4. MT statistics for different categories of vehicles

Opposing through traffic [vph]	Merging time [s]					
	2-W	3-W	SUV	car	LCV	average
>1000–1500	2.91	3.73	3.89	4.15	4.27	3.79
>1500–2000	2.85	3.56	3.87	3.92	4.21	3.68
>2000–2500	2.83	3.53	3.45	3.67	4.18	3.53
>2500–3000	2.81	3.48	3.57	3.64	3.84	3.47
>3000–3500	2.63	3.45	3.56	3.51	3.48	3.32
>3500–4000	2.50	3.15	3.51	3.5	3.87	3.30
>4000–4500	2.46	3.10	3.37	3.46	3.47	3.17
>4500–5000	2.14	3.01	3.22	3.41	3.27	3.01
>5000–5500	2.21	2.92	2.96	3.37	3.43	2.98
>5500–6000	2.10	2.65	2.83	3.23	3.41	2.84
Average	2.54	3.26	3.42	3.59	3.74	–

From the Table 4 it is observed, that MT is different for different types of vehicles and it varies with opposing traffic volume also. The variation among different categories of vehicles is mainly due to the variation in static and dynamic characteristics of vehicles, engine power to weight ratio, and driver behaviour (age, sex and driving experience) etc. The average MT for 2-W is the minimum followed by 3-W, SUV, car, and LCV. The average MT for a 2-W is less due to two reasons: (a) the dimensions and the frontal shape of two-wheelers facilitate acceptance of very small gaps, and (b) the unique driver behaviour of these vehicles in heterogeneous traffic condition, where every gap in the road space is explored to move into the stream. The average MT for 3-W

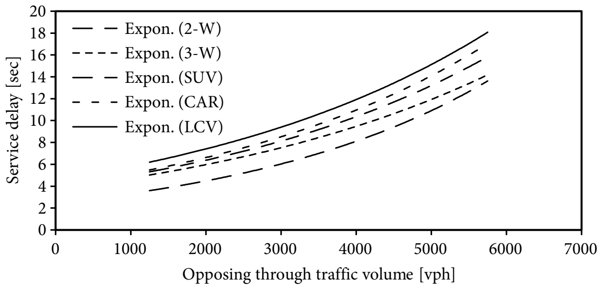

Fig. 10. Effect of opposing through traffic volume on SD

is less as compared to cars. This can be attributed to the smaller size of the auto rickshaw, its conical front shape, and driver aggressiveness (Kanagaraj *et al.* 2010). Mostly the car drivers are defensive because generally they drive their own vehicle, whereas the SUVs are mostly used for taxi purpose and operated by professional taxi drivers. Due to this reason, the car drivers are more cautious and likely to drive more safely. The car drivers are male or female, but there is hardly any female SUV driver in India. The age of the car drivers varies from 22 to 65 years and that for professional taxi drivers varies from 22 to 45 years. Male drivers are more likely to accept shorter gaps than female drivers and younger drivers accept shorter gaps than older ones (Obaidat, Elayan 2013). Due to these reasons and the aggressive nature of younger male taxi drivers, the average MT for SUV is less than that for a car. The average MT for an LCV is the maximum as compared to other category of vehicles. This is due to the larger size and the lesser power to weight ratio of these vehicles.

3.1. Effect of Opposing Through Traffic and SD on MT

The effect of opposing traffic on MT for different categories of vehicles is also studied and one such relation for car is shown in Fig. 11. Similar relations were observed for other categories of vehicles also. At high traffic volume the small gap sizes (less than critical gap) are rejected by the subject vehicle and the vehicle waits until the gap is greater than the critical gap. Thus, it is obvious that the presence of high opposing through traffic volume would result in rejection of more number of small gaps, which will in turn increase the SD. As the SD for

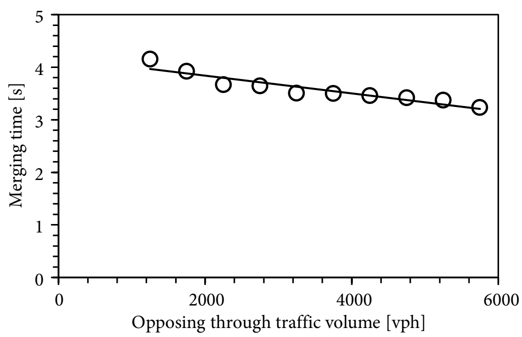

Fig. 11. Effect of opposing traffic on MT for the car

the subject vehicle increases, the impatient drivers become indignant and aggressive and accept shorter gaps, which would have otherwise been rejected by the vehicle at low traffic volume. The small gaps in high traffic volume are generally created by the opposing traffic to allow the subject vehicle to accomplish the merging manoeuvre. Upon accepting the shorter gaps at high traffic volume, the subject vehicle accelerates very fast resulting in shorter MT. The waiting time is also found to affect the gap acceptance behaviour of the driver. Obaidat and Elayan (2013) reported that drivers accept shorter gaps after longer waiting times. Tian *et al.* (2000) also reported that drivers use shorter critical gap at higher flow conditions. The mathematical equations relating MT with opposing traffic volume V for 5 different categories of vehicles are given in Table 5.

The effect of SD on MT to 2-W is shown in Fig. 12 and the developed mathematical equations are provided in Table 6.

