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Effect of Waiting Time, Flow and Speed on U-turn Critical gaps at Median Openings under Mixed Traffic

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ABSTRACT
The objective of this study is to deal with the effects of driver waiting time, conflicting traffic flow and speed on U-turn critical gaps at median openings without left-turn lanes. Video graphic data of nine conventional mid-block median openings on four and six lane urban roads were assembled. All these sites belong to the three cities of Bhubaneshwar, Rourkela and Ranchi situated in the eastern province of India. A new concept of "Merging Behavior" for U-turns is introduced for the first time to estimate critical gaps at these sites. Driver waiting times were calculated after processing the raw video data in the AVIDEMUX software. Conflicting traffic speed and flow were obtained in a similar manner. Flow was converted to standard passenger car units per hour (PCU/hr.) from vehicles per hour according to Indian traffic norms. The traffic composition was splitted into four motorized vehicular classes for simplicity. Empirical relationships between critical gaps and all the other factors were formulated after performing regression analysis in Statistical Package for Social Sciences (SPSS). Waiting time-critical gap relation followed power regression variation for all three modes except three wheelers (3W) which in turn followed a positive exponential variation. Also, longer waiting times affect U-turn critical gaps irrespective of the gap sizes. Critical gaps are also affected by conflicting traffic flow even during off-peak periods. At last, Vissim simulation outputs from the extracted field data are illustrated in order to signify the problems frequently encountered by U-turn drivers under mixed traffic situations.

Keywords: Conflicting Traffic, Critical gaps, Median Openings, Merging Behavior, Waiting Time

Abbreviations: INAFOGA – Influence Line for Gap Acceptance, SPSS-Statistical Package for Social Sciences

1. INTRODUCTION

Over the past few years there has been increased installation of non-traversable & directional medians all over India particularly on multi-lane roads in sub-urban part of cities. In India, bidirectional median openings prevail more than directional ones. A bidirectional median opening is simply an opening in the median for vehicles to make U turns from either direction. A bidirectional median opening does not consist of deceleration or storage lanes unlike directional ones as a result of which they permit one or two vehicles for a U-turn manoeuvre. Vehicles may enter from either direction. With high turning volumes, an interlocking effect is sometimes created (Boddapati, 2001). The motivation behind utilizing non-traversable and directional median openings is to kill issues connected with left-turns and crossing movements at intersections on multi-lane highways (Liu, 2006; Liu et al. 2007; Liu et al. 2008). In spite of the fact that the U-turn movement appears to be more mind boggling than right or left turning manoeuvres at un-signalized median openings, the general ideas and techniques produced for analysing gap acceptance are fundamentally the same. The time interval between the departure of one vehicle from the U-turn path and the entry of the first vehicle on the conflicting street is characterized as the accepted gaps. Gap acceptance is the methodology through which a driver needs to assess the gaps and judge whether they are sufficient or not for merging with the conflicting/through traffic flow. Gap contrasts from headway in the way that the latter is measured as time interval between the front bumpers of the successive vehicles on the conflicting street and the former as the time interval between the front bumper of the first vehicle and back bumper of the next vehicle on the same street. “Gap acceptance” analysis forms the prime objective for safe operation of U-turning vehicles at Median Openings under heterogeneous traffic situations. Critical gap is an important parameter in “gap acceptance” study. The definition of critical gap has undergone certain modifications over the past decades (Ashalatha et al. 2011). Critical gap for U-turns at median openings is defined as “the minimum time interval in between two through/conflicting traffic vehicles that allows complete merging movement for one U-turn vehicle at a median opening”. Gaps that are smaller than the critical gap usually are rejected, and all gaps larger than this critical gap are expected to be accepted.

Critical gap is difficult to measure directly in field. It is assumed to be a constant or follow a distribution depending on the driver psychology. Therefore, certain empirical methods like Raff’s, Harders, INAFOGA and Ashworth’s methods are applied for estimating critical gaps. The size of a U-turn critical gap depends upon certain driver behaviour related parameters like gender, age and driver waiting times on median openings. Traffic characteristics of conflicting/through traffic stream like speed and flow also benevolently affect the size of a U-turn critical gap as supported by previous studies on median openings. Driver waiting time for a U-turn vehicle is the time lost in waiting for a suitable accepted gap before making the turn to merge with the conflicting traffic stream at a mid-block median opening. The waiting time depends upon the total perception and re-action time of a driver along with the geometric and traffic characteristics of median opening. Under heterogeneous traffic conditions a lot of conflicting movements and illegal lane changing operations result in longer waiting times and larger accepted gap sizes. Relationships between gap acceptance and traffic/driver behaviour related parameters in lieu of median openings under varying road geometrics coupled with heterogeneous conditions has not been given proper consideration in the past. The traffic engineering manual HCM, even in its recent issue of 2010 had not addressed the empirical relationships for median openings.

The objectives of this research are to estimate critical gaps using the new concept of “merging behaviour” developed from INAFOGA method and then to study the effect of driver waiting time, conflicting traffic speed and flow on the estimated values of critical gaps at median openings under mixed traffic conditions. In lieu of this data is collected in the form of video recording of nine conventional mid-block bi-directional median opening sites on 4-lane and 6-lane roads situated in the states of Odisha and Jharkhand located in eastern India. To represent the Indian mixed traffic four motorized modes are considered in this study. Driver waiting time is calculated using the Merging behaviour concept introduced in this paper. Speed in kilometre per hour (kmph) is calculated from the video data collected. Flow in PCU/secs is converted from vehicles/seconds according to the PCU values for different vehicles as per Indian Roads Congress (IRC) – 1983, Code no. 86 stipulations. Empirical regression models are prepared in SPSS (Statistical Package for Social Sciences) software to show the effect of the traffic and driver behaviour related parameters described above on U-turn driver critical gaps.

2. PREVIOUS STUDIES

Traffic operations on median openings have not been addressed for years due to the complexity of U-turn movements unlike right/left turns at intersections. In spite of the fact that the U-turn movements is more intricate than right- or left-turning developments at un-signalized intersections, the general ideas and methods analyzing gap acceptance and other traffic or driver behavior related parameters at un-signalized median openings are exceptionally pivotal in this regard. Majority of literatures normally consider the accepted and rejected gaps as the key parameters for the estimation of critical gaps. “HCM 2010” states that critical headway/gap can be estimated on the basis of observations of the largest rejected and smallest accepted gap corresponding to a given transportation facility (HCM, 2010).

Raff and Hart (1950) first proposed the term “critical lag” as an important parameter in the determination of “gap acceptance” for a minor street driver willing to take a directional movement in an “un-signalized intersection”. Also the author proposed a graphical model in which two cumulative distribution curves related to the number of accepted and rejected gaps intersect to yield the value of Critical Lag (Brilon *et al.* 1999). Harders estimated the critical gap by the expectation of the cumulative frequency distribution curve for the proportion of accepted gaps provided to all U-turning vehicles (Gavulova, 2012; Vasconceles *et al*. 2012). Troutbeck (1992) gave a more precise form of Maximum Likelihood Method with a satisfactory mathematical derivation. The author used Log-Normal distribution for finding the critical gaps. Liu (2007) found the headway acceptance characteristics of U-turn vehicles on 4-lane divided roads.

