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Critical Gap Comparison between HARDERS and "INAFOGA" Methods for U-Turn Median Openings

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ABSTRACT
Unsignalized median openings are been installed every day on divided arterials at most of the developing cities in India during the past few years because of the non-accommodation of U-turn movements at unsignalized intersections. Studies of U-turn Gap Acceptance had been neglected under Indian traffic. In this paper, Critical gap has been used as the sole parameter for gap acceptance. Estimation of critical gaps for U-turns at median openings under mixed traffic conditions have not been addressed till today due to the complex and risky traffic interactions at these facilities. Video image processing of 4 U-turn median openings were done to extract the decision variables of the study. For the first time a new concept of merging behaviour of U-turn vehicles for evaluation of gaps by drivers has been introduced here. Two empirical methods namely Harders and Satish et al. "INAFOGA" are used for estimating critical gap considering four motorized modes of transport for all the four sections. Bar comparison plots for all four sections are drawn to compare the methods considering the four motorized modes. A paired sample T-test was done in IBM SPSS 22.0 which revealed that "INAFOGA" method yield critical gap values 28-41% more than those obtained by Harders method. This explained the effectiveness of "INAFOGA" method in judging mixed traffic conditions for U-turns at median openings.
***Keywords* -** critical gap, gap acceptance, Indian traffic, median openings, SPSS, U-turns, unsignalize

I. INTRODUCTION

For the few years there has been increased installation of non-traversable & directional medians all over India particularly in sub-urban cities on arterial highways. As a part of traffic management to improve intersection operation, some 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. 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 [1] [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 [2] [3] [4]. At un-signalized median openings vehicular interactions are extremely complex [5] [6]. 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 [7] [8] [9]. Gap differs from headway in the fact that the latter is measured as a time span between front bumpers of two successive vehicles whiles the former as the time length between back bumpers/wheel bases. "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 [10]. In [11], authors defined the 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. In [12], authors presented 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". 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 manoeuvre for one U-turn vehicle at a median opening". Critical gap is difficult to measure directly in field. The measurement varies for different drivers and with time instants depending upon manoeuvres of the U-turn vehicles under mixed traffic conditions prevailing on the median openings [10] [11] [13]. There are a bunch of useful estimation procedures for determination of critical gap corresponding to homogeneous traffic conditions. Some of the estimation procedures are empirical whereas rest have a strong theoretical background [11] [16]. In this paper some of the previous estimation techniques are used to estimate critical gaps for various modes of U-turning vehicles willing to merge with the through traffic stream at un-signalized median openings.

Bhubaneshwar is the capital of the Indian state Odisha. It constitutes of an average population of 1.2-1.4 million people as per the 2011 census [14]. The city of Bhubaneswar comprises of wide roads in grid form inside the central city. Bhubaneswar has approximately 1,600 kilometres (990 mi) of roads, with average road density of 11.82 square kilometres (4.56 sq. m) [15]. Due to the presence of a wide stretch of divided highways, the city consists of a fair amount of unsignalized median openings which focused our attention towards this area for our study

Gap acceptance analysis for median openings under heterogeneous traffic conditions has not been given proper attention in the previous years. Neither the global traffic engineering manual HCM even in its recent issue of 2010 had addressed the gap acceptance study for median openings. The obvious reason being the complex and haphazard behaviour caused by U-turn vehicles under mixed traffic situations compared to other movements like right turns/left turns at intersections [10] [17]. In this paper, an effort has been made to estimate critical gaps for different U-turning modes prevailing on the median openings in India which would further instigate to understand the gap acceptance concept under mixed traffic conditions.

II. STUDIES IN THE PAST

A large population of researchers have worked on "gap acceptance" during the past few decades, but majority of them considered homogeneous traffic flow conditions. Several techniques or models have been established since the year of 1947 in literatures to estimate "critical gap" as closely as possible [10] [11] [16]. 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 in estimation of critical gaps [7] [16] [18]. "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].

