

Comparative Evaluation of Statistical Methods for Critical Gap Estimation: A Case Study of U-Turns at Uncontrolled Median Openings in India

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ARTICLE INFO	ABSTRACT
	Gap acceptance and the lateral positioning of vehicles are vital factors that affect U-turn behavior at uncontrolled median openings in urban areas. Accurately determining the critical gap at these intersections is crucial for analyzing queue lengths, delays, and overall capacity, while also aiding safety assessments. The critical gap for a U-turn driver is the minimum time needed to merge into the main traffic flow. As a statistical measure, it cannot be directly observed. The maximum likelihood method is the most widely used technique for estimating this gap. This study focuses on U-turn driver behavior and estimates the critical gap using the maximum likelihood and modified Raff's methods based on data collected from four median openings in Bhubaneswar, India. Keywords: Critical Gap, Maximum Likelihood Method (MLM), Raff's method, Median opening, U-turns

1. Introduction

Understanding gap behavior is key to safety evaluation and determining the capacity of uncontrolled median openings. Capacity estimation for median opening is based on gap acceptance behavior. Determining the critical gap is crucial for determining the capacity of uncontrolled median openings. Different methods are being used to determine the critical gap, as it can't be calculated directly in the field. The Highway Capacity Manual (HCM 2016) defined critical gap as the median time headway between two successive vehicles in the major street traffic stream that is accepted by a driver in a subject movement who intends to cross or merge with the major street flow. HCM (2010) modified the definition, stating that the critical headway is the minimum time interval between the front bumpers of two successive vehicles in the major traffic stream that allows the entry of one minor street vehicle. The concept of gap acceptance behavior at an uncontrolled median opening is quite complex. Upon arrival, the U-turning driver evaluates the availability of gaps and judges whether to merge with the approaching traffic stream or to cancel the decision. Thus, based on the available gap sizes, a subject vehicle discards several gaps offered by the approaching traffic stream. As a final point, depending on the availability of an appropriate gap, the U-turning vehicle agrees to initiate the merging process. Therefore, it is a very challenging job to determine the critical gap.

Extensive research has been conducted to identify critical gaps, and numerous methods and empirical formulas have been proposed. However, the maximum likelihood method is one of the most reliable and acknowledged methods. The maximum likelihood method has been applied in various countries; however, there have been very few studies reported in mixed traffic conditions. The present study aims to estimate the critical gap of U-turns at uncontrolled median openings using the maximum likelihood method and a modified version of Raff's method, and to assess the effect of opposing traffic (approaching through) on critical gap values.

2. Literature Review

Numerous researchers have rigorously applied various methods to estimate the critical gap, each proposing distinct definitions. Notably, Weinert (2000) conducted an in-depth study on critical gaps and follow-up times using the maximum likelihood method, which was pivotal in developing comprehensive guidelines for rural unsignalized intersections in Germany. These key parameters were essential for accurately measuring the capacity of these intersections. Similarly, McGowen and Stanley (2012) leveraged the maximum likelihood

method to determine the critical gap. They further enhanced their contribution by comparing their results with a novel approach they introduced for analyzing gap acceptance behavior at two-way stop-controlled intersections. Their work underscores the importance of refining methods for better traffic management and safety.

The review of various empirical methods for estimating critical gaps conducted by Brilon et al. (1997) made a significant contribution to the field. Their extensive study encompassed simulations of both undersaturated and oversaturated traffic conditions, providing valuable insights. They concluded that the maximum likelihood method and Hewitt's method stand out as the most effective methods for estimating critical gaps. In further advancement, Tian et al. (1999) employed the maximum likelihood technique to measure drivers' critical gaps using field data. They affirmed its superiority, labeling it the most accurate method for estimating essential gaps at unsignalized intersections. Bunker (2012) made a significant step forward by introducing three innovative methods for estimating the critical gap across varying traffic volume levels: the Average Central Gap (ACG) method, the Strength-Weighted Central Gap (SWCG) method, and the Mode Central Gap (MCG) method. The robustness of these methods was rigorously assessed by comparing their estimates with those obtained from the maximum likelihood method (MLM). Bunker found that the MCG method yielded results strikingly similar to MLM, underscoring its reliability. Additionally, Guo (2010) utilized Ashworth's, Raff's, and the maximum likelihood method to calculate the critical gap, reinforcing the validity of these techniques. The author concluded that Raff's method and MLM emerged as the most trustworthy approaches for critical gap calculations, solidifying their importance in traffic studies. Gavulova (2012) argued that the maximum likelihood method is the most reliable statistical technique for accurately determining critical gaps at unsignalized intersections. Supporting this, Ibrahim and Sanik (2007) applied this method to estimate critical gap values for unsignalized T-intersections with mixed traffic flow on Malaysian roads.

Chen et al. (2013) conducted a crucial study on right-turn drivers, comparing results from maximum likelihood estimation (MLE) with their innovative logit model using real-world data. They found that their model significantly outperformed MLE in capacity estimation. Hamed et al. (1997) explored disaggregate gap-acceptance behavior at unsignalized T-intersections and revealed that factors such as driver waiting time and trip purpose heavily influence the critical gap distribution. Similarly, Liu et al. (2007) confirmed their headway study on U-turning vehicles aligned closely with the maximum likelihood method, indicating that median width affects U-turn decisions. They found critical headways of 6.4 seconds for wide medians and 6.9 seconds for narrow ones. In 2008, Martin analyzed critical gaps at 40 unsignalized intersections in the Czech Republic, demonstrating the effectiveness of the maximum likelihood method in enhancing traffic flow and safety. A comprehensive study on the critical gaps for U-turns at uncontrolled median openings utilized four distinct methodologies, gathering data from seven median openings across India (Dash et al., 2017). This research sheds light on the complex dynamics of heterogeneous traffic in India, where adherence to priority rules is frequently disregarded. The aggressive driving tactics of minor stream vehicles force major stream drivers to decelerate, creating essential gaps for safe U-turns. This compelling evidence underscores the urgent need for a deeper understanding of traffic behavior in these unique contexts, highlighting the importance of tailoring traffic management strategies to local conditions.

3. Maximum likelihood method

A comprehensive review of the existing literature identifies the maximum likelihood (ML) method as the most effective approach for estimating the critical gap, primarily due to its superior ability to yield unbiased estimates. This robust technique is based on the principle that a driver's critical gap lies between the largest gap they have rejected and the gap they have accepted. By accurately capturing this interval, the ML method provides a more realistic representation of typical driver behavior, making it an essential tool in traffic flow analysis and safety evaluation. The method assumes that driver behavior is consistent and homogeneous; therefore, observations where a rejected gap exceeds an accepted gap are excluded from the analysis. Only the accepted gap and the maximum rejected gap data are utilized. The ML method estimates the probability that an individual driver's critical gap falls between their largest rejected and accepted gaps. Troutbeck (1992) applied a lognormal distribution for this estimation, and his study offers a detailed explanation of the ML function, as originally proposed. The mathematical formulation and development of the ML technique for critical gap estimation are discussed as follows:

a_i = the logarithm of the gap accepted by the i th driver

r_i = the logarithm of the largest gap rejected by i th driver. $r_i = 0$ if no gap was rejected

μ = average of the distribution of the logarithms of the individual driver's critical gaps

σ^2 = variance of the distribution of the logarithms of the individual driver's critical gaps

$f()$ = probability distribution function for the normal distribution

$F()$ = cumulative distribution function for the normal distribution

The likelihood function L' is defined as the probability that the critical gap distribution lies between the observed distribution of the largest rejected gaps and the accepted gaps. The L of a sample of n observed U-turning drivers that their critical gap will be between the two vectors (r_i) and (a_i) is given by :

$$L' = \prod_{i=1}^n [F(a_i) - F(r_i)] \quad (1)$$

Where a_i = logarithm of the gap accepted by the i th driver,

r_i is the logarithm of the maximum gap rejected by the i th driver,

$f(t)$ and $F(t)$ = The probability density function and cumulative distribution function for the normal distribution, respectively.

The logarithm of function (1) is:

$$L = \sum_{i=1}^n [F(a_i) - F(r_i)]$$

The likelihood estimators μ and σ^2 that maximize L and the solution to the two equations:

$$\frac{dL}{d\mu} = 0 \quad (2)$$

$$\frac{dL}{d\sigma^2} = 0 \quad (3)$$

Likelihood estimators μ and σ^2 are solutions when the partial derivative of equation (2) reaches zero. They can be simplified as follows

$$\frac{dL}{d\mu} = \sum_{i=1}^n \frac{f(r_i) - f(a_i)}{F(a_i) - F(r_i)} = 0 \quad (4)$$

$$\frac{dL}{d\sigma^2} = \sum_{i=1}^n \frac{(r_i - \mu)f(r_i) - (a_i - \mu)f(a_i)}{F(a_i) - F(r_i)} = 0 \quad (5)$$

By iterating these two equations to zero, we get the value of the critical gap

$$t_c = \exp(\mu + 0.5\sigma^2) \quad (6)$$

Firstly, the mean and standard deviation of the logarithm of accepted gaps are considered as the preliminary values of μ and σ . Then the values of μ and σ are changed step by step in order to make the left functions of equations (5) and (6) zero. Finally, the values of μ and σ are determined if the error is in a small range. Equation (7) calculates and gives the value of the critical gap.

4. Study Area, Data Collection, and Extraction

Videos are collected using a video recording camera from various median openings located on 6-lane divided urban roads in Bhubaneswar city, India. The framework of the present study is presented in Fig. 1 below.

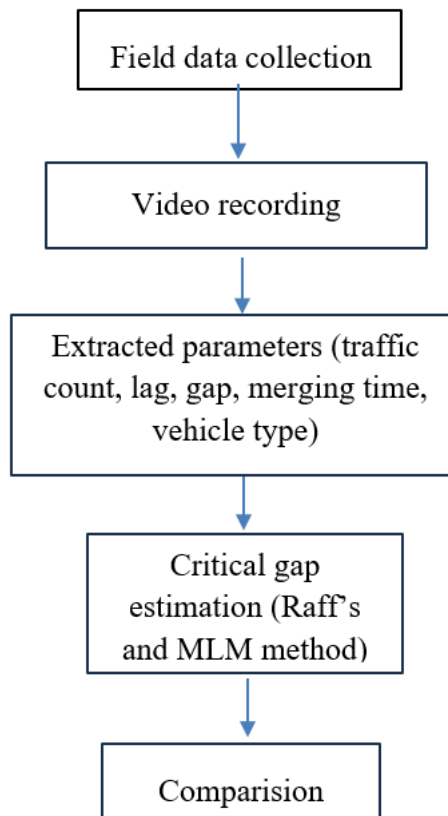


Figure 1. Framework for the Present Study

The section of the urban road stretching from Patia to Jaydev Bihar is the focus of this study. All the median openings in this particular stretch are similar in geometry, featuring three lanes on both sides of the median, and their locations are shown in Fig. 2. The traffic volume is considered from Patia towards Jaydev Bihar Junction, as illustrated in Fig. 2.

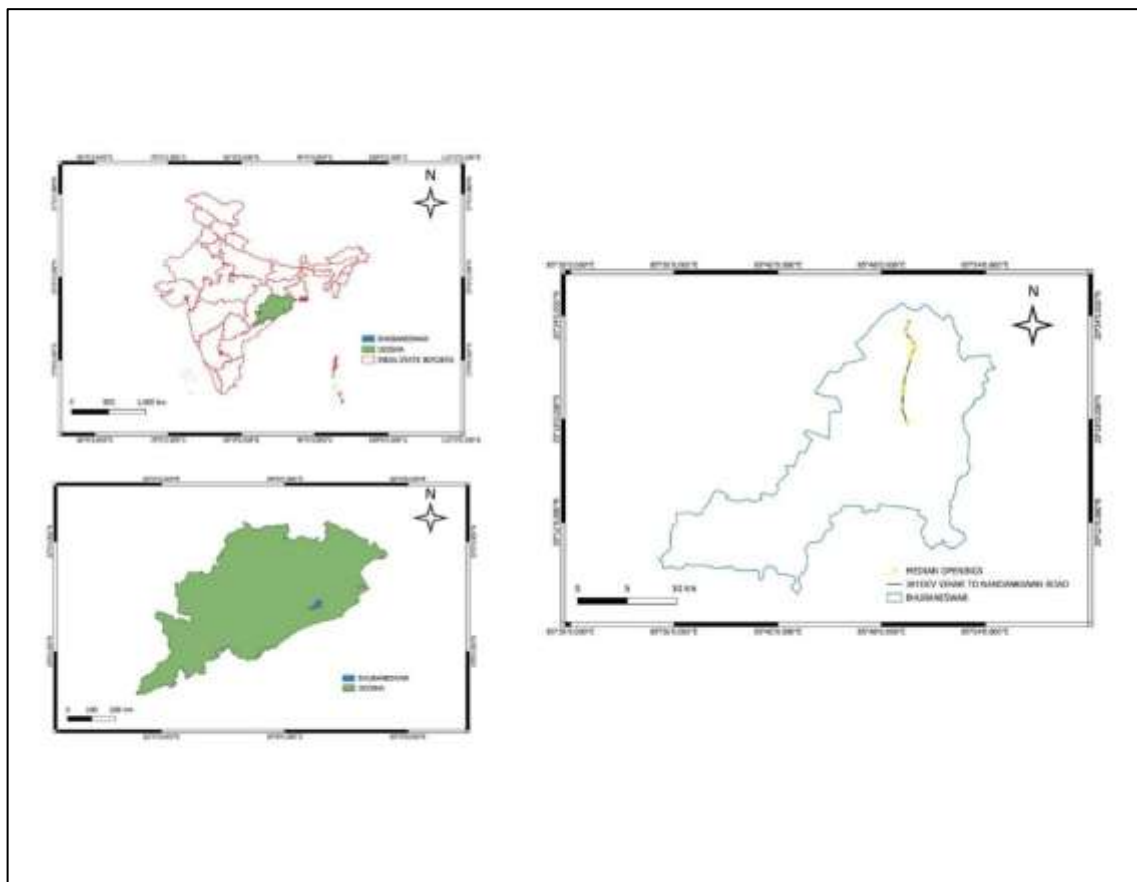


Figure 2. Spatial Layout of the Chosen Study Section

Figure 2 above shows the urban corridor from Jaydev Vihar to Patia Square in Bhubaneswar, Odisha, India, illustrating its alignment and spatial context. It clearly presents the roadway layout and locations of median openings, which form the basis for further analysis. All median openings along the divided urban corridor from Jaydev Vihar to Patia Square in Bhubaneswar were systematically mapped and documented to support traffic analysis and access management. Four major openings, identified as key junctions affecting traffic flow, are shown in Figure 3.

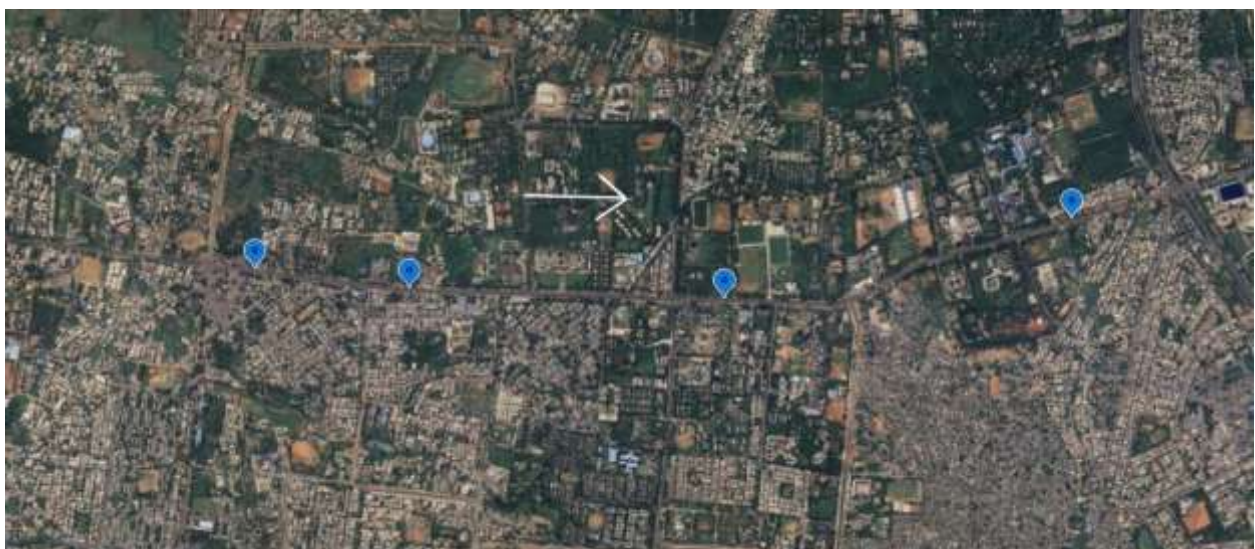


Figure 3. Different Location of Median Openings

All the median opening sites were free from any upstream and downstream junctions, pedestrian movements, bus stops, side frictions, and curvature. All the recording sites were in plain terrain, and adequate sight distances were available for each movement. Data were collected on various weekdays during both peak and off-peak hours. The snapshot of the data collection location is shown in Figure 2. The details of the traffic composition of car, two-wheeler (2-W), three-wheeler (3-W), sports utility vehicle (SUV), light commercial vehicle (LCV), and heavy vehicle (HV) at different test sections with traffic volumes are given in Table 1.

Table 1 Traffic Composition at Different Median Opening Sections

Section	U-turning Composition (in %)							Directional flow (15min)
	CAR	2-W	3-W	SUV	LCV	HV	Others	
1	16.24	52.22	22.61	3.8	2.54	0.63	1.91	942
2	11.67	64.70	73.35	3.40	1.36	0.60	1.30	882
3	6.75	80.18	10.36	1.80	.900	-	-	222
4	0.225	108	67.50	1.875	.625	-	-	160

The data presented in Table 1 indicate that 2-W vehicles have the highest road occupancy, followed by 3-W vehicles and cars. The least road-occupying vehicle types are LCV and SUV. From the preliminary analysis, it is evident that a significant number of aggressive U-turns are also executed by riders of two-wheeled vehicles.

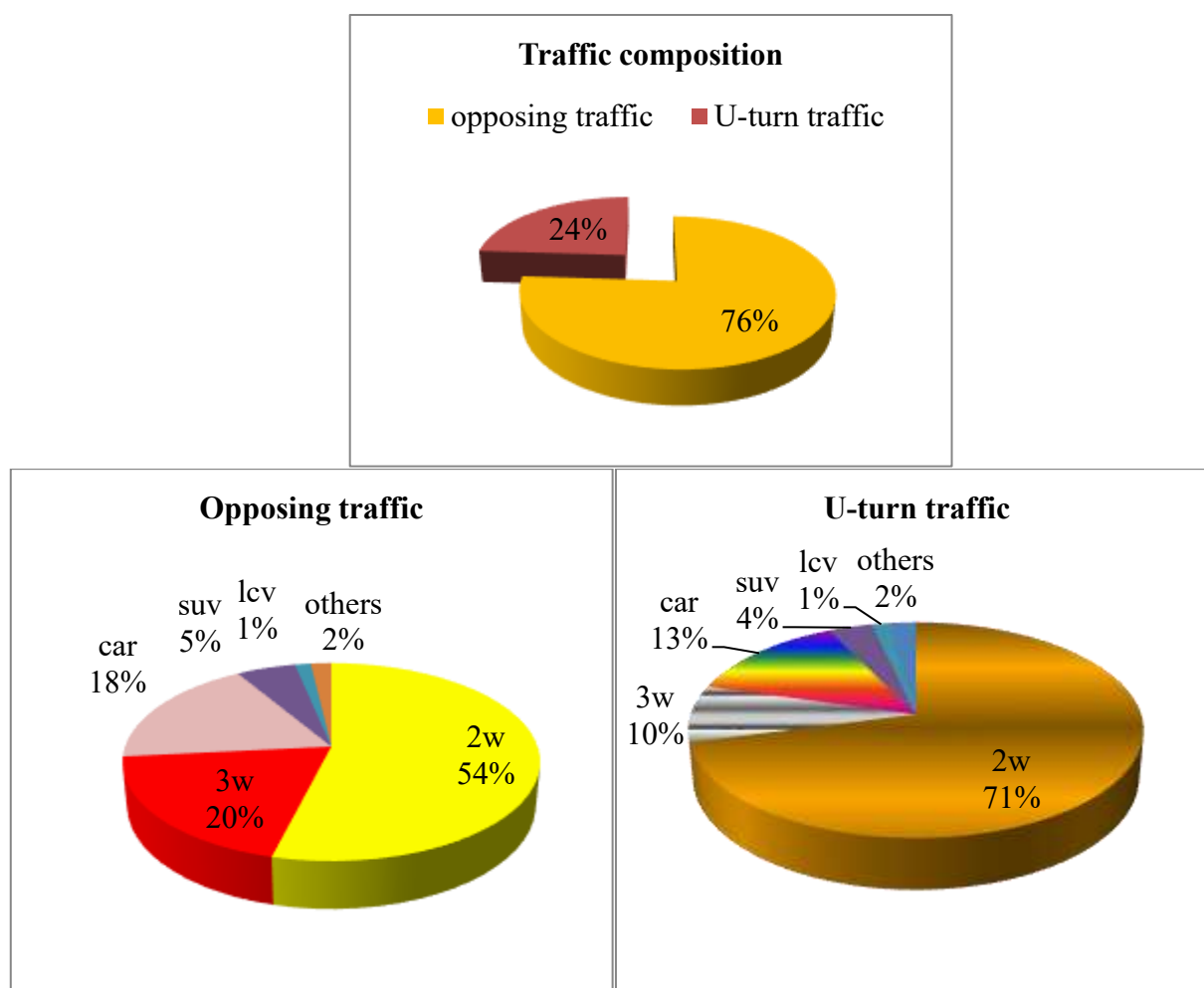


Figure 4. Composition of Traffic

The data presented above in Figure 4 reveal that U-turning vehicles represent a significant portion of traffic, with a notable 24% of all vehicles making U-turns in this particular section of the road. Furthermore, the analysis shows that opposing traffic comprises over 50% two-wheelers (2Ws), while an alarming 70% of U-turning vehicles are also two-wheelers. This trend underscores the pressing need to address the implications of U-turns and their impact on road safety and traffic flow management for median openings in Bhubaneswar.

5. Median opening

Table 2 presents the geometric characteristics of the selected median openings. Each opening maintains a uniform width of 2.4 meters, consistent with standard design practices that facilitate vehicle turning movements and safe crossing on divided carriageways. In contrast, the lengths of the openings vary slightly, ranging from 18.08 meters to 19.971 meters. These differences are likely due to site-specific factors such as roadway geometry, available median space, and the turning radius requirements for various vehicle types. Median Opening 2 has the greatest length at 19.971 meters, which may offer a larger maneuvering area and reduce potential turning conflicts. In comparison, Median Opening 4 is the shortest at 18.08 meters, likely due to geometric or spatial constraints at that location. The data suggest that while width is standardized, minor length adjustments are made to optimize operational efficiency and safety within the constraints of existing roadway geometry.

Table 2. Details of Median Opening

Location	Length (meters)	Width (meters)
Median opening 1	19.69	2.4
Median opening 2	19.971	2.4
Median opening 3	19.41	2.4
Median opening 4	18.08	2.4

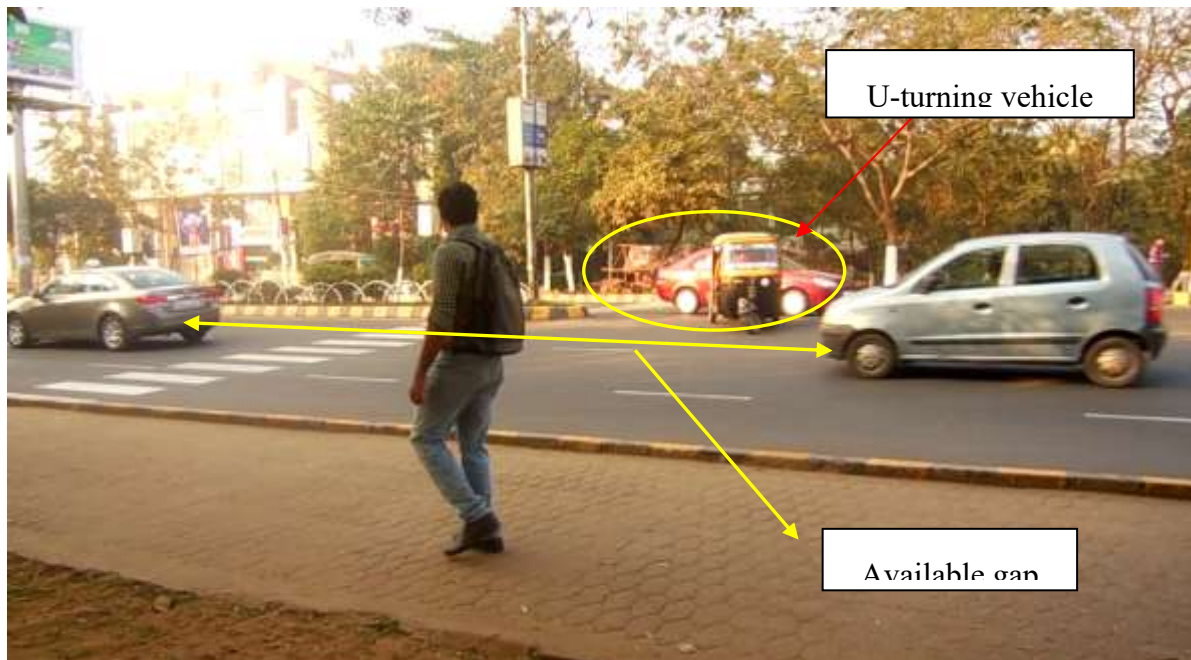


Figure 5. Data Collection Site

The histogram presented in Figure 5 illustrates the distribution of accepted gaps for young and old drivers, along with their corresponding Gaussian (normal) distribution fits. The graphical analysis reveals a distinct variation in gap acceptance behavior across the two driver age groups. The distribution for young drivers (represented in red) is concentrated within a shorter range of accepted gaps, predominantly between 1 to 3 seconds, with a pronounced peak around 2 seconds. This indicates a tendency among younger drivers to accept smaller time gaps, reflecting a relatively higher risk-taking attitude and quicker decision-making during merging or crossing maneuvers. In contrast, the distribution for older drivers (depicted in blue) exhibits a broader spread, ranging from approximately 3 to 7 seconds, with the Gaussian fit peaking at around 4.5 seconds. This rightward shift signifies a more cautious approach among older drivers, characterized by the preference for longer and safer gaps before initiating maneuvers. The comparative Gaussian fits further emphasize the difference in mean and variability between the two groups, suggesting that driver age significantly influences critical gap acceptance behavior, with older drivers demonstrating more conservative and safety-oriented decision patterns.

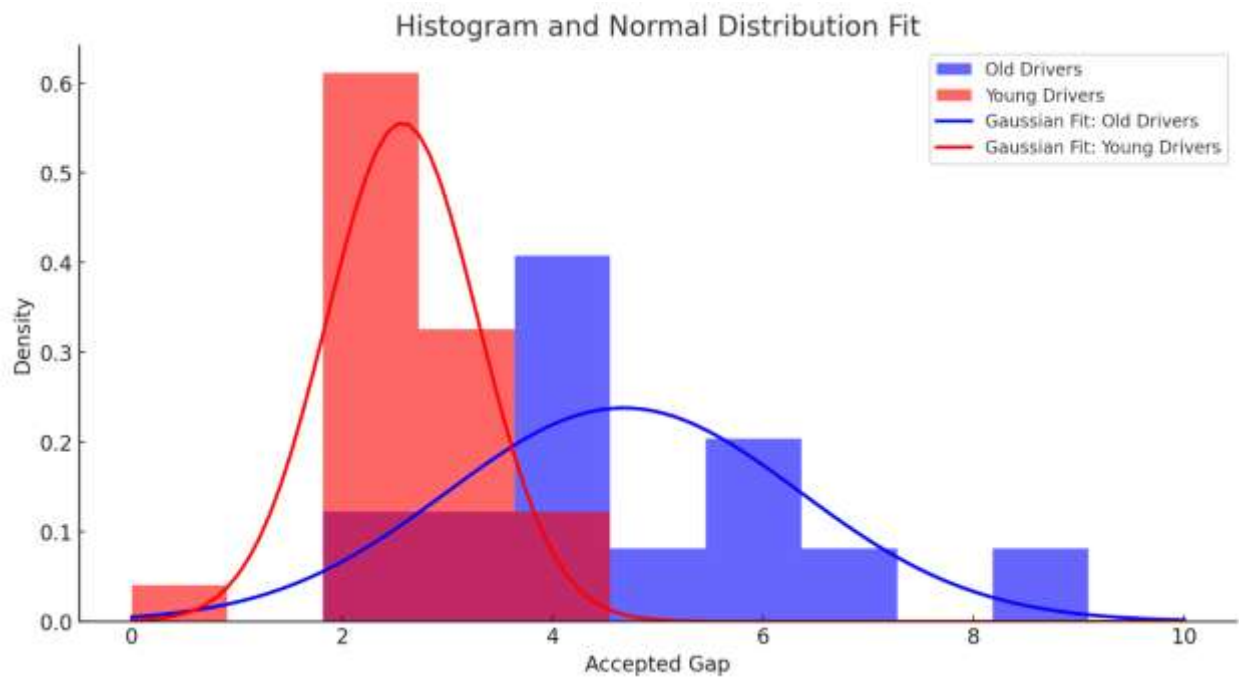


Figure 6. Fitting of Gaps

In the microscopic study, all rejected gaps and those accepted by an individual driver were noted. The step-by-step procedure for gap acceptance behavior by an individual vehicle, as marked in the image (3-W) below, is shown in Figure 7.





Figure 7. Photographic Presentations of Gap Acceptance Behavior of a Vehicle

Three types of gap acceptance behaviors are observed.

- Lag acceptance
- Rejecting the first gap and accepting the next gap
- Rejecting several gaps and accepting the suitable gap

The study was conducted to estimate the critical gaps for different categories of vehicles (2W, 3W, car, SUV, and LCV) at various approaching through traffic (opposing traffic) volumes, ranging from 1000 vph to 6000 vph. The recorded videos at different volume levels were played back using a large-screen monitor with AVIDEMUX 2.6 software. Each individual U-turn drive was rejected for gaps, and accepted gaps were noted down. The data were extracted with an accuracy of 0.033 sec (fps 30 camera frames).

5.1 Parallel U-turn

Parallel U-turn behavior is generally observed for 2-wheeled drivers when they take the shield of a larger vehicle while performing a U-turn maneuver. As the Volume of vehicles needing to make U-turns rises, the conventional median U-turn is becoming less common. In such instances, a parallel U-turn maneuver is employed. Our study highlights a notable increase in the prevalence of parallel U-turns, particularly among two-wheeler drivers.

The data in the table indicates a correlation between an increase in parallel U-turns and higher opposing Volume at median openings. Additionally, the data suggests that younger drivers (under 50 years old) are more likely to perform parallel U-turns compared to older drivers (over 50 years old).

Table 3 Data of Old and Young Drivers

Opposing through Volume	Parallel	Young driver (%age)	Old driver (%age)
1000-1500	14.63	50.00	50.00
2500-3000	45.00	55.55	44.45
3000-3500	43.07	58.92	41.07
3500-4000	49.00	63.46	36.53
4000-4500	57.45	60.00	40.00
4500-5000	61.64	66.67	33.34

The rise in parallel U-turns alongside an increase in opposing traffic volume suggests a growing impatience and aggressiveness among young drivers compared to older ones.

6. Results by Maximum Likelihood Method

According to the assumption considered by the Maximum likelihood method, the drivers are consistent and homogeneous; accordingly, drivers with a rejected gap greater than the accepted gap are discarded in the present study. For each consistent driver, the accepted and maximum rejected gap data have been considered in estimating the critical gap. Equations (5) and (6) were iterated simultaneously until the values tended to 0, and the final μ and σ^2 values were used to calculate t_c . For ease of understanding, the procedure is explained with the help of an example. The accepted gap (a) and the maximum rejected gap (r) of the consistent car drivers are presented in Table 2. The step-by-step procedure to calculate the critical gap for a car using Microsoft Office Excel is explained in Table 3.

Table 2 Accepted and Maximum Rejected Gap for Individual Car Drivers

Accepted gap in sec (a)	Rejected gap in sec (r)	Accepted gap in sec (a)	Rejected gap in sec (r)	Accepted gap in sec (a)	Rejected gap in sec (r)	Accepted gap in sec (a)	Rejected gap in sec (r)
3.84	0.00	6.07	0.00	8.31	0.00	6.24	0.00
5.51	1.47	4.71	2.40	3.94	0.00	5.84	0.00
4.24	1.44	3.84	0.67	5.81	0.00	5.68	0.00
3.07	1.70	3.84	0.67	7.70	2.90	1.44	0.00

Accepted gap (a) and maximum rejected gap (r) of different car drivers are considered for this study.

- The first two columns represent the corresponding accepted gap (a) and maximum rejected gap (r), respectively.
- The logarithm of the accepted gap (a) and the maximum rejected gap (r) are calculated as shown in columns (3) and (4), respectively.
- The mean (μ) and standard deviation (σ) of all $\ln(a)$ and $\ln(r)$ are calculated and are 0.8366 and 0.7924, respectively.
- Standard normal variable for logarithm of accepted gaps (Z_a) and rejected gaps (Z_r) are calculated separately in columns (5) and (6), respectively, as follows.

$$Z_a = \frac{(1.345 - 0.8366)}{0.7924} \text{ and } Z_r = \frac{(0.00 - 0.8366)}{0.7924}.$$

- The cumulative probability and the probability density of accepted gap (a) and rejected gap (r) are calculated and shown in columns (7) to (10).

The detailed procedure for calculating the critical gap (t_c) using the Maximum likelihood method is described step by step.

a = accepted gap by individual driver in sec

r = maximum rejected gap by individual driver in sec

$Z(a)$ = standard normal variable for the logarithm of accepted gaps

$Z(r)$ = standard normal variable for the logarithm of rejected gaps

The given steps have been followed for the estimation of the critical gap:

Step 1- The logarithms of all the accepted and highest rejected gaps are calculated and are $\ln(a)$ and $\ln(r)$, respectively, as shown in col (3) and (4) of Table 3.

Step 2- The mean (μ) and standard deviation (σ) of all $\ln(a)$ and $\ln(r)$ are calculated.

Step 2- The standard normal variable (Z_i) for all the $\ln(a)$ and $\ln(r)$ are calculated separately by using the formula as given below:

$$Z_i = \frac{(x_i - \mu)}{\sigma}. \text{ The values have been calculated as shown in columns 5 and 6 of Table 3.}$$

Step 3- Cumulative distribution and density function of $\ln(a)$ and $\ln(r)$ are calculated as shown in col(7), col(8), col(9), and col (10) respectively.

Step 4- The values of Equations (5), (6), and (7) are calculated.

The detailed procedure for estimating critical gaps for the vehicle category of cars, covering a volume range of 300-3500, is explained as follows.

- The accepted and maximum gap rejected by the category of car at a volume level of 3000-3500 vph is shown in Table 2.
- The logarithms of accepted and rejected gaps have been calculated as shown in col 3 and 4 of Table 3.
- The mean (μ) and standard deviation (σ) of the logarithms of all accepted and rejected gaps have been calculated as .8366 and .7924, respectively. For example: $Z_a = \frac{(a - 0.8366)}{0.7924}$ and $Z_r = \frac{(r - 0.8366)}{0.7924}$.
- The standard normal variables Z_a and Z_r have been calculated using the above mean and standard deviation values and are shown in col (5) and col (6) respectively.
- The Cumulative distribution and density function of all $\ln(a)$ and $\ln(r)$ have been calculated as shown in col (7), col (8), col (9), and col (10), respectively.
- The first iteration has been done by using the preliminary values of mean ($\mu = .8366$) and standard deviation ($\sigma = .7924$), and the sum of equations 5 and 6 has been calculated as 0.5377 and -52.179, respectively.

By this method, the mean=0.855 and standard deviation=0.369 are obtained when the left functions of Equations (5) and (6) tend to zero. The critical gap (t_c) value has been calculated by Equation (7).

Table 5. Critical Gap Values by the Maximum Likelihood Method

Opposing Volume Range (vph)	Critical gap (sec)			
	2w	3w	car	suv
1000-1500	1.73	2.90	2.43	-
1500-2000	2.46	2.55	2.69	2.61
2000-2500	2.04	2.46	2.78	2.04
2500-3000	1.84	1.91	2.19	2.90
3000-3500	1.94	2.12	2.51	3.00
3500-4000	2.12	1.99	2.65	2.67
4000-4500	1.98	2.23	2.46	2.63
4500-5000	1.67	1.97	2.34	2.54

6. Analysis by Modified Raff

Modified Raff does consider gaps with zero value, so 82 gaps can be sorted as shown in Table 5. In this method, the gap value depends on the range of the data values. The range of increment should be chosen by the trial-and-error method. Here, the increment value was determined by trial and error to be 0.3. The cumulative probability of the accepted gap is smaller than the upper limit of the range. For example, the cumulative probability of the accepted gap, 0.024, at the range of 2.0-2.3s refers to the probability that the accepted gap is smaller than 2.3s. In contrast, the cumulative probability of a rejected gap is the probability of a value being larger than the lower limit range. The cumulative probability of the accepted gap is smaller than the upper limit of the range. For example, the cumulative probability of the accepted gap, 0.024, at the range of 2.0-2.3s refers to the probability that the accepted gap is smaller than 2.3s. In contrast, the cumulative probability of a rejected gap is the probability larger than the lower limit of the range. The curves of the cumulative probability of acceptance and rejection are drawn as shown in Figure 3, and the intersecting point represents the critical gap, which is determined to be 2.15.

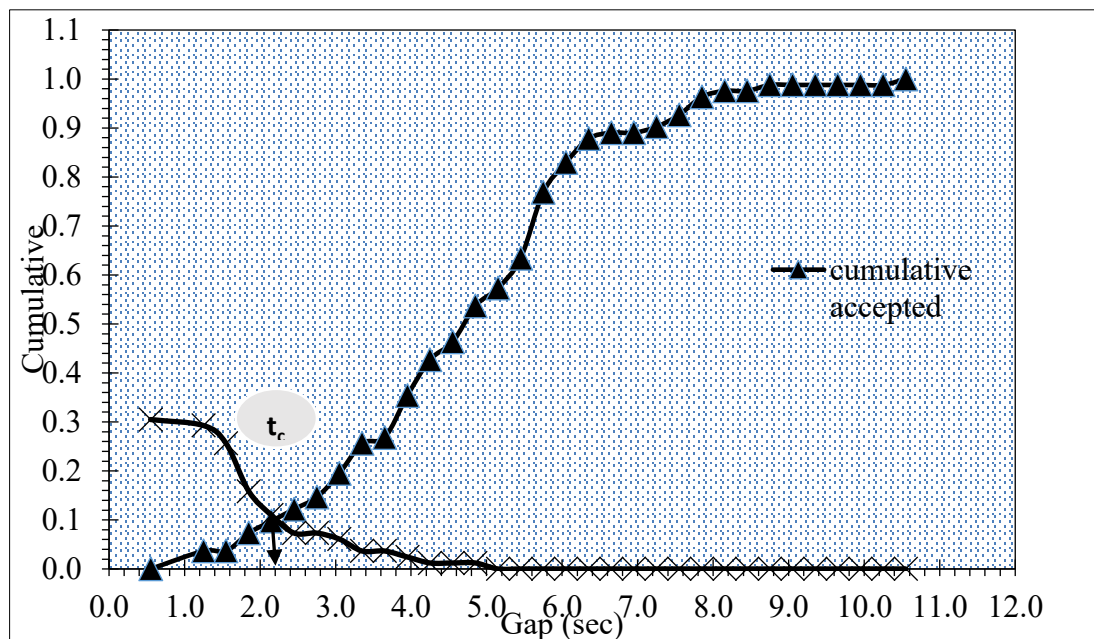


Figure 8. