

Which Method is Appropriate- INAFOGA or PROBABILITY EQUILIBRIUM for Critical Gap Estimation of U-turn Vehicles at Median Openings In Urban Indian Context?

[Suprabeet Datta, P.K.Bhuyan]

Abstract— Over the past few years there has been increased installation of non-traversable un-signalized median openings in most of the urban regions in India. The motive behind this installation is to eliminate problems associated with illegal U-turns at intersections and other traffic facilities close to the median openings on multi-lane urban roads. Data collected for this study is in the form of video-images of six U-turn median openings on 4-lane and 6-lane roads situated in the cities of Bhubaneswar, Rourkela and Ranchi located in the eastern part of India. This paper introduces a new concept on merging behavior of U-turn vehicles for evaluation of gaps accepted by drivers at median openings based on the “INAFOGA” method; which is further compared with the critical gap values obtained by and Macroscopic Probability Equilibrium concept for heterogeneous traffic flow in the urban region of the Indian states. IBM-SPSS 22.0 has been used to perform a paired-sample Hypothesis (t-test) between these two methods which reveal that critical gap values obtained by “INAFOGA” are 18-31% more than those obtained by Probability Equilibrium method. Radar plots, box-plots, t- statistic, two-tailed significance value coupled with higher critical gap values for different modes of transport (except Sport Utility Vehicles) validates the fact that “INAFOGA” method is indeed appropriate under mixed traffic conditions. This observation on influence area of gap acceptance at median openings using the merging behavior concept has given sufficient clue to carry out further research on critical gaps at roundabouts or interchanges.

Keywords— *Critical-gap; Gap acceptance; INAFOGA; Median openings; Mixed traffic; SPSS; U-turn vehicles*

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I. Introduction

As a part of traffic management system in order to improve intersection operation, some illegal traffic movements are not permitted at selected intersection locations, especially along divided arterials. In most cases, such minor movements are accommodated at separate U-turn median openings. During the recent era there has increased installation of un-signalized median openings to accommodate these illegal U-turns in most of the Indian states. This increased installation reflects the much needed attention towards Access Management [1,2]. One of the best ways of accessing roads is by installing non-traversable and un-signalized median openings [2,3]. The purpose of using non-traversable and directional median openings is to eliminate problems associated with left-turns and crossing movements at intersections on multi-lane highways [1,2,3]. At un-signalized median openings vehicular interactions are extremely complex [3,4]. Thus, a U-turning vehicle driver needs to accept a gap or time span between the arrivals of successive vehicles on the through street after it has arrived at a close vicinity of the median opening. This defines the phenomenon of “Gap Acceptance” for median openings. Conventionally, Gap is defined as the time or space headway between two successive vehicles in the through traffic stream [6,7]. “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. Raff and Hart (1950) defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it [11]. “Highway Capacity Manual (2010)” in its Volume 3, Page 19-7 names critical gaps as “Critical Headway” and defines “as the minimum time interval in the major street traffic stream that allows intersection entry for one minor-street vehicle” [12]. Regarding the above definition we tried to define “Critical Gap” for U-turns at median openings as “the minimum time interval in between two through/conflicting traffic vehicles that allows complete merging maneuver for one U-turn vehicle at a median opening”. Critical gap is difficult to measure directly in field. Critical gap is constant for a driver category. The measurement varies for different drivers and with time depending upon the geometric fashion of maneuvers of the U-turn vehicles prevailing on the median openings [11,13]. There are a bunch of useful estimation procedures for determination

of critical gap corresponding to homogeneous traffic conditions. Some of these estimation procedures are empirical whereas rest have a strong theoretical background [16]. In this paper, an intrepid effort has been taken to estimate and compare critical gaps of different U-turning modes prevailing on the median openings in India which would further prompt to understand the gap acceptance concept under mixed traffic environments. In this repute, video data has been collected from three cities located in the eastern part of India.

I. Previous Studies

Many researchers have worked on “gap acceptance” during the past few decades, but majority of them considered homogeneous traffic flow conditions. According to available literatures several techniques or models have been established since the year of 1947 to estimate “critical gap” as closely as possible. Thus, it is clear that literatures regarding gap acceptance phenomenon is rich. Majority of literatures normally consider the accepted and rejected gaps as the key parameters for the estimation of critical gaps [8,19]. “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 [12].