Table 5. Models for MT for different vehicles

Category	Models	R^2 value
2-W	$MT = -0.00020 \cdot V + 3.24478$	0.937
3-W	$MT = -0.00022 \cdot V + 4.02889$	0.954
Car	$MT = -0.00017 \cdot V + 4.17688$	0.876
SUV	$MT = -0.00045 \cdot V + 5.15415$	0.911
LCV	$MT = -0.00025 \cdot V + 3.42222$	0.956

Table 6. Proposed models for MT for different categories of vehicles

Category	Models	R^2 value
2-W	$MT = -0.095 \cdot SD + 3.268$	0.923
3-W	$MT = -0.094 \cdot SD + 4.183$	0.952
Car	$MT = -0.060 \cdot SD + 4.205$	0.737
SUV	$MT = -0.183 \cdot SD + 5.375$	0.822
LCV	$MT = -0.106 \cdot SD + 4.894$	0.810

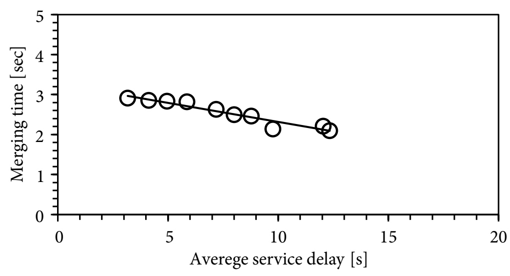

Fig. 12. Effect of SD on MT of 2-W

3.2. Comparison of SM and GM

From the preliminary study, it was observed that two types of merging are predominant; SM and GM. In the case of SM, the rule of priority is followed whereas in the other case the priority becomes shared, which is known as a limited priority situation. The drivers associated with SM are generally defensive in nature and therefore they generally wait until they get a sufficiently large gap to accomplish the manoeuvre. The impatient drivers become aggressive after a long waiting time period and they start to roll and gradually try to enter the opposing traffic stream. Due to rolling of vehicles at very low speed, the time required to finish the merging is also higher as compared to SM. Kanagaraj *et al.* (2010) also opined that aggressive drivers find certain gaps to be acceptable, even when the lag vehicle speed is high, whereas the defensive drivers do not consider merging when the lag vehicle speed is high. The time required by different categories of vehicles for the two different types of merging at various traffic volume levels is presented in Table 7. A two-tailed t-test was conducted to compare the average MT required during SM μ_1 and during GM μ_2. The null hypothesis is that the average MT for two different types are not different and accordingly the following two hypotheses are made:

Null hypothesis (H_0): $\mu_1 = \mu_2$;

Alternative hypothesis (H_1): $\mu_1 \neq \mu_2$; (7)

For example, the calculated t-value is –2.08 and critical value is –2.01 at the 5% level of significance for 2-W when the opposing through traffic volume of 2000–2500 vph. The test was conducted for all the four different categories of vehicle at all the opposing though traffic volume and in all the cases the calculated value is more than the critical value indicating the rejection of the null hypothesis i.e. the average MTs for two different types of merging are not same.

Conclusions

U-turns at median openings are complex because the vehicles are required to take 180° turn and merge with the opposing through traffic. The merging process at uncontrolled median openings under limited priority condition is very complex and unsafe. In this paper, different types of merging manoeuvres occurring at median openings under limited priority conditions have been identified and explained. To meet the objectives of the study, data were collected at different locations in India. The delay experienced by the vehicles before merging is studied and the effect of opposing traffic volume on delay is investigated. The MT required by the vehicles is also studied by identifying the merging lines (virtual bar downstream the nose of the median where the turning vehicle completely merges with main line traffic) for individual category of vehicles from the field data. The analysis shows that, the MT is different for different categories of vehicles and this is attributed to (a) vehicular characteristics; (b) the drivers' attitude like defensive or aggressive; (c) driver characteristics like age, sex, and driving experience; and (d) opposing traffic volume. The small size, flexibility of movement, and unique driver behaviour of 2-W demand less time to merge with the opposing through traffic. The analysis shows that the effect of opposing traffic volume and SD on MT is inversely proportional and separate mathematical models have been proposed for different categories of vehicles. It is observed that SM and GM are

Table 7. The merging statistics for different categories of vehicles

Opposing through traffic volume [vph]	Car		2-W		3-W		SUV	
	SM	GM	SM	GM	SM	GM	SM	GM
>1000–1500	3.35	4.49	2.56	3.06	3.28	3.92	3.35	3.91
>1500–2000	3.10	4.27	2.60	2.96	3.18	3.72	3.27	3.95
>2000–2500	3.29	3.83	2.58	2.94	3.22	3.66	3.24	3.72
>2500–3000	3.27	3.80	2.55	2.93	3.08	3.65	3.11	3.73
>3000–3500	3.31	3.59	2.28	2.78	3.09	3.60	3.04	3.78
>3500–4000	3.18	3.63	2.37	2.55	2.97	3.23	2.74	3.96
>4000–4500	3.18	3.58	1.98	2.66	2.78	3.22	2.68	3.81
>4500–5000	3.12	3.54	2.01	2.19	2.90	3.06	3.29	3.39
>5000–5500	3.02	3.52	1.80	2.38	2.64	3.02	2.69	3.07
>5500–6000	2.98	3.34	1.83	2.21	2.53	2.70	2.06	2.97

predominant at median openings and time required for these two types have been estimated for all the categories of vehicles. The time for GM is found more than that for SM. It is attributed to the fact that during SM the priority of movement is followed whereas during GM the rule of priority is shared. The findings of the present study and proposed models can be used in simulation of traffic flow at an uncontrolled median opening under mixed traffic conditions. The results of this study can also be used to assess the impact of merging process on traffic flow characteristics, which can eventually be used to determine the Level Of Service (LOS).

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