Service Delay and Merging Time Evaluation at Median Openings

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Abstract

Studies have been carried out on delays at unsignalized intersections but there is hardly any report is available on delays at unsignalised median openings on multi-lane divided urban roads. The present study estimates the average service delay to vehicles and proposes service delay models based on microscopic analysis of delay data under highly heterogeneous and unruly traffic conditions. The data for the study were collected by video recording at seven different uncontrolled median openings on multi-lane divided urban roads in India. The conflicting traffic was measured as the exact number of conflicting vehicles (n) as seen by a particular U-turning vehicle. The number of conflicting vehicles and the opposing through traffic were found to affect the service delay and mathematical models have been proposed. The merging time was also estimated for different categories of vehicles. Furthermore, the effect of opposing traffic volume and delay on merging time is studied.

*Keywords:*Service delay, conflicting traffic, merging, U-turns, median opening.

Introduction

Median openings are provided at different locations along a multilane divided urban road to have access to abutting land use or to reverse the direction of movement of a vehicle. These are also provided as an alternate to right turning traffic at an upstream or downstream intersection. U turns at median openings are complex because the vehicle is required to take 180° turn in a smaller width of the road. The snapshot of a typical median opening is shown in Figure 1. U turns are possible only in the face of the gaps available in the opposing traffic stream and turning vehicles will be delayed if sufficient gaps are not available. In such cases, the turning vehicles will delay the through going

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vehicles in the same lane and will reduce the speed of traffic movement and the capacity of the road. When delay to the turning vehicles increases beyond a certain limit, the driver starts getting frustrated and then tries to force its entry through the opposing traffic creating a dangerous situation.

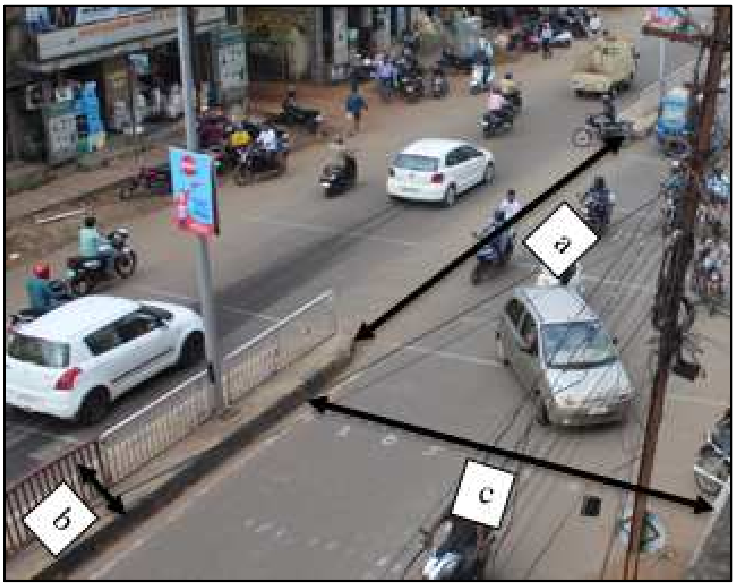

Figure 1: Snapshot of a typical median opening

Highway Capacity Manual (HCM 2010) of the United States uses the term service time for the delay experienced by a driver at the stop line of a priority intersection. The service delay has great influence on traffic movement and performance and safety at uncontrolled median openings. It is related to departure headway also, which is used to estimate the capacity of the U-turns at median openings. There are several studies in the literature for estimation of service delay to a vehicle at uncontrolled intersections (for example, Khattak and Jovanis, 1990; Zongzhong et al.,1997; Chandra et al., 2009; Al-Omari and Benekohal, 1997, 1999; Bonneson and Fitts, 1999; Teply et al., 1997), but there are very few studies reported for U-turns at median openings. Al-Masaeid (1999) estimated capacity of U-turn at median openings. He found that the capacity and average total delay models for U-turn movements at median openings are significantly influenced by the conflicting traffic flow conditions. Obaidat and Elayan (2013) studied gap acceptance behavior at U-turn median openings in the city of Jordan and found that the male drivers tended to accept shorter gaps than female drivers and the younger drivers were more likely to accept shorter gaps than older ones. The waiting time was also found to affect the gap acceptance behavior of the drivers. Drivers tended to accept shorter gaps after longer waiting times. Similar finding is also reported by Tian et al. (2000). The situation at U-turns is more complex due to very low turning speed and encroachment of turning vehicles on opposing lanes. It is particularly important under mixed traffic conditions of the type prevailing on roads in India and many other developing countries, where highly heterogeneous traffic condition prevails. The present study was undertaken with the objective of estimation of average service delay and merging time for different categories of vehicles and also to assess the influence of opposing traffic on delay and merging time. The effect of service delay of merging time has studied as well.