Raff (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”. The author defined it as the gap/lag for which the number of accepted lags shorter than it is equal to the number of rejected lags longer than it. 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 [16]. In 1974, A.J. Miller corrected the Raff’s model and concluded that the developed model is suitable for light-to-medium traffic but is not acceptable for heavy traffic conditions [18]. The author also verified that the model gives satisfactory results for “gaps” as that obtained for “lags”. This means “critical gap” can also be obtained by the method. Miller (1972) developed a simple gap acceptance model to compare nine different methods of critical gap estimation. Simulation study was used to generate artificial data and comparison was based on the central value estimated by each method. It has been found that Ashworth’s method and maximum likelihood technique gave satisfactory results [19]. Ashworth (1968, 1970 and 1979) estimated the average Critical Gap from the Mean and Standard Deviation of gaps accepted by a driver through an empirical mathematical relation with the through traffic volume in vehicles per second assuming exponential distribution of accepted gaps. Harders (1968) estimated the critical gap by the expectation of the cumulative frequency distribution curve for the proportion of accepted gaps of size i , provided to all U-turning vehicles [19,20]. 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 [16,20]. Pan Liu in 2007 found the headway acceptance characteristics of U-turn vehicles on 4-lane divided roads. Turki et al. in their publication on April 2013, modelled estimated length of time

gap needed by a U-turn driver based on factors such as Age, Gender and the elapsed 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 [5].

For heterogeneous traffic flow conditions, Ashalatha and Satish 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 values which highlighted the limitation of the methods to address mixed traffic situations [10]. Thus, the authors came up with an alternate procedure 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 was selected as the base for the present study because of its robustness 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 in this study.

II. Study Area and Data Collection Details

A. Area of study

The study area comprised of six busy median opening sites from three cities located in the eastern part of India. Observed details on geometry and traffic characteristics of the six median openings are shown in Table 1. In order to include variation in road geometric and traffic characteristics, data were collected from two median openings corresponding to each city. Rourkela and Bhubaneswar belongs to Odisha State while Ranchi is the capital 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.

B. Details of traffic data collection

Data collection primarily comprised of video recording of the selected median openings by a Sony Handycam capable of playing videos at a frame rate of 30 frames/second during the months of January, March, April and September. Peak hours of U-turns were surveyed and video shooting was done for the morning (8:30- 10:30 AM), noon (12:30-2:00 PM) and afternoon (4:00-5:00 PM) sessions depending on the importance of the days. Shooting was done only during weekdays. Weekends and public holidays were generally neglected due to variation of U-turning traffic at median openings. Video recording of all the three sections resulted in an average proportion of U –turning and through traffic of 20-40% and 65-85% respectively. Classes of U-turning vehicles considered are as pointed below:

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

The variation of U-turning flow with respect to through or conflicting traffic volume can graphically represented as a cumulative distribution in PCU/hr. The conversion from no. of vehicles to their corresponding Passenger car equivalents was done according to Table 2 adopted from Indian Roads Congress (IRC): 86-1983(Geometric Design Standards for Urban Roads on Plains). Fig. 1 shows the distribution of U-turn flow for the three different sections with respect to the increasing through traffic volume in PCU/hr. with increase in through traffic volume there is an exponential or power decrease in U-turn traffic gap acceptance.

TABLE I. TRAFFIC CHARACTERISTICS AND GEOMETRY OF THE SIX 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) – Bhubaneswar, Odisha	20	2.1	2490	894(20%)
4	In front of CS Pur HPCL petrol pump – Bhubaneswar, Odisha	20.3	2.1	1980	828(25%)
5	Near Patia IOCL petrol pump – Bhubaneswar, Odisha	20.4	2.0	6570	670(23%)

6	Midway between Zedek Polytechnique and Urdu Library on Main Road , Ranchi, Jharkhand	17.9	2.8	7950	1500(43%)
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d= horizontal width of median openings; c = width between outer edges of inner lanes