For Indian heterogeneous/mixed traffic flow conditions, Ashalatha and Chandra (2011) used some of the existing methods like HARDER, Logit, Probit, Modified Raff and Hewitt methods for estimation of critical gap at an un-signalized intersection. There was significant variation

(12-38%) among the critical values which highlighted the limitation of the methods to address mixed traffic situations. Thus, the authors came up with an alternate technique making use of clearing behavior of vehicles in conjunction with gap acceptance data. The new method proposed in this study was simple and easy to implement under Indian conditions. With due consideration, this paper has given significant background for the present study because of its heftiness towards mixed traffic conditions prevailing in India. The "clearing behavior" in the paper was converted to "merging behavior" in case of U-turns at median openings for the sake of this study.

Reno (1992) had found that speed limit of 30 or 35 miles per hour (mph) on the conflicting street did not fundamentally influence the gaps accepted by the U-turn drivers. The reason may be that when approach speed is low, most drivers judge the gaps in the same manner. When speed is relatively high (say 55 to 60 mph), the ability to correctly judge the gaps will decrease. At this point, diverse individuals settle on choice in an alternate manner, bringing about a huge break in gap acceptance. Probably, the gaps accepted by drivers when speed is 35 mph will be rejected when speed reaches 60 mph. The author likewise found that the bigger the traffic volume/flow of the conflicting stream, the littler the time gap that was utilized. The author credited this to the driver's fretfulness because of the long waiting time before the U-turn. As demonstrated in another study made by Al-Masaeid (1999) that the critical gaps are unequivocally associated with the average total delay and conflicting traffic speed. In the study the author utilized regression comparison to analyze the relationship between U-turn critical gaps and delay/speed. The equation ($t_c = 6.31 - 0.07 \times TD + 0.026 \times SP$, where t_c=critical gap in second; TD=average total delay in sec/veh; SP=speed in km/h) utilized as a part of this study showed that critical gaps of U-turns was not consistent yet changes as indicated by the average total delay and the speed of the conflicting stream. This regression was based on the 68 observations collected during the summer in 1996. The mean value of U-turn critical gap is 6.72 second with minimum value of 4.55 seconds and maximum value of 7.90 seconds. Yang *et al.* (2001) developed multivariate regression models relating U-turn critical gaps with total average delay and conflicting traffic speed. The authors collected data from ten mid-block median opening sites located in Tampa, Florida. The authors found that the low t-statistic value (1.66) of speed indicated that speed is not significantly related to the gap acceptance of the U-turn drivers at the sites. The authors also concluded that number of lanes doesn't affect the U-turn gap acceptance at a median opening but driver randomization has a definite effect on critical gaps. Obaidat and Elayan (2013) demonstrated estimated length of time gap needed by a U-turn driver based on factors such as age, gender and the lapsed time between arriving and experiencing the gap. The study narrates driver-related factors on critical gap acceptance for which data were obtained by analyzing 4 Median U-turn openings in Irbid City, Jordan.

3. EXTENT OF THE STUDY

The study area from three cities are considered in such a fashion that the road networks give the required input data for analyzing "Critical Gap" and comparing the same between different modes of transport. Median openings at four-lane and six-lane divided urban roads are considered in the present study. In Indian context, median openings are generally provided in urban areas on major streets for minimum flow of 500 vehicles/day with maximum speed limit of 70-80 kmph.

It comprised of nine busy median opening sites from three cities located in the eastern part of India. In order to include variation in road geometric and traffic characteristics, data were collected from two median openings each from Rourkela and Ranchi and five median openings from Bhubaneswar city. Rourkela and Bhubaneshwar belongs to Odisha State while Ranchi is the capital city of Jharkhand State. To represent mixed traffic conditions in India, various motorized modes such as three wheelers (four-stroke Auto- rickshaws and delivery vans), light commercial vehicles (4 wheeler tempos), different models of cars namely Sedans, Hatchbacks and Sports utility or Multi-utility vehicles (SUVs/ MUVs) are considered in this study. Heavy vehicles like busses, trucks and multi-axle vehicles are not taken into consideration because of the imposed restrictions on their maneuverability at U-turns. It is observed that, percentage of vehicles make U-turn at median openings is proportionately high as the distance of the openings from signalized/un-signalized intersections increases. Considering this fact, median openings roughly spaced at about 400-550 feet from their nearest intersections or rotaries are observed in this research. All the median openings are nearly similar in geometry with two or three lanes each on either side of the medians. The speed limit displayed on the roadsides for the conflicting or through traffic varies from 35-55 kmph for different mode of transportation. The median opening sections are all on plain terrain and thus sufficient sight distances were maintained for each movement.

4. ASSEMBLAGE OF DATA AND ANALYSIS

Data collection primarily comprised of video recording of the selected median openings by a Sony Handycam capable of playing videos at a rate of 30 frames/second. Data sets were collected during peak hours for the morning (8:30- 10:30 AM), noon (12:30-2:00 PM) and afternoon (5:00-6:00 PM) between September 2013 and April 2014. Shooting was done only during weekdays. Weekends and public holidays were generally neglected due to large discrepancy among data sets which leads to erroneous estimation of critical gaps of U-turning traffic at median openings. Video recording of all the nine locations resulted in an average proportion of U –turning and through traffic of 20-40% and 65-85% respectively. Basic statistics of data collected comprising of accepted, rejected gaps and merging times are tabulated in Table 1. Through traffic comprised of vehicles including Heavy Vehicles (HVs), Light Commercial Vehicles (LCVs), discounted non-motorized vehicles and pedestrians. The classes of vehicles considered in this study are as follows:

1. Motorized 4 Wheelers (Including Sedan and Hatch Backs)
2. Motorized 2 Wheelers (Driver: Male / Female, Motor-bikes, Scooters)
3. Motorized 3 Wheelers (4-stroke-Auto-rickshaws, 3 Wheeler delivery vans)
4. Sports utility vehicles / multi utility vehicles (SUVs)

The variation of U-turning flow with respect to through or conflicting traffic flow can graphically represented as a cumulative distribution in Passenger Car Unit (PCU)/hr is shown in Fig 1. The conversion factor, PCU for different vehicle types are followed as per the conversion factors given in Indian Roads Congress (1983), Code number -86 (*Geometric Design Standards for Urban Roads on Plains*) which are shown in Table 2 of this paper. It has been observed from this figure that with increase in percentage of through traffic vehicles at a particular point of time, there is an exponential decrease in the percentage of U-turns at the selected median openings as observed for all the three cities considered in this study. Fig 2 shows the schematic diagram of a median opening on a 4-lane divided carriageway drawn in *AUTOCAD 2009*. Observed details on geometry and traffic characteristics of the nine median openings are shown in Table 3.