Data collection and extraction

Data for the present study were collected at seven locations of median openings on six-lane divided urban roads in Bhubaneswar, the capital city of Odisha, India. All the sections were free from any side friction activity like a bus stop, parking or pedestrian movement. The details of road geometry at median opening of all the test sections are provided in Table 1.

Table 1: Detailed geometry at different road sections

Section no.	1	2	3	4	5	6	7
a	15.7	14.8	15.3	14.7	15.1	15.5	15.2
b	1.0	1.2	1.0	1.2	1.4	1.1	1.0
c	9.6	9.5	9.5	9.6	9.4	9.8	9.6

* *All the values are in (m).*

Data at each median opening were collected by placing the video camera at a suitable vantage point so as to cover the total turning movement and opposing flow on a typical weekday and data were recorded for 10 to 12 hours, including the morning and evening peak and non-peak periods. The recorded film was played in the laboratory to get the desired information. All vehicles in the traffic stream were divided into six major categories as car, motorized two wheelers (2W), motorized three wheelers (3W), sports utility vehicle (SUV), light commercial vehicle (LCV) and heavy vehicles (HV). The details of U-turning traffic composition at all the test locations during peak period are given in Table 2. Heavy vehicles were found to be very low and therefore these were not considered in the present study and the analysis was done for first five categories of vehicles only.

Table 2: Traffic composition at different sections

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

For the measurement of service delay experienced by U-turns, identification of the reference line is very important. For a stop controlled junctions, this reference line is taken at the stop bar and the service time for a vehicle is measured from the time the front bumper arrived at the stop bar until the rear bumper passed over the stop bar (Al-Omari and Benekohal, 1997). However, in the case of U-turns, the vehicles invariably stop in the median opening encroaching on adjacent lane and interfering with through traffic from the opposite direction (NCHRP–524, 2004). This situation is more frequent in mixed traffic conditions and untidy behavior of drivers. From the preliminary observations of videos, it was found that almost 80 percent of the U-turning vehicles stop 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 time and departure time of a vehicle. Therefore, service time (or delay) of a 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. The process of service delay data extraction process has been illustrated in Figure 2.

U-turning vehicle approaching towards reference line

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)

Figure 2: Photographic presentations for the estimation of service delay

The microscopic analysis of service delay of a vehicle also requires the definition of the conflicting traffic flow as seen by the subject vehicle. Here the concept of instantaneous conflicting traffic as proposed by Kyte et al. (1991) was used. It is described below.

Let t_0 = Time of arrival of the subject turning vehicle at the reference line.
t_d = Time of departure of the subject turning vehicle.
n = Number of observed conflicting vehicles for the subject vehicle, including the conflicting vehicle passing just after departure of the subject turning vehicle.
t_n = Time of arrival of n^{th} conflicting vehicle at the reference point.

The definition of the conflicting flow rate as seen by the subject turning vehicle is the number of observed conflicting vehicles divided by the observation time.

$$\text{Conflicting flow rate} = \frac{n}{t_n - t_0} \tag{1}$$

At low traffic volume it is common for the conflicting vehicle, representing the end of the accepted gap to pass through the median opening long after the departure of the subject vehicle. Thus the subject vehicle would not see this conflicting vehicle. Kittelson and Vandehey (1991) proposed that a maximum value 12 s can be used for accepted gap based on criteria of sight distance and major street speed. In the present study also, when $t_n - t_d$ was greater than 12 s, the vehicle representing the end of accepted gap was not considered as conflicting vehicle.