TABLE II. PASSENGER CAR EQUIVALENTS FOR CALCULATION OF FLOW AS GIVEN IN IRC : 86-1983

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

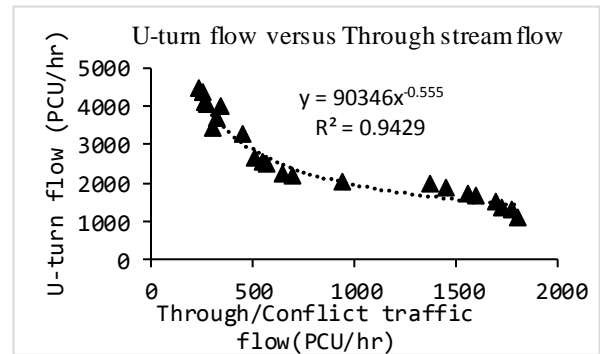


Figure 1. U-turn flow versus through traffic volume in PCU/hr.

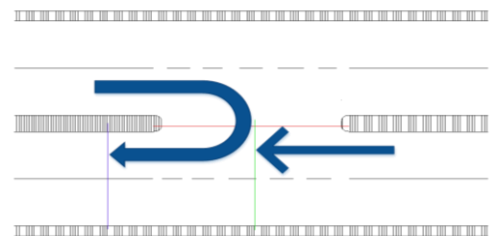
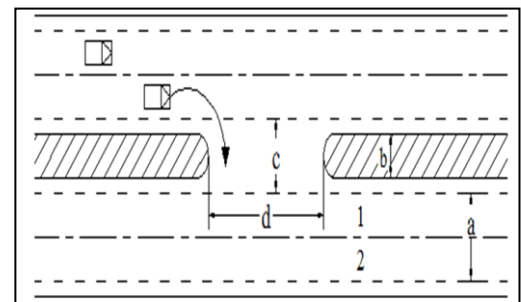


Figure 2. Line diagram of the study area in AutoCAD 2009



b = width of median in meters
 a = distance between the outer edges of lane 1 and 2 in meters
 1 & 2 = first lane and second lane respectively ##

Figure 3. Schematic representation of the study area

III. The New Concept of Merging Behavior for U-turns

Figure. 2 & 3 represents the schematic diagram of a median opening on a 4-lane divided road in AUTOCAD 2009 representing the “INAFOGA” method. 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 $\{(d/2) + 2.2 \text{ m}\}$ while the breadth (W) as $\{a + (c/2)\}$. All these measurements have been experimentally proved in general for all the six 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 dimensions of the median openings. The “Blue” line is at $d/2$ distance horizontally from the face of the median.

IV. Methods Compared

A. Macroscopic Probability Equilibrium Method

In 2006, Ning Wu introduced a new model for estimation of critical gaps for unsignalized intersections. Theoretical background of this model is based upon Probability Equilibrium between the Rejected & Accepted gaps. Equilibrium is established macroscopically using the cumulative distribution of rejected & accepted gaps. Calculation of critical gaps for the six sections were carried out in MS-Excel 2013 according to the following steps:

- All measured and relevant (according to whether all or only the maximum rejected gaps are taken into account) gaps t in the U-turning stream noted into the first column of the spreadsheet
- The accepted gaps were marked with "a" and the rejected gaps with "r" in second column of the spreadsheet respectively
- All gaps (together with their marks "a" and "r") are then sorted in an ascending order
- The accumulate frequencies of the rejected gaps were then calculated, n_{rj} , in the third column of the spreadsheet (that is: for a given row j , if mark="r" then $N_{rj}=N_{rj}+1$ else $N_{rj}=N_{rj}$, with $N_{r0}=0$)
- Similarly, the accumulate frequencies of the accepted gaps, N_{aj} , were calculated in the fourth column of the spreadsheet (that is: for a given row j , if mark="a" then $N_{aj}=N_{aj}+1$ else $N_{aj}=N_{aj}$, with $n_{a0}=0$)
- Then the Probability Density Function (PDF) of the rejected gaps, $F_j(r)$, were calculated in column 5 of the spreadsheet (that is: for a given

raw j , $F_j(r)=N_{rj}/N_{r,max}$ with $N_{r,max}$ =number of all rejected gaps)

- Similarly, the PDF of the accepted gaps, $F_a(tj)$, in sixth column of the spreadsheet (that is: for a given raw j , $F_a(tj)=N_{aj}/N_{a,max}$ with $N_{a,max}$ =number of all accepted gaps)
- The PDF of the estimated critical gaps, $F_{tc}(tj)$ were then calculated, in column 7 of the spreadsheet as $F_{tc}(tj)=F_a(tj)/[F_a(tj)+1-F_r(tj)]$ for any j
- Frequencies of the estimated critical gaps, $P_{tc}(tj)$, was calculated between the raw j and $j-1$ in column 8 of the spreadsheet as per $P_{tc}(tj)=F_{tc}(tj)-F_{tc}(tj-1)$
- The class mean, $T_{d,j}$, between the raw j and $j-1$ in is the calculated in column 9 of the spreadsheet (that is: $T_{d,j}=(T_j+T_{j-1})/2$)
- Then, the average critical gap value and the variance of the estimated critical gaps (that is: $T_{c,average}=\sum[P_{tc}(tj)*T_{d,j}]$ and $\sigma^2=\sum[P_{tc}(tj)*T_{d,j}^2]-(\sum[P_{tc}(tj)*T_{d,j}])^2$) is found out

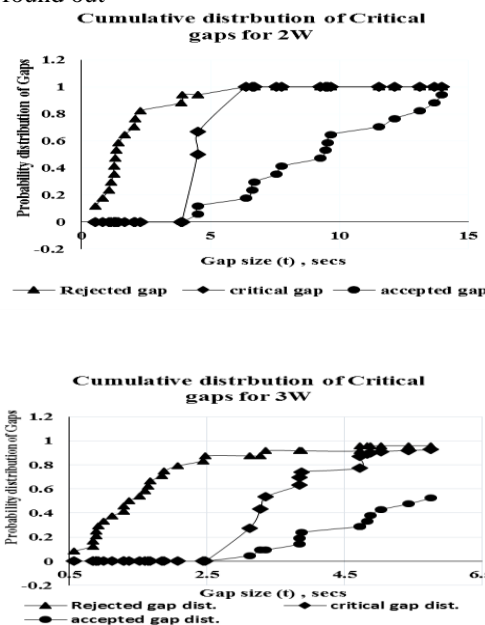


Figure 4. Critical Gap Distribution by Probability Equilibrium Method for two (2W) and (3W) three wheelers

B. Influence line for Gap acceptance “INAFOGA” method

Satish et al in the year of March 2011 introduced a new concept for measuring critical gap making use of clearing behavior of vehicles in conjunction with gap acceptance data. He proposed an area named as INAFOGA (Influence Area for Gap Acceptance) which had a dimension of $L*W$, where $L=3.5 \text{ m}$ (lane width) & $W=1.5$ times width of crossing /merging vehicle. The method takes into account the clearing behavior

of a vehicle (clearing time is the time taken by the minor street/U-turn vehicle to clear the influence area) & gap acceptance behavior. Following are the characteristics of “INAFOGA” [10] for a typical T-type intersection:

- i. 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.
- ii. Difference between the arrivals of successive major street Vehicles at the upstream end of the INAFOGA is considered as ‘Gap’
- iii. In this method, a typical cumulative frequency distribution curve for clearing time of a minor street vehicle against its corresponding Lag & Gap Acceptance curve is plotted having 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.

v. Results and Analysis

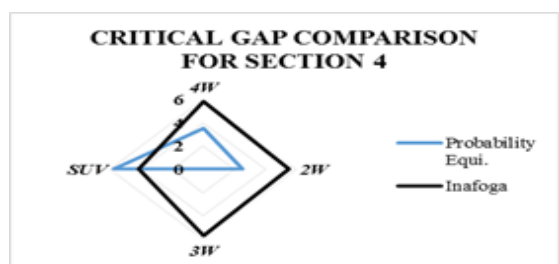
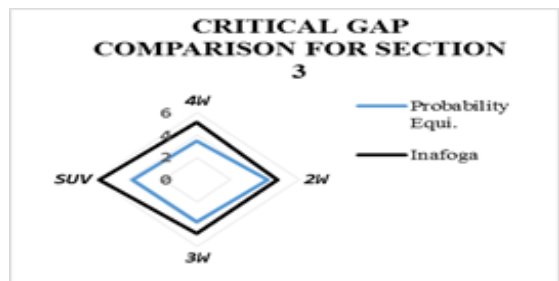
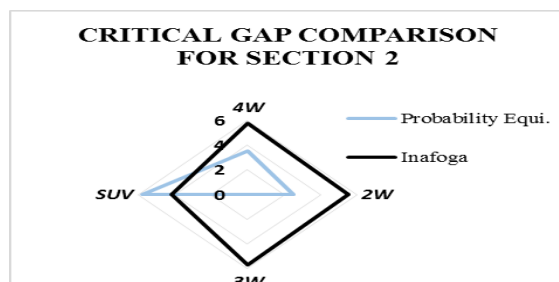
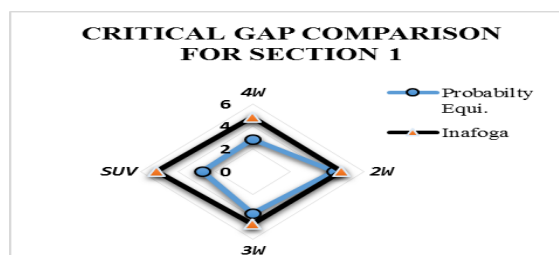
Tables III displays the critical gap values for six different sections of median openings on 4-lane divided roads of Bhubaneswar. Four different categories of vehicles explicitly cars (4W), 2-wheelers, 3-wheelers and Sport utility vehicles have been considered in this study. Values in parenthesis for table III indicate the sample sizes and the symbol ** indicates either low or nil sample size. Radar plots (Fig. 6) are shown to compare the critical gap values between different sections based on the values represented in tables 3 and 4.

A paired sample T-test as shown in Table IV was done for the critical gap values obtained by Probability Equilibrium and “INAFOGA” methods to find out the difference in means of the values in IBM SPSS (Statistical Package for Social Sciences) software version 22.0.

TABLE III. CRITICAL GAP VALUES FOR MIXED TRAFFIC ESTIMATED USING PROBABILITY EQUILIBRIUM AND “INAFOGA” METHOD

Median Opening Section no.	Vehicle Type	Critical Gap (secs) for U-turn vehicles by	Critical Gap (secs) by
		Probability Equilibrium Method	“INAFOGA ”
1	4-WHEELER	3.38	4.78(65)
	2-WHEELER	3.95	4.75(90)
	3-WHEELER	4.50	4.65(75)
	SUVs/MUV	4.25	5.15(35)
2	4-WHEELER	3.75	5.40(84)
	2-WHEELER	3.25	5.80(42)
	3-WHEELER	3.75	5.50(33)
	SUVs/MUV	4.15	5.70(20)
	4-WHEELER	4.25	5.55(34)

3	2-WHEELER	3.25	6.00(26)
	3-WHEELER	4.25	5.85(22)
	SUVs/MUV	4.25	**
4	4-WHEELER	3.45	5.15(43)
	2-WHEELER	4.15	4.75(52)
	3-WHEELER	3.75	4.80(21)
	SUVs/MUV	3.75	5.75(20)
5	4-WHEELER	3.45	6.05(45)
	2-WHEELER	2.87	4.25(42)
	3-WHEELER	4.75	5.15(34)
	SUVs/MUV	3.38	4.75(21)
6	4-WHEELER	4.25	5.55(34)
	2-WHEELER	2.75	3.15(33)
	3-WHEELER	3.68	3.75(48)
	SUVs/MUV	**	4.8(27)



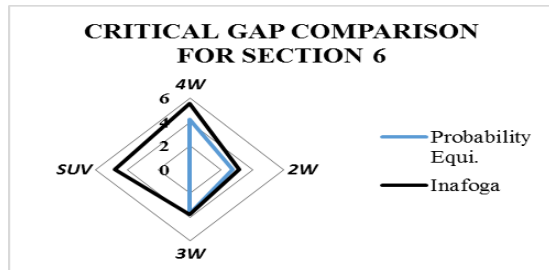
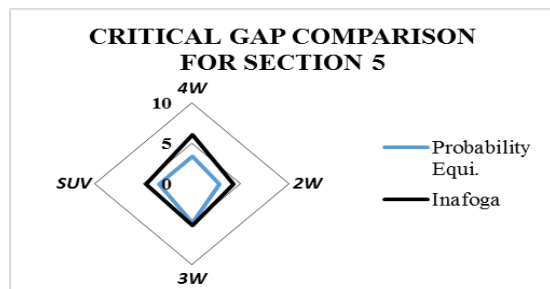


Figure 6. Radar Plots for critical gap comparison between 6 different sections under mixed traffic

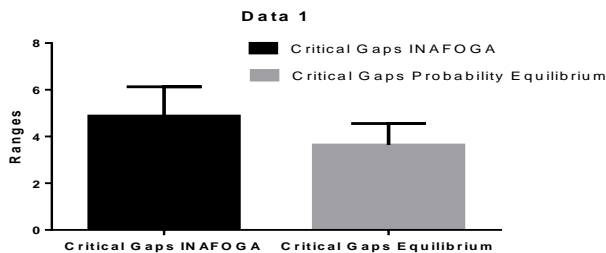


Figure 7. Box plots showing difference in mean and median values between the two methods compared in the study

TABLE IV. STATISTICAL DETAILS OF THE PAIRED SAMPLE T-TEST FOR COMPARISON BETWEEN PROBABILITY EQUILIBRIUM – “INAFOGA” METHODS IN IBM SPSS 22.0

Descriptive Statistics:

	N	Mean	SD	SEM	Median
"Critical Gaps by Equilibrium Method"	24	3.63375	0.92416	0.18864	3.75
"Critical Gaps by INAFOGA"	24	4.87625	1.25488	0.25615	5.15
Difference	24	-1.2425	1.54491	0.31535	-1.375
Overall	48	4.255	1.25806	0.18159	4.25

** SD=Standard Deviation; SEM=Standard Error Mean; N= no. of samples

T-statistics:

t -Statistic	DF	Two-tailed Significance
-3.94004	23	6.52801E-4

Null Hypothesis: mean1-mean2 = 0
 Alternative Hypothesis: mean1-mean2 < 0
 At the 0.05 level, the difference of the population means is significantly different from the test difference (0).

VI. Conclusions and Discussions

This research initiative introduces the new concept of merging behavior for estimating critical gaps of U-turn drivers at median openings on multi-lane roads under mixed traffic flow in Indian context. Merging time indicates the complete merging maneuver of U-turn vehicles at median openings. In this study data was collected in the form of video recording from six median openings on 4-lane and 6-lane roads located in the urban regions of Bhubaneswar, Rourkela and Ranchi cities situated in the eastern part of India. Basic statistics of the decision variables used for estimating critical gaps in this study are tabulated and two methods discussed in the available literatures are used to determine critical gaps of U-turn drivers at median openings. The first one is the “INAFOGA” method while the second one is “Macroscopic Probability Equilibrium Method”. A paired sample t-test between critical gap values for Probability Equilibrium and “INAFOGA” method was performed to find out the difference in means of the values. The t-statistic and the two-tailed significance values shows sufficient influence of parameters such as critical gaps, merging time, accepted and rejected gaps to compare these two methods. Radar plot illustrates the variation of critical gap values for the four different modes (4W, 2W, 3W and SUVs) considered in this study for all the six sections. It is clear from the radar plots that the critical gap values obtained using merging behavior concept is higher than those values obtained using the Probability Equilibrium method by 18% to 31%. This difference is because of clear under-estimation of the critical gap values obtained by Probability Equilibrium method for U-turns. It can be admitted from these results that the probability equilibrium method does not take into account the unpredicted vehicular collaborations of non-motorized traffic with motorized ones under Indian mixed traffic conditions. The limitation observed by using Probability Equilibrium method in studying gap acceptance is the difficulty in estimating the critical gap values under mixed traffic conditions. “INAFOGA” method on the other hand is found to be more suitable in addressing the unpredictable vehicular interactions under mixed traffic.

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