5. "MERGING BEHAVIOUR" TO ESTIMATE CRITICAL GAPS

5.1 "INAFOGA" Method

Satish et al. (2011) introduced a new concept for measuring critical gap making use of clearing behaviour of vehicles in conjunction with gap acceptance data. He proposed an area named as INA-FOGA (Influence Area for Gap Acceptance) which had a dimension of L*W, where L= 3.5 m (lane width) & W= 1.5 times width of crossing /merging vehicle. The method takes into account the clearing behaviour of a vehicle (clearing time is the time taken by the minor street/U-turn vehicle to clear the influence area) & gap acceptance behaviour. Following are the characteristics of "INA-FOGA" for a typical T-type intersection:

1. A vehicle taking right turn from Minor Street waits at the stop line near INAFOGA & is said to clear the intersection when its tail end crosses the stop line in the major street.
2. Difference between the arrivals of consecutive major street Vehicles at the upstream end of the INAFOGA is considered as 'Gap'

In this method, a typical cumulative frequency distribution curve for clearing time of a minor street vehicle against its corresponding Lag & Gap

3. Acceptance curve is plotted obligating a common point of intersection. This point of intersection indicates the minimum/critical gap sufficient for the vehicle to enter the INAFOGA keeping in mind the Safety aspect.

5.2 "MERGING BEHAVIOUR" Concept of "INAFOGA" for Median Openings

The INfluence Area FOr Gap Acceptance (INAFOGA) of a U-turning vehicle is the rectangular area bounded by the Red, Green and Blue lines. "Red" line represents the stop line of the U-turn vehicle after approaching the median opening while the "Yellow" and "Blue" lines form the upstream and downstream ends of "INAFOGA". The length (L) of the area measures {(d/2) + 2.2 m} while the breadth (W) as {a + (c/2)}. All these measurements have been experimentally proved in general for all the nine sections. The U-shaped and the straight arrows show the directions of the U-turning and through traffic respectively. Here, 'a' represents the distance between inner lanes while 'b', 'c' &'d' are measurements of the median openings. The "Blue" line is at d/2 distance horizontally from the face of the median. Fig 3 presents the screenshot and the pictorial representation of the "Merging Behaviour" concept for the selected median opening sections in AVIDEMUX 2.6.

The time frames chosen during extraction of data with the aid of AVIDEMUX software are as follows:

- T_0 = time instant front bumper of through traffic vehicle preceding the subject vehicle touches the U/S end of INAFOGA
- T_1 = time instant front bumper of the subject vehicle touches the stop line in b/w the median opening
- T_2 = time instant front bumper of the first through traffic vehicle after arrival of the subject vehicle touches the U/S end of "INAFOGA"
- T_3, T_4… T_n = corresponding time instants for arrival of through traffic vehicles on the U/S end of "INAFOGA"
- T_w = time instant at which back bumper of the subject vehicle touches the stop line
- T_m = time instant back bumper of the subject vehicle touches the D/S end of "INAFOGA"

The time frames extracted from the raw video data were then represented in an Excel spreadsheet and the following decision variables or inputs were found out using the existing methods as de-scribed below:

- LAG (only accepted) = time interval b/w arrival of U-turn vehicle on opening and arrival of first through traffic vehicle= T_2-T_1
- GAP (accepted & rejected) = difference b/w arrivals of consecutive through traffic vehicles at U/S end of "INAFOGA" = $T_{n+1} – T_n$
- Merging Time of U-turning Vehicle = the time span required for a U-turn vehicle to complete the U-turn/merge with the conflicting traffic stream = $T_m – T_w$
- U-turn driver Waiting Time = the time lost in waiting for a suitable gap to complete the U-turn by the driver before making the turn = $T_w – T_1$

6. ILLUSTRATION FOR CRITICAL GAP ESTIMATION BY "INAFOGA" METHOD

Both accepted lags and gaps are used in this method to determine critical gaps in the INAFOGA method. Cumulative frequencies of lags and gaps are plotted against merging time expressed as frequency distribution. The point of intersection between the frequency lines of merging times and lag/gap acceptances is projected on to the gap size axis (x-axis). This projection gives the ultimate value of the critical gaps in seconds. Fig. 4 gives the cumulative frequency plots of merging time – lag/gap acceptances for estimation of critical gaps for 4 wheelers and Sport Utility Vehicles respectively.

7. RESULTS AND DISCUSSION

Table IV depicted below shows the critical gap values in seconds for the four motorized modes of transport such as cars; 2 wheeler scooters and bikes; 3 wheeler autos and pick-up vans & Sport Utility / Multi-Utility Vehicles for the nine different median opening sections form the cities of Rourkela, Bhubaneshwar and Ranchi belonging to the states of Odisha and Jharkhand. The critical gaps obtained ranged between 3.00 – 6.00 seconds showing a wide variation in vehicle accepted gaps at median openings.

7.1. Effect of "Conflicting Traffic" Speed on U-turn Critical gaps

Fig. 5 shows the critical gap versus through/conflicting speed (kmph) plots for the four motorized modes. With the increase in the speed of the through/conflicting traffic vehicles there is linear de-cay in the U-turn critical gap acceptances. As observed from the video data, the above graphical symmetry is true because of the fact that any U-turn drivers avoids shorter gaps and are literally afraid of accepting gaps prior to high speed vehicles

7.2. Effect of Conflicting Traffic Flow on U-turn Critical gaps

The somewhat scattered U-shaped residuals around the dotted horizontal mean line of the Critical gaps (secs) – through/conflicting traffic flow (PCU/secs) plot for the 4 wheeler drivers indicate a mildly significant power regression between the variables considered in this model. The residual plot signifies the difference between the observed and predicted values of critical gaps of 4 wheelers (4Ws) in this model. Table 5 and Fig. 5 shows the statistical, parametric details and critical gaps-through traffic flow plot for the 4 wheeler drivers.

7.2.1 For 2 wheelers

Table 6 and Fig. 7 shows the critical gap versus through traffic flow regression details for two-wheelers. The adjusted R-squared value comes to be 0.95126 which denotes best fit for the linear regression model in Origin LAB. The somewhat distributed residual plot around the horizontal line signifies that the fit is indeed linear in nature. Thus, there is a linear decrease in U-turn critical gaps with increase in the no. of vehicles per second per lane on the oncoming/through street. The model summary as tabulated above shows the standard values of the co-efficient a and b used in the linear equation of the fit. The summary shows the reduced chi-square value (0.005 < 0.025) and adjusted R-squared value of 0.951 close to 1.00 proving the model to be significant in judging the effect of flow on critical gaps for 2 wheelers.

7.2.2. For Three Wheelers (3W)

The unevenly scattered residuals around the mean predicted values of residuals as shown by the horizontal line in the residual plot for the non-linear fit predicts that the fit may be linear but in order to substantiate all the samples at a time, a power fit has been made. With increase in the conflicting traffic there is a power decrease in critical accepted gaps for three wheelers. The R-squared value of 0.95019 is considered sufficiently significant as can be seen from table 7 and the fit shown in fig. 8 is non-linear in nature. The model summary as tabulated above shows the standard values of the co-efficient a and b used in the linear equation of the fit. The summary shows the reduced chi-square value (0.005 < 0.025) and adjusted R-squared value of 0.951 close to 1.00 proving the model to be significant in judging the effect of flow on critical gaps for 3 wheelers.

6.2.3. For Sport Utility or Multi Utility Vehicles (SUV/MUV)

Table 8 and Fig. 9 shows the regression parameters and power fit plot between critical gaps and oncoming/through traffic flow. The U-shaped dispersion of the residuals show a non-linear fit i.e. power of the relationship/model.

7.3. Effect of Driver Waiting Time on U-turn Critical gaps

The regression plots shown in figure 10 indicate the influence of driver waiting times on U-turn critical gaps for the four motorized modes of transportation. The plots show power decay of critical gaps with increase in waiting time at the median openings. The R-squared values of these models shown in fig.10 varied from 0.95-0.98 with a mean of 0.94745 indicating a perfect curve fit as per regression analysis is concerned. Three wheelers like Autos, pick-up vans or delivery vans showed exponential decay of critical gap acceptances with longer waiting times at U-turn bays. Rest of the three modes showed power variation. Also found from the analysis that there is significant dependence of waiting times on critical gaps irrespective of gap size depending upon the size of the vehicle. Table 9 summarizes all the models and shows the relationships between critical gaps and other parameters like waiting times, speed and flow in a tabular manner.

7. CONCLUSION

The critical gap acceptance at mid-block median openings is an interesting research topic for study especially under the presence of multi-lanes and varied forms of traffic. This is the first time in years such an initiative has been undertaken to evaluate mixed traffic operations on un-signalized mid-block median openings in India. The first and foremost model formulated relates U-turn critical gaps with conflicting/through traffic speed which concluded that speed is extremely significant in predicting the sizes of critical gaps(R^2 = 0.97-0.99) with a mean R^2 of 0.9846.

The above fact contradicts the finding of Yang *et al.* (2001) who found very low t-statistic (1.66) value for speed in a multi-variate model on critical gaps indicating independence of U-turn critical gaps with increasing through traffic speed. With reference to the model prepared, U-turn critical gaps followed linear regression decay with increase in conflicting traffic speed. The reason behind this is that with high through traffic speeds, U-turn drivers become reluctant to accept threat to accident and rejects more number of gaps and ultimately accepts lower gap sizes which in turn reduce U-turn critical gaps. The second model shows the effect of conflicting traffic flow on U-turn critical gaps. In this model, both 4 wheelers and 3 wheelers showed power decay in U-turn critical gaps at median openings with increase in number of conflicting traffic vehicles. On the other hand, 2 wheelers and Sport Utility vehicles show linear decay in critical gaps with increase in through traffic flow. During peak hours of traffic, U-turn vehicles wait longer before taking a turn and as a result accept low gap sizes which ultimately decrease the critical gap acceptance. The third model relates driver waiting time with U-turn critical gaps. From field observations it was concluded that longer waiting times (>5 seconds) showed significant decrease in U-turn critical gaps (< 1 seconds). The regression fit showed power decay of critical gaps with longer waiting times at median openings (R^2 =0.95-0.98). Whereas, three wheelers showed exponential decay (R^2 = 0.9827). The model also contradicts the fact that accepted gaps less than 2 seconds gets unaltered by waiting times at median openings as stated by Yang *et al.* (2001).

SUMMARY OF RESEARCH

The present research revolves around two major objectives. The first one is to estimate critical gaps for U-turns using the concept of "Merging Behavior" of INAFOGA. The second is to study the effect of traffic and vehicular characteristics like driver waiting time, conflicting traffic flow and speed on critical gaps of various categories of U-turn vehicles at mid-block median openings. To account for mixed traffic, four categories of motorized U-turn vehicles are considered in this study. Conducting extensive field observations and analysis, conflicting traffic flow and speed both were found to significantly affect the critical gap acceptance of U-turn vehicles. Speed in kmph and flow in vehicles per seconds are calculated by playing the videos in general demuxer software. Flow is converted to its corresponding Passenger Car Units (PCU) from vehicles/second as per the Indian guidelines (IRC: 86-1983).

FUTURE ISSUES

This new concept of merging behavior used for finding critical gaps of U-turns have never been used previously and can be unpretentiously used by any traffic engineer under heterogeneous traffic situations. Thus, the concept introduced in this paper will definitely serve as a handy tool for future traffic engineers/ policy makers to improve traffic operations on un-signalized median openings. However, there is little doubt about the utilization of the merging behavior concept to other transportation facilities such as roundabouts, interchanges, etc. and thus further research in this regard is recommended in the future.