Merging time was also analyzed in this study. It 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. The merging line was defined as a virtual bar downstream the nose of the median where the turning vehicle completely merges with main line traffic. The merging position where the subject vehicle completes the merging process was found to be dependent on the size of the merging vehicle and the average position of the merging line as observed in the field is given in Table 3.

Table 3: Position of merging bar for different categories of vehicles

Vehicle Category	Position of merging line downstream the median nose (m)
Two-wheeler	2.0
Three-wheeler	2.5
SUV and Car	3.0
LCV	3.3

Computation of service delay and merging time

The microscopic analysis carried out in the present study provided a large number of data on service delay and number of conflicting vehicles (n) as seen by a particular U-turning vehicle. The analysis was done to assess the effect of number of conflicting vehicles on delay experienced by different categories of U-turning vehicles at all the different median openings. The effect of opposing through traffic volume on service delay to subject movement (U-turns) is also studied. The time required to merge with the opposing through traffic is studied for different categories of vehicles at various traffic volumes. The analysis is described in the following sections.

Effect of number of conflicting vehicles (n) on service delay

The simultaneous arrival of U-turning vehicle and opposing through vehicles in the median opening area will create the possibility of conflict. The conflicting flow rate as seen by any particular U-turning vehicle is explained in Equation (1), which demands that conflicting flow rate is directly proportional to n and inversely proportional to t_n-t_0. However, it is also very common that t_n-$t_0$is directly proportional to n. At higher volume level a number of small headways are rejected by U-turning vehicle which in turn increases the t_n-t_0 (hence delay). Therefore, as there is an increase in the number of conflicting vehicles, there is no significant change in conflicting flow rate. Similarly, at a low traffic volume the small headways are less in number and obviously it inflict for less waiting time. Therefore, estimation of instantaneous conflicting flow rate does not represent the actual effect of opposingtraffic on the behaviour of U-turning vehicle. The Equation (1) is rewritten as follows:

$$\text{Conflicting flow rate} = \frac{n}{(t_n - t_d) + (t_d - t_0)}$$

$$= \frac{n}{(t_n - t_d) + SD} \qquad (2)$$

The above equation clearly shows that the conflicting flow rate is a function of service delay. Therefore, the effect of conflicting flow rate on service delay gives an error in the estimation of service delay. To eliminate this error in the estimation of service delay, the actual number of conflicting vehicles as seen by a particular U-turning vehicle was considered and it gives a better estimation.

Upon arrival at the median opening, a typical action is generally taken by U-turning vehicle by stopping at the median opening and waits for a suitable gap in the opposing through traffic. In other words, it can be explained that the subject vehicle may reject a number of small gaps (generally less than critical gap) whereas accepts only one gap (generally greater than critical gap) to merge with the opposing through traffic. However, the size of the gap depends on the arrival pattern of vehicles. This gap rejection behaviour of U-turning vehicles clearly indicates the avoidance of conflict with opposing through vehicles. Therefore, more number of gap rejection means avoidance of the more number of vehicles which would inflict more service time (or delay) to a U-turning vehicle. This aspect was explored mathematically in the present study. Figure 3 shows the scatter plot between service delay and corresponding number of conflicting vehicles for car and the relationship is linearly increasing.

Plots were made between service time and the number of conflicting vehicles for other categories of vehicles and in all the cases a linear increasing trend was observed. The mathematical equations suggested for all the categories of vehicles are tabulated in Table 4.

Effect of opposing through traffic on service delay

The effect of opposing through traffic volume on service delay to individual category of vehicles was also studied and one such relation for car is shown in Figure 4. 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 available 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 service delay. The service delay statistics (mean and standard deviation) for each vehicle category was estimated from the collected data at different opposing traffic volume are presented in Table 5.