In [16], author 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". Author also 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 and proposed a graphical model in which two cumulative distribution curves related to the no. of accepted and rejected gaps intersect to yield the value of Critical Lag (Tl). In [19], author corrected the Raff's model and concluded that it gave suitable results for light-to-medium traffic but is not acceptable in heavy traffic conditions. 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. Simulation study was used to generate artificial data and comparison was based on the central value estimated by each method. They found that Ashworth's method and maximum likelihood technique gave satisfactory results [16] [19]. A model of estimated length of time gap needed by a U-turn driver based on driver's Age, Gender and the elapsed time between arriving and experiencing the gap is proposed in [5]. The study related driver-related factors on critical gap acceptance whose data were obtained by analysing 4 Median U-turn openings.

In [16], authors estimated the average Critical Gap (Tc,avg) 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. In [11] [19] 20], authors estimated the critical gap (Tc) by the expectation of the cumulative frequency distribution curve [Fc (t)] for the proportion of accepted gaps of size i, provided to all U-turning vehicles. A more precise form of Maximum Likelihood Method with a satisfactory mathematical derivation and used Log-Normal distribution for finding the critical gaps (Tc) [17] [21].

In [10], authors used some of the existing methods like HARDER, Logit, Probit, Modified Raff and Hewitt methods for estimation of critical gap at un-signalized intersections [10]. There was significant variation (12-38%) among the values which highlighted the incapability of the methods to address mixed traffic situations. Thus, they came up with an alternate procedure making use of clearing behaviour of vehicles in conjunction with gap acceptance data [10]. The "clearing behaviour" was converted to "merging behaviour" in case of U-turns at median openings in this study.

This critical review of the previous literatures instigates the need for evaluation of critical gaps for U-turning vehicles at median openings under heterogeneous traffic situations prevailing in Indian states.

III. MIXED TRAFFIC PROBLEMS IN INDIA

Estimation of critical gap under mixed or heterogeneous traffic situations is more complex than that under homogeneous traffic conditions. The different types of vehicles found in India and many other developing countries have varying operational characteristics such as speed, maneuverability, effective dimensions, power-weight ratio and response to the presence of other vehicles in the traffic stream [10]. Smaller size vehicles often squeeze through any available gap between large size vehicles and move into the influence area in haphazard manner [5] [6]. A single gap in the through traffic stream can be accepted by more than one vehicle moving parallel to each other and after crossing the conflicting traffic these vehicles move in a single file, after one another [10]. The combined effect of all these factors makes the estimation of critical gap a more challenging task. These situations require a re-look into the concept of critical gap & conflict area near median openings and method of data extraction.

IV. STUDY AREA DETAILS

The area of study can be broadly classified based on the necessity of data for analyzing “Critical Gap” and comparing the same between different modes of transport as shown in Fig 2. Two types of median openings prevail in INDIA. First one being on a typical 4-lane divided highway and the second one on a 6-lane divided street. Median openings are provided in urban areas for minimum major street flow of 500 vehicles/day having a maximum speed limit of 70-80 kmph (40 miles/hr.).

Bhubaneswar being the capital of Odisha consists of a broad network of roadways on which mixed traffic is dominant. Some of the motorized modes include 3 wheelers like four-stroke Auto-rickshaws and pick-up vans, light commercial vehicles which includes 4 wheeler tempos, variable categories of cars namely Sedans and Hatchbacks, Sports utility or Multi-utility vehicles (SUVs/ MUVs). About 4 different sections of median openings on 4-lane divided highways having 75-90 % of U-turning vehicles were selected for the study. All the sections involved with the case study for Bhubaneswar varied in their geometry. Assumptions were made regarding the geometrical variations for individual sections. Each median opening selected for the study were spaced about 600-700 feet apart from their near unsignalized intersections as per the stipulations in HCM 2010.