DISCLOSURE STATEMENT

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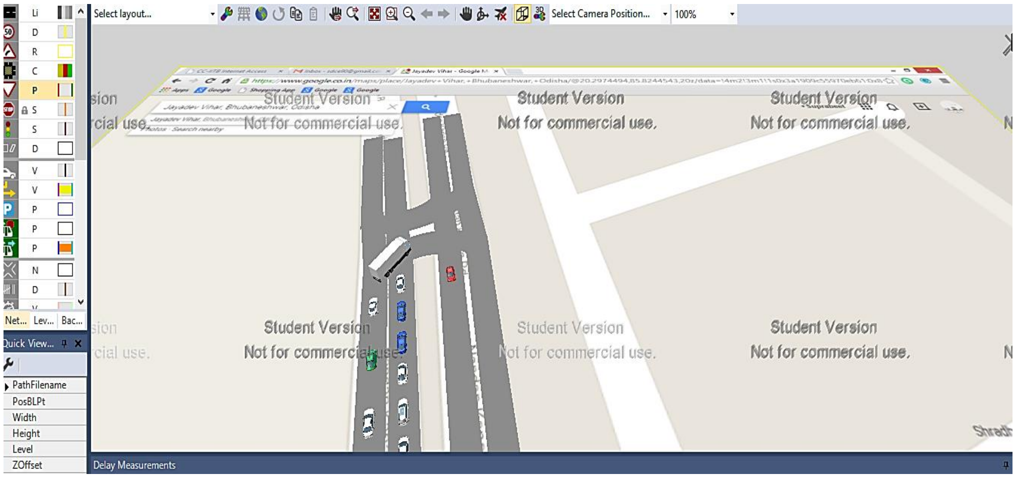
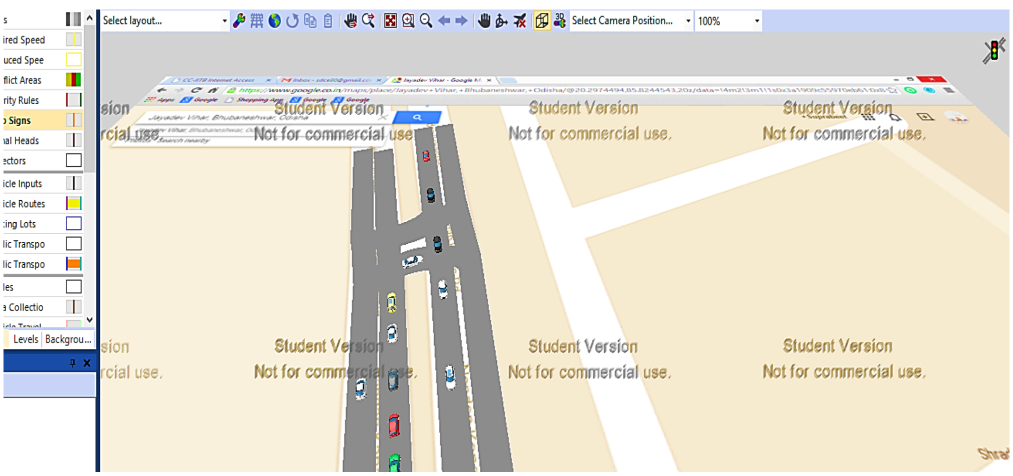
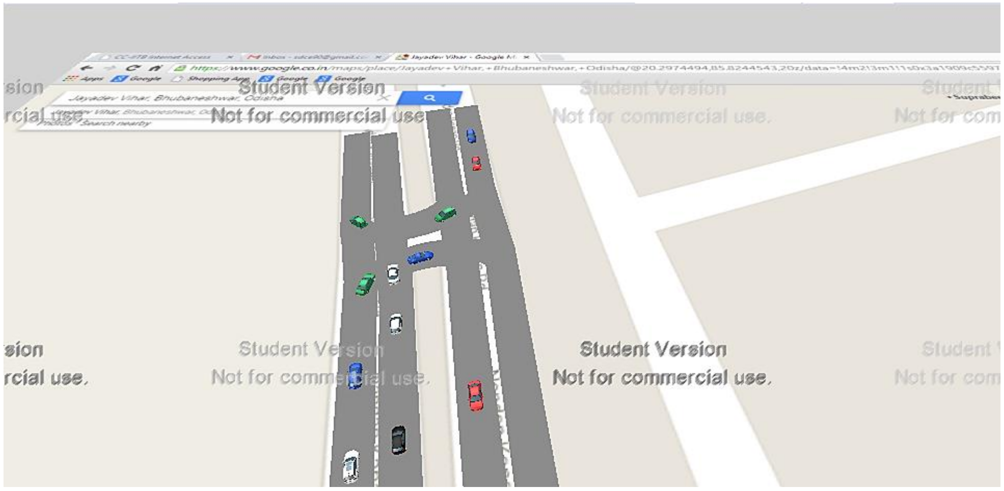
APPENDIX – I-VISSIM OUTPUTS DESCRIBING MIXED TRAFFIC SITUATIONS AT THE SITES



Vissim Simulation showing gap acceptance of a heavy vehicle under mixed traffic causing blockage to oncoming vehicles and thus formation of large queues for the Section 3(Pal Height Mall)



** Another visual simulation representation in Vissim showing U-turn vehicle waiting for suitable gap for an entry into the conflicting traffic stream for section 9 (Midway between Zedek Polytechnique and Urdu Library, Ranchi **



Another situation at which the oncoming (white coloured) vehicle attempts forced gap acceptance in between the green and blue coloured U-turn vehicles for section 2 (Near Rainbow Training center, Rourkela) which is a common apologue under Indian mixed traffic conditions #

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Table 1

Basic Statistics of Data Collected

Modes	Measures	Accepted Gaps, secs	Rejected gaps, secs	All Gaps, secs	Merging Times, secs
4W	Mean	4.55	1.94	2.64	2.46
	Standard Deviation	2.835	1.64	2.505	0.744
	Minimum	1.28	0.433	0.433	1.634
	Maximum	14.24	15.6	15.6	4.52
2W	Mean	5.28	1.38	2.45	2.46
	Standard Deviation	2.84	0.726	2.505	0.744
	Minimum	0.88	0.52	0.52	0.45
	Maximum	13.12	4.72	13.12	14.08
3W	Mean	5.369	1.705	2.83	2.49
	Standard Deviation	1.83	1.21	2.101	0.873
	Minimum	3.04	0.4	0.4	1.733
	Maximum	9.567	5.833	9.567	2.5
SUVs/MUVs	Mean	5.97	1.79	2.65	2.77
	Standard Deviation	3.39	1.09	2.265	0.92
	Minimum	1	0.466	0.466	0.93
	Maximum	13.44	4.384	13.44	6.6

***4W= four-wheelers; 2W=two-wheelers; 3W=three-wheelers; SUVs/MUVs=Sport/Multi Utility Vehicles. ***

Table 2.

PCUs for Calculation of Conflicting/Through Traffic flow (*Source: Indian Roads Congress, IRC- 1983, Code No. 86*)

Serial Nos.	Vehicle Types	PCU Equivalents
1.	4W, LCV,3W,SUV	1.0
2.	HV like truck,bus,lorry	3.0
3.	2W(motor-bikes, scooters)	0.5

##HV=Heavy Vehicles with multiple axles; LCV=Light Commercial Vehicles##

Table 3

Traffic Characteristics and Geometry of the Nine Median Opening Sections Observed

Median Opening Section No.	Location	Median Opening Width		Volume of through traffic (PCU/hr.)	Proportion of U-turn drivers
		d*	c**		
1	Near Rourkela Institute of Management Studies – Rourkela, Odisha	14.8	2.2	4100	1184(34%)
2	Near Rainbow Software Training Complex on Panposh Road – Rourkela, Odisha	20.1	2.3	4570	715(28%)
3	In front of Pal Height Mall (Towards Jaydev Bihar) – Bhubaneshwar, Odisha	20	2.1	2490	894(20%)

4	In front of CS Pur HPCL petrol pump – Bhubaneshwar, Odisha	20.3	2.1	1980	828(25%)
5	Near Patia IOCL petrol pump – Bhubaneshwar, Odisha	20.4	2.0	6570	670(23%)
6	In front of Eastern Railway Headquarters, Bhubaneshwar	17.9	2.8	7950	1500(43%)
7	In front of SBI colony, Bhubaneshwar	15.3	2.2	2652	667(20%)
8	Near Ranchi Cricket Stadium, Ranchi, Jharkhand	15.7	1.6	3086	1582(34%)
9	Midway between Zedek Polytechnique and Urdu Library on Main Road , Ranchi, Jharkhand	19.8	2.2	2881	1184(29%)