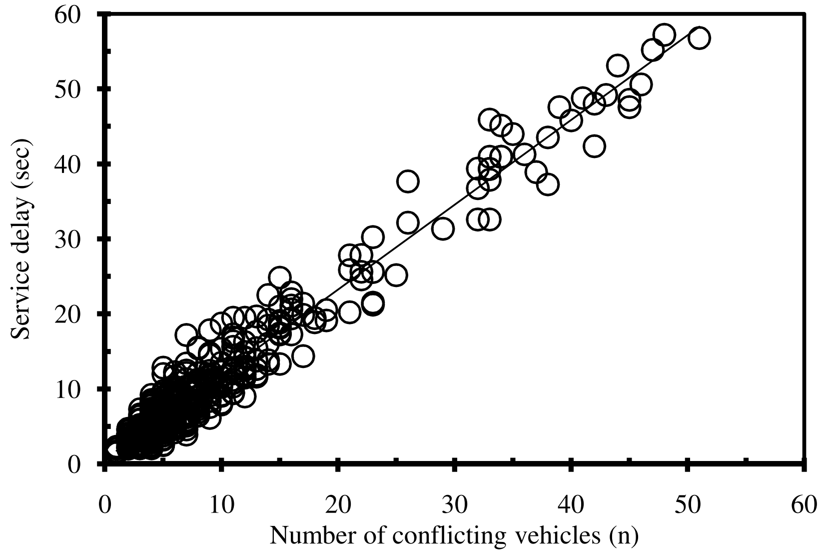

Figure 3: Effect of conflicting vehicles on service delay to car

Table 4: Models for service delay

Category of vehicle	Model	R^2 value
2-w	SD = 1.077*n + 0.413	$R^2 = 0.82$
3-w	SD = 1.053*n + 0.438	$R^2 = 0.92$
SUV	SD = 1.133*n + 0.608	$R^2 = 0.87$
Car	SD = 1.131*n + 0.597	$R^2 = 0.95$
LCV	SD = 1.044*n + 0.991	$R^2 = 0.92$
SD in second (sec), n in numbers of vehicle (integer)		