4.2. Data Collection Details

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, noon and afternoon 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 4 sections resulted in an average proportion of U – turning and through traffic of 70-90% and 65-85% respectively. All of these 4 sections are median openings on 4-lane divided roads. Through traffic volume comprised of all types of vehicles including HVs, LCVs excluding non-motorized vehicles and pedestrians. Classes of U-turning vehicles considered are as pointed below:

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 , 3W Pick-up vans)
4. 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 1 adopted from IRC: 86-1983 (Geometric Design Standards for Urban Roads on Plains). Fig 1 shows the distribution of U-turn flow for the 4 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 1: Passenger Car Equivalents (PCU) for Flow Calculation as per 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

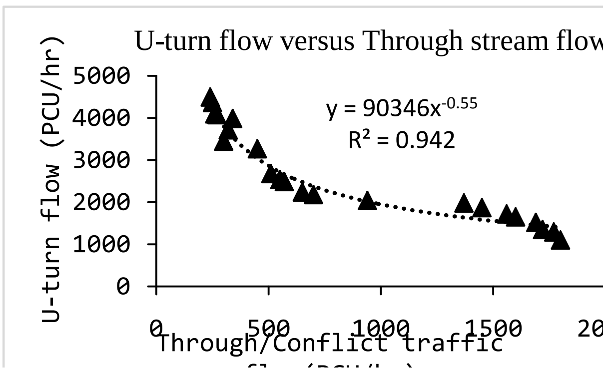


Fig 1: U-turn flow versus through traffic volume in PCU/hr.

4.3 Gap Acceptance Concept by "INAFOGA"

After video shooting of the median openings, extraction of necessary decision variables for estimation of critical gap was done as per Satish et al "INAFOGA" method. The video data collected from the field was converted to .AVI format from .MPG file type. All necessary decision variables were extracted by playing the .AVI videos in a demuxer software named as AVIDEMUX Version 2.6 capable of running videos at a frame rate of 25 frames/second. The time frames chosen for data extraction were based on the concept of "INAFOGA" as given by Satish et al in his theory of gap acceptance under mixed traffic conditions in India in 2011. Fig 3 represents the schematic diagram of a median opening on a 4-lane divided carriageway 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 m} while the breadth (W) as {a + (c/2)}. All these measurements have been experimentally proved in general for all the 4 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 "Green" line is at d/2 distance horizontally from the face of the median.

Fig 2: Pictorial representation of the Study Area

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

1. T_0 = time instant front bumper of through traffic vehicle preceding the subject vehicle touches the U/S end of INAFOGA
2. T_1 = time instant front bumper of the subject vehicle touches the stop line in b/w the median opening
3. 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"
4. T_3, T_4, T_n = corresponding time instants for arrival of through traffic vehicles on the U/S end of "INAFOGA"
5. T_w = time instant at which back bumper of the subject vehicle touches the stop line
6. T_m = time instant back bumper of the subject vehicle touches the D/S end of "INAFOGA"

V. METHODS COMPARED

A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

The time frames extracted from the raw video data were then represented in an MS-Excel spreadsheet and the following decision variables or inputs were found out to estimate the critical gaps using the existing methods as described earlier in section 4 of this paper:

1. 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
2. GAP (accepted & rejected) = difference b/w arrivals of consecutive through traffic vehicles at U/S end of "INAFOGA" = $T_{n+1} - T_n$
3. Merging Time Of U-turning Vehicle = $T_m - T_w$

5.1 Harders Method

Harders (1968) have developed a method for t_c estimation that has become rather popular in GERMANY. The method only makes use of gaps. For Harder's method, lags should not be used in the sample. The time scale is divided into intervals of constant duration, e.g. Δt = 0.5 secs. The center of each time interval i is denoted by ti. For each vehicle queuing on the minor street, we have to observe all major stream gaps that are presented to the driver and, in addition, the accepted gap. From these observations we calculate the following frequencies and relative values:

Ni = number of all gaps of size i, that are provide to minor street vehicle; Ai = number of accepted gaps of size i; ai = Ai / Ni

Now, these ai values can be plotted over ti. The curve generated by doing this has the form of a cumulative distribution function of critical gaps. It is treated as the function Fc (t). However, nobody has provided any conclusive mathematical concept that this function ai= function (ti) has real properties of Fc (t) [19, 21].