Table 4

Critical Gap Values for Various Modes Estimated using “Merging Behaviour” concept of “INAFOGA”

Median Opening Section Details	***Critical gap values by “Merging Behaviour” Concept of “INAFOGA” in seconds***			
	Motorized Four wheelers	**Motorized Three Wheelers**	**Motorized Two Wheelers**	**Sport Utility Vehicles**
1(Rourkela Institute of Management Studies)	3.375	4.50	3.45	3.15
2(Panposh Road, Rourkela)	4.50	4.75	5.15	6.00
3(Pal Heights towards J.V., Bhubaneshwar)	3.00	3.20	3.50	3.25
4(C.S. Poor HPCL Petrol Pump, Bhubaneshwar)	5.15	4.75	4.80	3.45
5(Near Patia IOCL Petrol Pump, Bhubaneshwar)	6.05	5.25	5.15	4.75
6(Eastern RailwayHeadquarters, Bhubaneshwar)	5.55	3.15	3.75	4.80
7(Near Ranchi Cricket Stadium, Ranchi, Jharkhand)	4.15	5.85	3.25	4.00
8(Near Kalinga Stadium Bhubaneshwar)	3.20	6.00	5.55	2.75
9(Zedek Polytechnique and Urdu Library Ranchi, Jharkhand)	3.04	4.15	5.25	4.55

Table 5

Parametric details of the Conflicting traffic flow-critical gap model for 4 wheelers

	a		***b***		***Statistics***	
	Value	***Standard Error***	***Value***	***Standard Error***	***Reduced Chi-Square***	***Adj. R-Square***
Conflicting Traffic flow	12.777	1.30515	-2.198	0.081	0.004	0.96

Table 6

Parametric details of the Conflicting traffic flow-critical gap model for 2 wheelers

	a		***b***		***Statistics***	
	Value	***Standard Error***	***Value***	***Standard Error***	***Reduced Chi-Square***	***Adj. R-Square***
Conflicting Traffic flow	4.991	0.374	-1.77	0.071	0.005	0.951

Table 7

Parametric Details of the Linear Regression model for Three Wheelers

	a		***b***		***Statistics***	
	Value	***Standard Error***	***Value***	***Standard Error***	***Reduced Chi-Square***	***Adj. R-Square***
Conflicting Traffic flow	8.87	0.88	-2.12	0.08	0.00	0.95

Table 8

Parametric Details of the Linear Regression model for Sport Utiltiy Vehicles

		Value	***Standard Error***
Conflicting Traffic flow	a	8.69222	0.9283
	b	-2.17058	0.09702

Table 9

Summary of the Regression Models Developed in the Present Study

Variables Considered	***Type of Relationship/Model with Expressions***			
	4 wheelers	***2 wheelers***	***3 wheelers***	***SUVs/MUVs***
Critical gaps – Waiting Time	$T_c = 2125.4.T_w^{-3.67}$ $\mathbf{R^2 = 0.9756}$ Power Regression	$T_c = 114.8.T_w^{-1.909}$ $\mathbf{R^2 = 0.9485}$ Power Regression	$T_c = 50.674.e^{-0.582.T_w}$ $\mathbf{R^2 = 0.9827}$ Exponential Regression	$T_c = 135.31.T_w^{-2.193}$ $\mathbf{R^2 = 0.9567}$ Power Regression
Through/Conflicting traffic speed – Critical gaps	T_c=7.5668-0.1045. V_{th} $\mathbf{R^2=0.9846}$ Linear regression	T_c=7.6364-0.1088. V_{th} $\mathbf{R^2=0.9913}$ Linear regression	T_c=6.833-0.0871. V_{th} $\mathbf{R^2=0.9837}$ Linear regression	T_c=6.9717-0.0918. V_{th} $\mathbf{R^2=0.9757}$ Linear regression
Critical gaps – Conflicting/through traffic flow	T_c= 12.77.$Q_{th}^{-2.19807}$ $\mathbf{R^2=0.96235}$ Power Regression	T_c= 4.991-1.7747.Q_{th} $\mathbf{R^2=0.95126}$ Linear Regression	T_c= 8.8796 $Q_{th}^{-2.12433}$ $\mathbf{R^2=0.95019}$ Power Regression	T_c= 8.69 – 2.17. Q_{th} $\mathbf{R^2=0.94613}$ Linear Regression

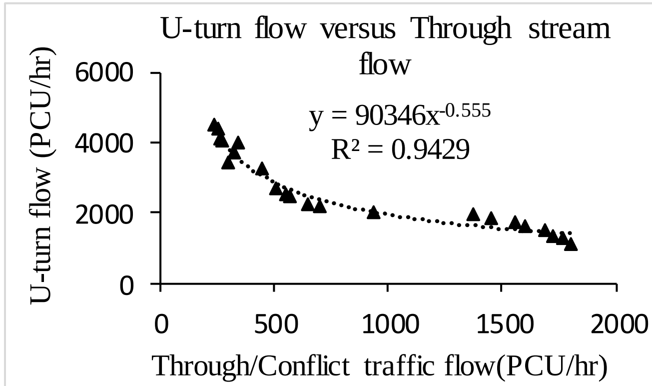

Figure 1

Cumulative distribution plot for variation of U-turn flow with through traffic flow in PCU/hr

(A)

(B)

Figure 2

(A) Pictorial representation of ***Section 3***; (B) Data extraction process of ***Section 3*** video-recording in the AVIDEMUX 2.6.1 software

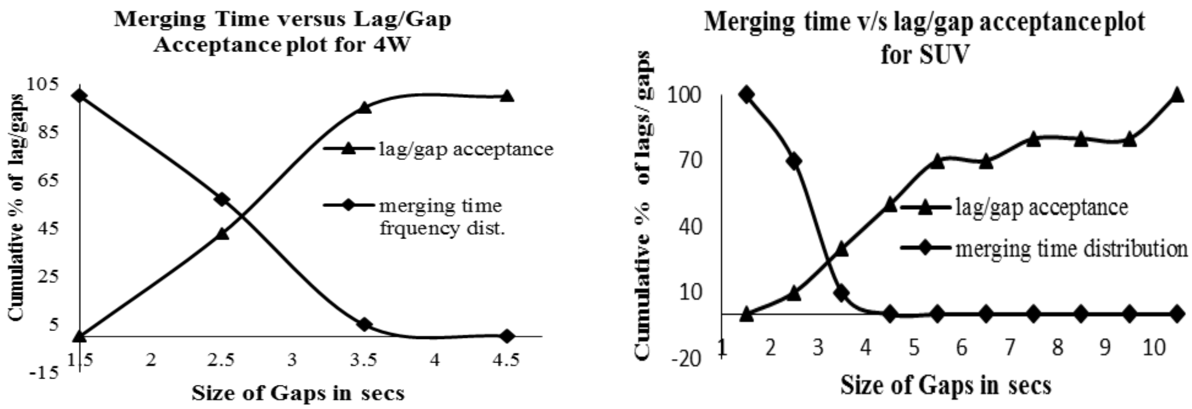

Figure 3

Illustration regarding Estimation of Critical Gaps by the “Merging Behaviour” Concept of INAFOGA

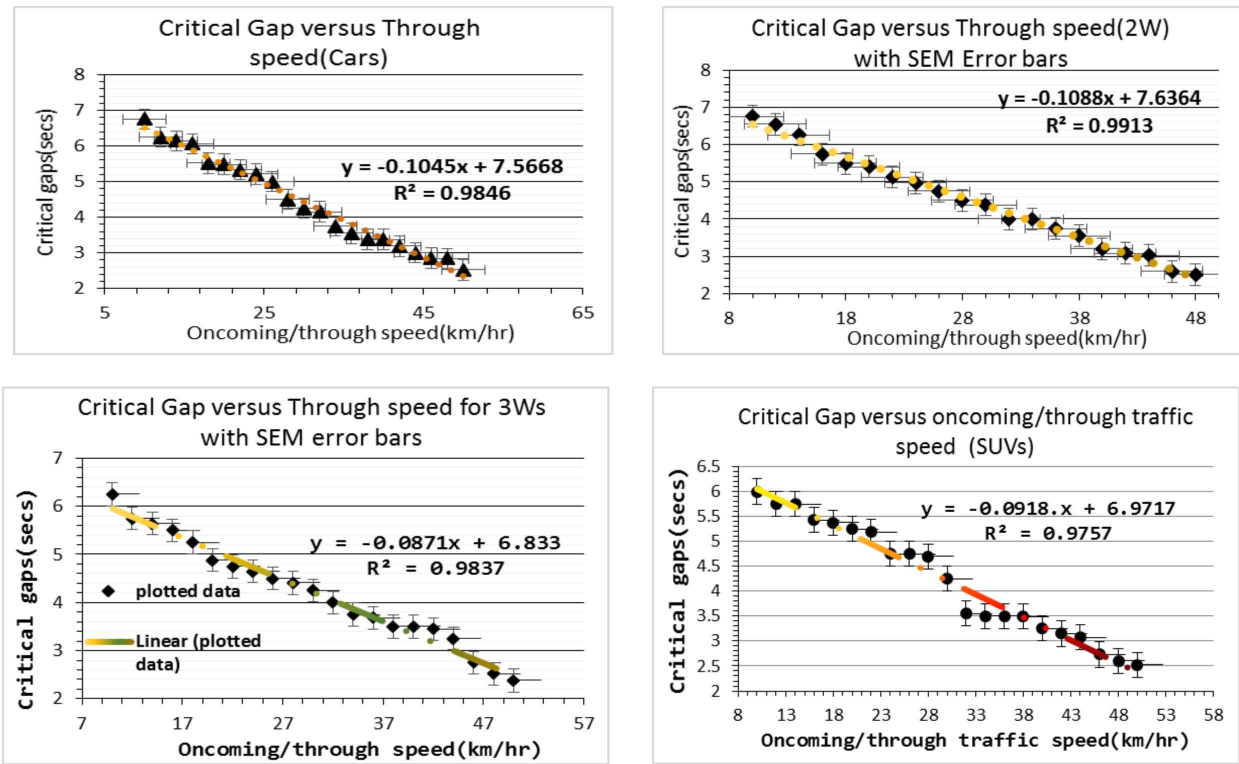

Figure 4

Regression plots Showing Influence of Conflicting Traffic Speed (Kmph) on U-turn driver’s Critical Gaps under Mixed Traffic.

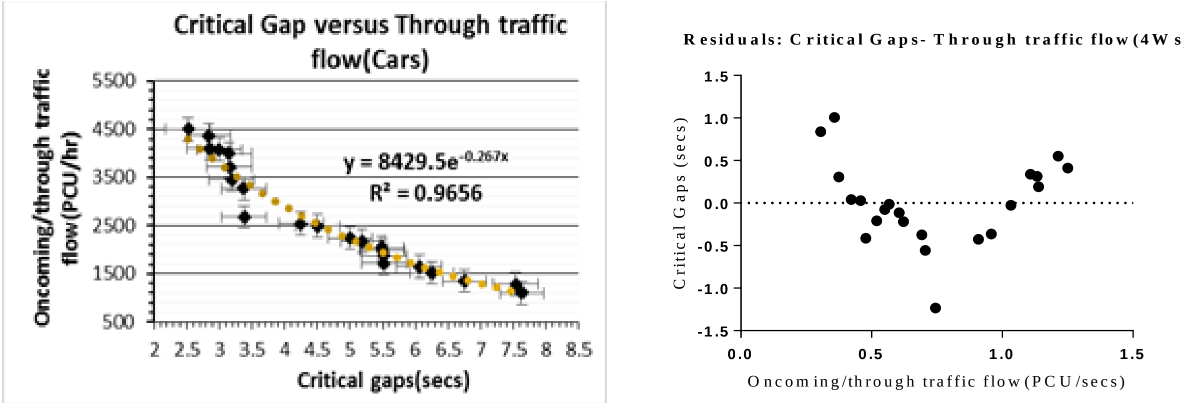

Figure 5

Effect of Oncoming Traffic flow (PCU/sec) on U-turn Four Wheelers (4Ws) Critical Gaps

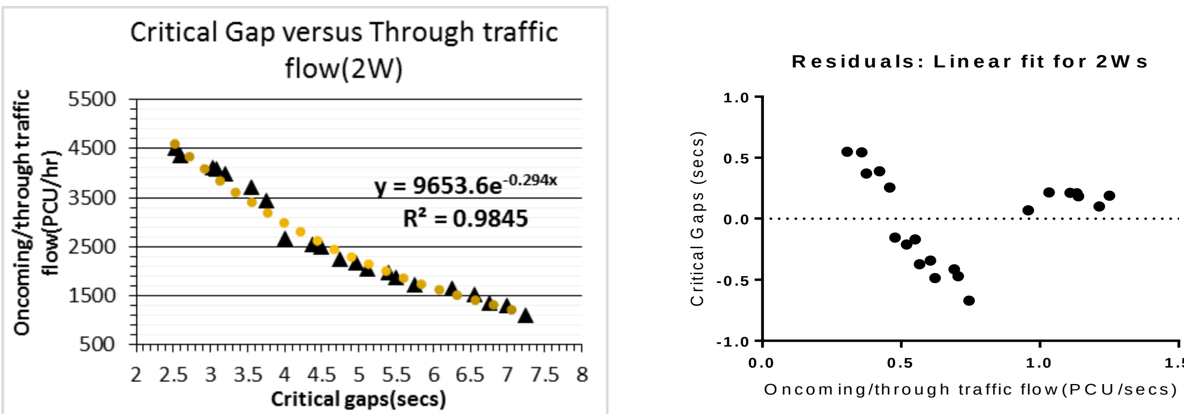

Figure 6

Linear variation of U-turn Two Wheelers (2Ws) Critical Gaps with Increasing Through/Oncoming Traffic flow in PCU/seconds