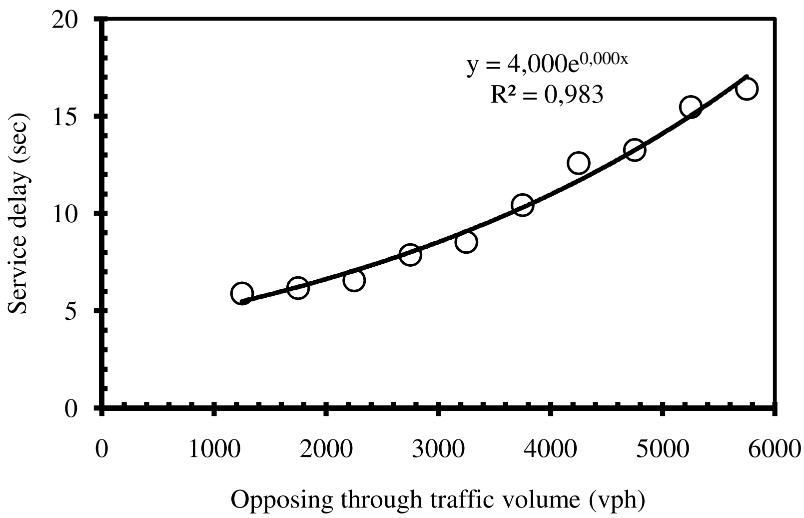

Figure 4: Effect of opposing through traffic on service delay for car

Table 5: Effect of opposing through traffic on service delay

Volume (vph)	Service delay (sec)									
	2-w		3-w		SUV		Car		LCV	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
>1000 – 1500	3.17	2.13	5.03	2.94	5.44	2.02	5.89	2.93	5.83	2.99
>1500 – 2000	4.13	2.93	5.61	3.22	5.98	2.00	6.16	4.15	6.13	3.76
>2000 – 2500	4.96	2.28	6.18	2.40	6.42	2.78	6.57	3.27	8.31	2.39
>2500 - 3000	5.86	3.03	7.35	1.99	7.65	3.27	7.87	3.91	9.81	4.16
>3000 – 3500	7.19	4.27	7.58	4.46	7.75	4.99	8.53	4.58	10.94	3.62
>3500 – 4000	8.01	4.35	9.52	3.83	10.94	2.76	10.43	7.80	11.02	4.54
>4000 – 4500	8.79	4.72	10.25	4.27	11.34	3.12	12.59	10.70	13.12	2.23
>4500 – 5000	9.76	6.54	10.44	3.95	13.57	3.05	13.26	11.06	14.97	3.29
>5000 – 5500	12.05	4.76	13.31	4.52	13.88	3.97	15.46	9.57	15.73	1.93
>5500 – 6000	12.34	5.90	13.89	4.90	14.57	4.32	16.41	9.49	16.23	4.56

Where, μ = mean service delay, andσ = standard deviation

The descriptive statistics presented in Table 5 shows the variations in service delay to different categories of vehicles and it varies with opposing traffic volume also. The variation in delay among different categories of vehicles are mainly due to the wide variation in static and dynamic characteristics of vehicles, engine power to weight ratio, and the driver behavior (age, sex, driving experience) etc. The average service delay to 2-w is the minimum followed by 3-w, SUV, car, and LCV. The average service delay to 2-w is less due to the fact that, they accept small gaps for their merging. This is observed to be for two reasons: (a) the dimensions and the frontal shape of two-wheelers facilitate acceptance of very small gaps, and (b) the unique driver behavior in heterogeneous traffic condition, in which every gap in the road space is explored to move into the stream. The average delay experienced by 3-W is less as compared to that experienced by cars. For similar gaps, more numbers of auto- rickshaws accomplished merging 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). In India mostly the car drivers are the owner of the vehicle, whereas the SUV 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 and wait for longer time before merging. The car drivers are male or female, but there is hardly any female SUV drivers in India. The age of the car drivers varies from 22 years to 65 years and that for professional taxi drivers generally 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 and Elayan, 2013). Shinar and Compton (2004) also reported that drivers 45 years-old or older were less likely to drive aggressively than younger ones. Due to all these reasons and the aggressive nature of younger male taxi drivers, the average service delay to an SUV is less than that for a car. The average engine capacity for SUV is about 2600 c.c. or even more whereas the engine capacity for standard cars is about 1400 c.c. So, the SUV can generate more propulsive force as compared to a car. The high engine power and aggressive nature of the SUV drivers enable to accept a gap, which is generally rejected by a standard car. The average service delay to LCV is the maximum due to the lower power to weight ratio and longer static dimensions. The effects of opposing through traffic volume (vph) on service delay to different categories of vehicles were also studied and the proposed mathematical models are tabulated in Table 6.

Table 6: Category wise models

Category of vehicle	Model	R^2 value
2-w	$SD = 2.2964e^{0.0003v}$	0.969
3-w	$SD = 3.7619e^{0.0002v}$	0.984
SUV	$SD = 3.9215e^{0.0002v}$	0.965
Car	$SD = 4.0002e^{0.0003v}$	0.983
LCV	$SD = 4.6016e^{0.0002v}$	0.952
SD in second (sec), v in vph		