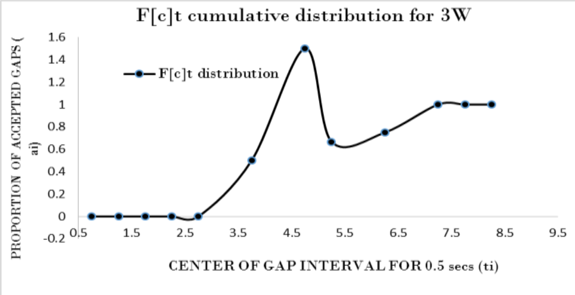


Fig 3: Critical Gap for 3W by Harders Method

Decision variables or inputs used are no. of accepted gaps along with total no. of all gaps. A cumulative distribution curve showing variation of critical gap with time is plotted between the proportions of accepted gaps (ai) {ratio of no. of accepted to total no. of all gaps} and time elapsed divided into constant durations of 0.25 seconds. Fig 3 and Fig 4 shows the F[c]t distribution of critical gaps for 3 wheelers and SUVs respectively.

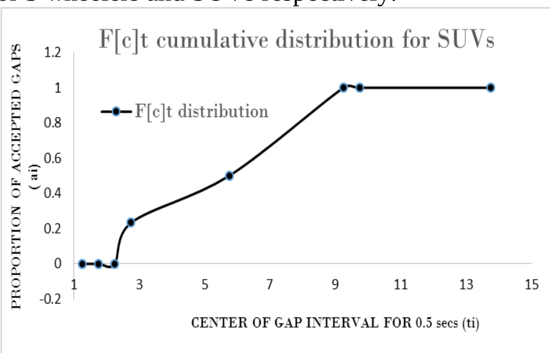


Fig 4: Critical Gap for SUVs by Harders Method

5.2 "INAFOGA" Method

In [10], author 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 INAFOGA (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. It takes into account the clearing behaviour of a vehicle (clearing time is the time taken by the minor street vehicle to clear the influence area) & gap acceptance behaviour. Following are the characteristics of "INAFOGA":

- 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.
- 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 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.

Both accepted lags and gaps are used in this method to determine critical gaps. Cumulative frequency percentages of lags and gaps are plotted against merging time expressed as frequency distribution. Fig 5 and Fig 6 predicts the critical gap of U-turning 3 wheelers and SUVs using "INAFOGA" method.

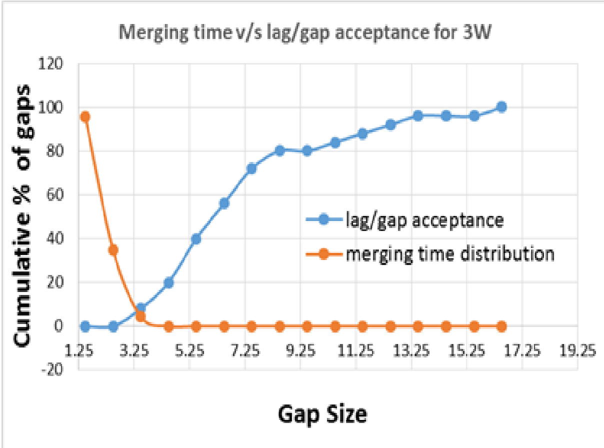


Fig 5: Critical gap by "INAFOGA" method for three wheelers (3W)

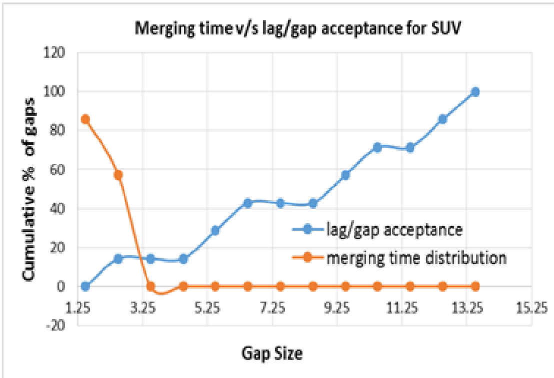


Fig 6: Critical gap by "INAFOGA"method for Sport utility vehicles (SUVs)

VI. RESULTS AND ANALYSIS

Table 2: Critical gap Values for Various Modes Estimated Using Harders Method

Median Opening Section no.	Vehicle Type	Critical Gap (secs) for U-turn vehicles by HARDERS Method
1	CAR	3.38
	2-WHEELER	3.95
	3-WHEELER	4.50
	SUVs/MUV	4.25
2	CAR	3.75
	2-WHEELER	3.25
	3-WHEELER	3.75
	SUVs/MUV	4.15
3	CAR	4.25
	2-WHEELER	3.25
	3-WHEELER	4.25
	SUVs/MUV	4.25
4	CAR	3.45
	2-WHEELER	4.15
	3-WHEELER	3.75
	SUVs/MUV	3.75

Tables 2 and Table 3 displays the critical gap values for 4 different sections of median openings on 4-lane divided roads of Bhubaneshwar. Four different categories of vehicles namely cars (4W), 2-wheelers, 3-wheelers and Sport utility vehicles have been considered in this study. Table 3 gives the critical gap values as obtained by applying “INAFOGA” method while Table 2 shows the same for Harders method. Values in parenthesis for Table 3 indicate the sample sizes and the symbol ** indicates either low or nil sample size. Cluster plots are shown to compare the critical gap values between different sections based on the values represented in tables 2 and Table 3. Referring to the cluster plots in Fig 8, for Harders method, critical gap values obtained for 2 wheelers were more than that of other modes except for section 1 where it contradicted for SUVs {2W(4.75s)<SUVs(5.75s)}. So, Harders method fail to optimize critical gap values for section 1. On the other hand, it can be concluded that Harders method is well efficient and best suited in determining critical gap values for cars (4W) and 2 wheelers respectively.

Table 3: Critical gap Values for Various Modes Estimated Using “INAFOGA” Concept

Median Opening Section No.	Mode/Vehicle Type	Critical Gap (secs) by “INAFOGA”
1	CAR	4.78(65)
	2-WHEELER	4.75(90)
	3-WHEELER	4.65(125)
	SPORTS UTILITY VEHICLES	5.15(35)
2	CAR	5.40(84)
	2-WHEELER	5.80(42)
	3-WHEELER	5.50(33)
	SPORTS UTILITY VEHICLES	5.70(20)
3	CAR	5.55(34)
	2-WHEELER	6.00(26)
	3-WHEELER	5.85(22)
	SPORTS UTILITY VEHICLES	**
4	CAR	5.15(43)
	2-WHEELER	4.75(52)
	3-WHEELER	4.80(21)
	SPORTS UTILITY VEHICLES	5.75(20)

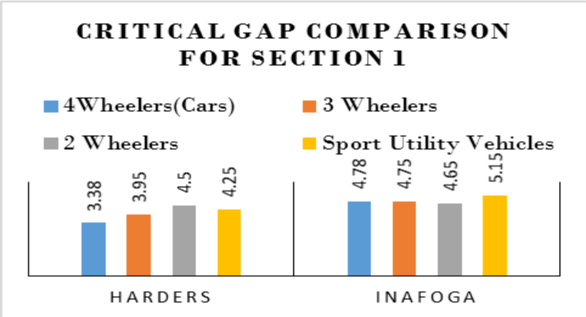
A paired sample T-test was done for the critical gap values obtained for Harders and “INAFOGA” method to find out the difference in means of the values in IBM SPSS (Statistical Package for Social Sciences) software version 22.0. The results indicated a significance value of 0.044 which was lower than ($p = 0.050$) which in turn signified that the critical gap values for the two methods can indeed be compared. After a manual calculation it was certified that the critical gap values obtained using Merging behaviour concept of U-turn vehicles inspired from Satish et al “INAFOGA” method shown in Fig 7, are found to be higher by 28-41% as compared to those obtained by Harders method which has been used normally under uniform traffic conditions. Reason being the abrupt vehicular interactions in mixed traffic conditions. This indicates that the “INAFOGA” concept is successful than Harders method in gap acceptance analysis under mixed traffic.

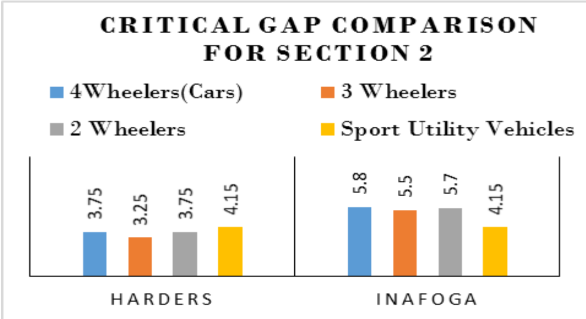
Paired Samples Statistics					
		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair	Harders	4.8163	32	.90157	.31875
	"INAFOGA"	4.031250	32	.4292331	.1517568

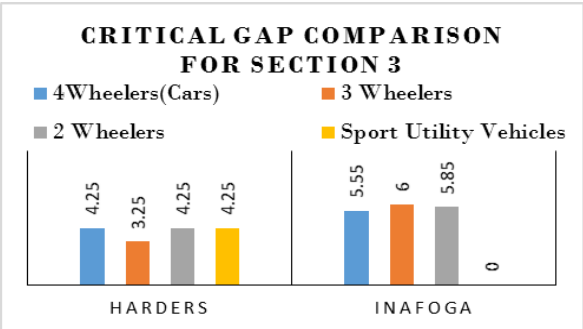
Paired Samples Correlations				
		N	**Correlation**	**Significance**
Pair	Harders & "INAFOGA"	32	.872	.005

Paired Samples Test									
		Paired Differences					**t-statistic**	**D.f**	**Sig.(2-tailed)**
		Mean	**Std. deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
					Lower	**Upper**			
Pair	Harders– "INAFOGA"	.4850000	.5676518	.2006952	.0104312	.9595688	-2.417	31	.0444

Fig 7: Statistical Details of The Paired sample T-test Between Harders & "INAFOGA" methods for Critical Gaps







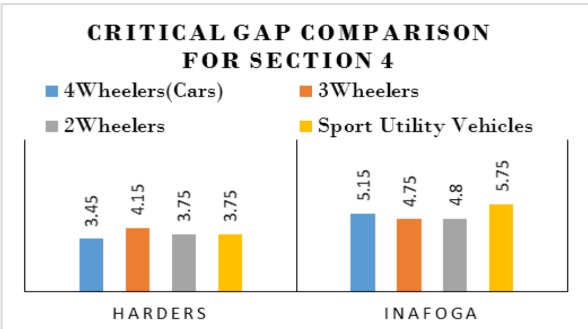


Fig 8: Cluster Plots of critical gap comparison for 4 different sections under mixed traffic conditions

VII. CONCLUSIONS

A general estimation and comparison of critical gaps between four types of motorized modes has been shown in this paper for four different median opening sections under mixed traffic conditions. Data involved video recording of median openings of Bhubaneshwar city in the state of Odisha. Two existing methods available in previous literatures were used to estimate the critical gap values. Using the "INAFOGA' concept for data extraction, estimation of critical gaps for U-turns at median openings under mixed traffic conditions have been done in this paper. The only limitation found while studying gap acceptance is the inefficiency of Harders method in predicting appropriate critical gap values under mixed traffic conditions. The reason being the use of this method by previous researchers under uniform traffic conditions only. A paired sample T-test between critical gap values for Harders and "INAFOGA" method was performed to find out the difference in means of the values. The values were found to be 28-41% lesser as compared to the values obtained using form Satish et al "INAFOGA" method. A new concept of merging time inspired from Satish et al "INAFOGA" method for U-turn vehicles at median openings is introduced in this paper. Merging time indicates the complete merging maneuver of a U-turn vehicle at a median opening. Cluster diagrams plotted gives the comparison of critical gap values for the four different modes considered in this study for all the four sections. The new concept used for finding critical gaps of U-turns has never been used previously and is simple and easy. Thus, the concept introduced for critical gap estimation for U-turns at unsignalized median openings will definitely serve as a handy tool for traffic engineers working on median openings.

REFERENCES

[1] Pavani Boddapati, "Comparative study of Type 2 Median Crossovers and median U-turns", *Technical Report, University of Missouri, Columbia, 2010.*

[2] Pan Liu, Evaluation of Operational Effects of U-turn Movements, *Technical Report, University of Florida*, 2006.

[3] Pan Liu, Jian Liu, Fengxuan Hu, "Headway Acceptance Characteristics Of U-turning Vehicles On 4-lane Divided Roadways", *86th Annual Meeting of TRB, 2007.*

[4] Pan Liu, Jian John Liu, Fengxuan Hu, Gary Sokolow, "Capacity Of U-turning Movement at Median Openings on Multi-lane Highways", *Journal of Transportation Engg. , ASCE, 134 (4), 2008, 147-154.*

[5] Turki I. Al – Suleiman Obaidat , Muhammad S. Elayan, "Gap Acceptance Behavior At U-turn Median Openings – Case study in Jordan", *Jordan Journal of Civil Engg., 7 (3) , 2013, 332-341.*

[6] Abdul Khalik Al-Taei, "Gap Acceptance and Traffic Safety Analysis on U-turn Median Openings of Arterial Roads, *Al-Rafidain Engg., 18 (6), 2010, 42-53.*

[7] P.Solberg, J.C. Oppenlander, "Lag and Gap Acceptances At Stop-controlled Intersections: Technical Paper", *Joint Highway Research Programme (JHRP), Purdue University, Purdue-e-Pubs, 1964, 1-58.*

[8] C.B.Uber, "Driver Gap Acceptance Phenomenon", *Doctoral diss., J. Transportation Engg. M.ASCE, 110 (1), 1984, 145-147.*

[9] Rui-Jun Guo, Bo-liang Lin, "Gap Acceptance at Priority Controlled Intersections", *Journal of Transportation Engg. ASCE, 137(1), 2011, 296-276.*

[10] Ashalatha R., Satish Chandra, "Critical Gap through Clearing Behavior at Un-signalized Intersections", *KSCE Journal of Civil Engineers, Springer Publications, 15(2), 2011, 413-425.*

[11] R.H.Hewitt, "Measuring Critical Gap", *Transportation Science, 17(1), 1983, 87-109.*

[12] "Highway Capacity Manual", *Transportation Research Board, Washington D.C., 2010.*

[13] Tomer Toledo, Haneen Fareh, "Alternative definition of Passing Critical Gaps", *TRR, Journal of the Transportation Research Board, 2260(09), 2011, 76-82.*

[14] City Development Plan: Bhubaneswar, *JNNURM, Government of India, Retrieved 2012.*

[15] "Preface of Comprehensive Development Plan for the Bhubaneswar-Cuttack Urban Complex", 2011.

[16] W. Brilon, R. Koenig and R.J. Troutbeck, "Useful Estimation Procedures for Critical Gaps", *Transportation Research, 33(3), 1999, 161-186.*

[17] Ashalatha R, Satish Chandra and K.Prasanth, "Critical Gap at Un-signalized Intersection Using Maximum Likelihood Technique", *Technical Paper, Indian Highways, India, 2005.*

[18] Antje Weinert, "Estimation of Critical Gaps and Follow –up Times at Rural Un-signalized Intersections in Germany", *Transportation Research Circular E-C018:*

4th International Symposium on Highway Capacity, Bochum, Germany, 2001

[19] Adrea Gavulova, "Use of Statistical Techniques for Critical Gap Estimation", *12th International Conference on "Reliability and Statistics in Transportation and Communication-2012", Riga. Liva. , 2012, 20-26.*

[20] L.Vasconceles, A.B.Silva, A.Seco and G.Rouxinol, "Estimation of Critical headways at un-signalized intersections- a microscopic approach", *Journal of Advances in Transportation Studies, 29, 2012, 59-72.*

[21] Z.Tian , Mark Vandehey , Bruce W. Robinson , Wayne Kittelson , Michael Kyte , Rod Troutbeck , Werner Brilon and Ning Wu , 'Implementing the maximum likelihood methodology to measure a driver's Critical Gap", *Transportation Research Part A , Elsevier Ltd., 33 (3-4), 1999, 187-199.*

[22] Ning Wu, 2006, "A New Model for Estimating Critical Gap and its Distribution at Un-Signalized Intersections Based on the Equilibrium of Probabilities", *5th International Symposium on Highway Capacity and Quality Of service, 2006-7, 517-526.*