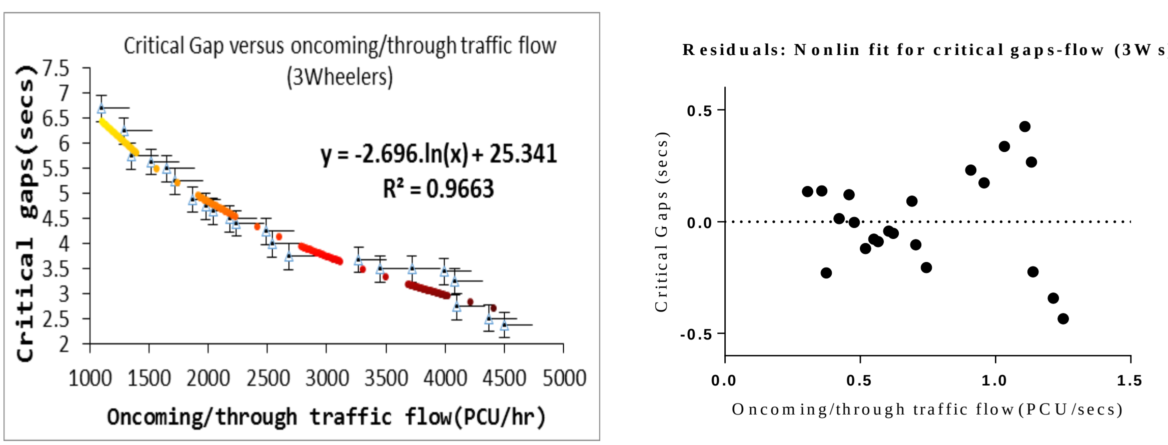

Figure 7

Power Regression Variation of through/conflicting Traffic Flow (PCU/secs) with Three Wheelers (3Ws) Critical gaps

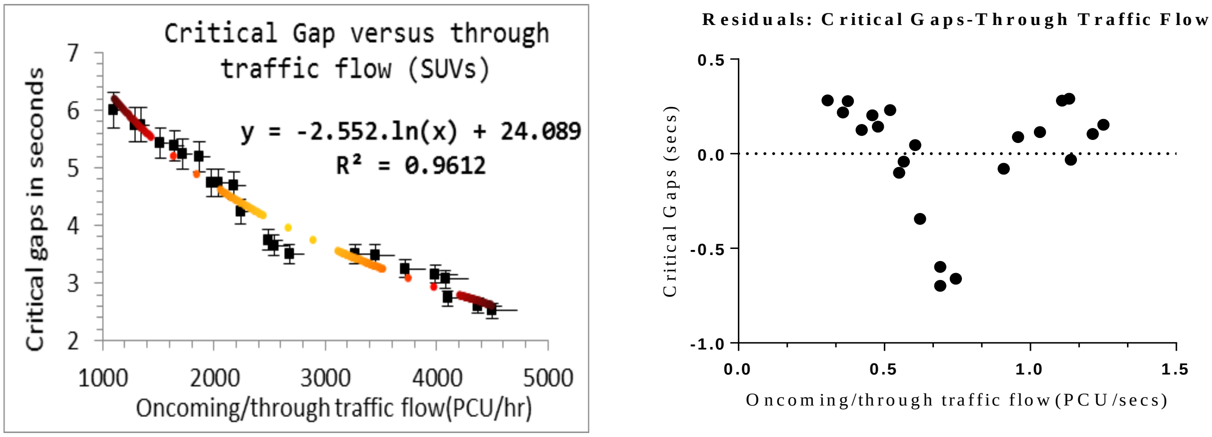

Figure 8

Effect of through Traffic flow (PCU/secs) on U-turn Critical Gaps for Sport Utility Vehicles (SUVs)

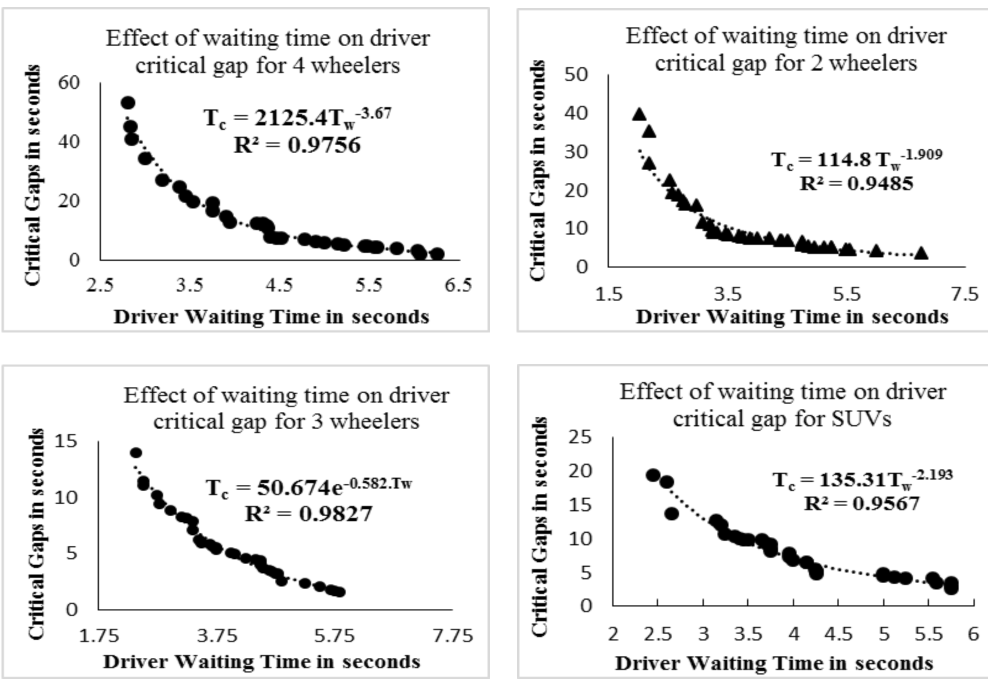

Figure 9

Regression equation plots for effect of driver waiting times on critical gaps under homogeneous traffic situations

Bhuyan and Datta,
Effect of Waiting Time, Flow and Speed on U-turn Critical gaps at Median Openings under Mixed Traffic,
Indian journal of engineering, 2015, 12(28), 1-15,