Effect of opposing through traffic and service delay on merging time

The time required by the different categories of U-turning vehicles are also studied and the statistics (mean) of merging time are presented in Table 7. It is clear that the merging time differs with the type of U-turning vehicle. It is mainly due to the variation in vehicular characteristics (both static and dynamic) as well as driver behavior (age, sex, driving experience etc.). The average merging time is the minimum for 2-W followed by 3-W, SUV, car, and LCV. It is obvious that the two-wheelers accomplish merging in less time due to their flexibility in movement and narrow static dimension. The behavior of 3-W drivers is generally characterised as "aggressive driving", namely honking, cutting across suddenly in front of other vehicles. This aggressive nature, generally force their vehicles into the opposing through traffic stream, obliging conflicting vehicles to slow down in order to accommodate the manoeuver. This type of manoeuvre may result in lower merging time at the expense of higher risks. Moreover, the driver characteristics (age, driving experience, aggressive nature etc.), vehicle characteristics (type, engine power, braking characteristics etc.), and ownership of vehicle influence the merging behaviour of vehicles. Due to all these reasons, the merging time of the SUV is less than that of a car. Shinar and Compton (2004) also opined that, drivers of passenger cars were no more aggressive than drivers of commercial vehicles.

The effect of opposing through traffic on merging time for different categories of vehicles is also studied and one such relation for car is shown in Figure 5. 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 service delay. As the service delay for 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. Drivers are more likely to behave aggressively during rush hours (Shinar and Compton, 2004). Moreover, in many circumstances the U-turning vehicles force themselves to accomplish merging manoeuvre and force opposing through vehicles to slow down. Upon accepting the shorter gaps at high traffic volume, the subject vehicle accelerates very fast resulting in shorter merging time. The waiting time is also found to affect the gap acceptance behaviour of the driver. Obaidat et al. (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 opposing traffic volume (V) with merging time (MT) for 5 different categories of vehicles are given in Table 8. The effect of service delay (SD) on merging time to 2-W is shown in Figure 6 and the developed mathematical equations are provided in Table 9.

Table 7: Merging time statistics (mean) for different categories of vehicles

Opposing through traffic (vph)	Merging time (sec)					
	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	3.59	3.42	3.74	

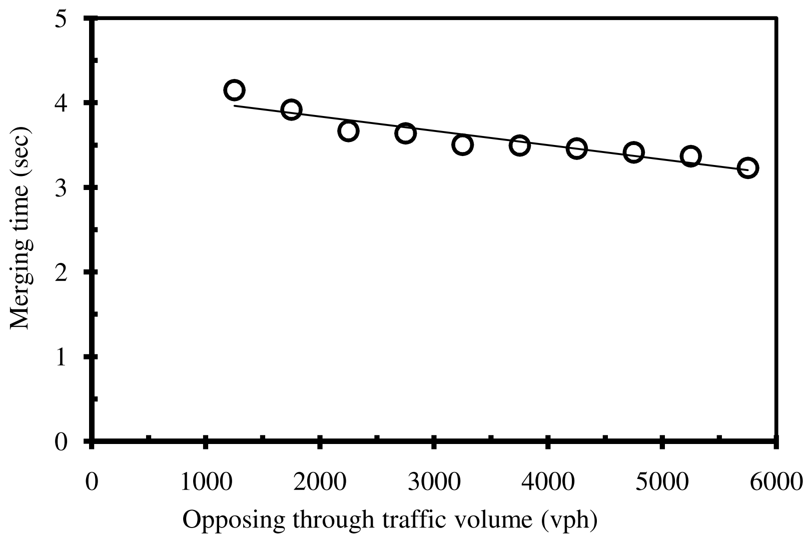

Figure 5: Effect of opposing traffic on merging time for car

Table 8: Models of merging time for different vehicles

Category	Models	R^2 Value
2w	MT= -0.00020* V+ 3.24478	0.937
3w	MT = -0.00022* V+ 4.02889	0.954
Car	MT = -0.00017* V + 4.17688	0.876
SUV	MT = -0.00045* V + 5.15415	0.911
LCV	MT = -0.00025* V + 3.42222	0.956
MT in second (sec), V in vph		

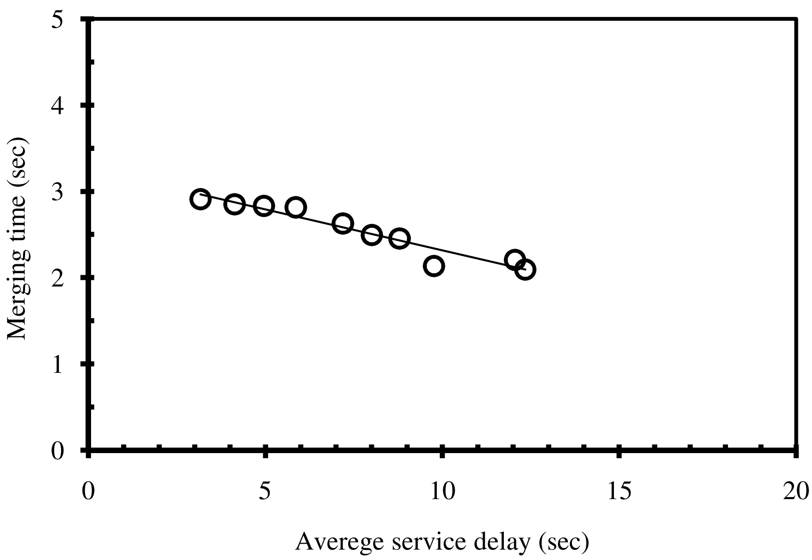

Figure 6: Effect of service delay on merging time of 2-W

Table 9: Proposed models for merging time for different categories of vehicles

Category	Models	R^2 Value
2w	MT = -0.095*SD + 3.268	0.923
3w	MT = -0.094*SD + 4.183	0.952
Car	MT= -0.060*SD + 4.205	0.737
SUV	MT = -0.183*SD + 5.375	0.822
LCV	MT = -0.106*SD + 4.894	0.810
MT in second (sec), SD in second (sec)		

Conclusions

The traffic operation at an uncontrolled median opening is very much complex. The median openings are uncontrolled because there is no traffic signal, no stop or yield sign, and no traffic police to regulate the traffic, but with an inherent understanding that traffic laws assign priority to through-moving vehicles over u-turning vehicles. The moment the U-turning vehicles arrive at the median opening, the gaps in the opposing through traffic are assessed and in view of that, the subject vehicle (U-turning) may reject a number of small gaps (generally less than critical gap) which results in delay. However, in reality, these median openings functions with very less respect to the priority of movement rule, and it is quite common to see that the U-turning vehicles become aggressive after a certain limit of waiting time and force themselves to complete the merging manoeuvre.

The present study attempts to assess the waiting time before the initiation of merging (service delay) and time required by the U-turning vehicles to merge at median openings where traffic operates with partial respect of traffic laws. Data were collected at seven different median openings on multi-lane divided urban roads in India. It is observed that service delay to a particular U-turning vehicle mainly depends upon the number of conflicting vehicles (n) as seen by a particular vehicle. This issue was explored microscopically and the effect is in the linearly increasing order and the mathematical equations have been proposed for individual category of vehicles. This study investigated the effect of opposing traffic volume on service delay and it is exponentially increasing. Due to the variation in vehicular characteristics (static and dynamic) and driver characteristics (age, sex, and driving experience) and driver attitude (aggressive or defensive) the delay faced by the different categories of vehicles vary. The time required to merge with the opposing through traffic is also estimated from the field data and are found that longer waiting time results in less merging time.

The models developed under homogeneous and lane disciplined traffic conditions can not be applied to the mixed traffic scenario at uncontrolled intersections. Due to the impatient and unruly behavior of drivers, it is very common to observe that the rule of priority is hardly followed in the field. Furthermore, the model developed in homogenous condition becomes unrealistic to implement due to variance in the static and dynamic characteristics of vehicles in India and other developing countries. Furthermore, the models developed for uncontrolled intersections can not be used for uncontrolled median openings as well. The proposed model is developed for mixed traffic conditions of the type prevailing on Indian roads and can be used to better estimate the service delay to U-turning movements at uncontrolled median openings. Service delay is related to the departure headway, which in turn, is the inverse of capacity of a movement type. Therefore, service delay models suggested here can also be used by practicing engineers to estimate the capacity of U-turning movement at uncontrolled median openings for better traffic operational management as well as to facilitate the better level of service.

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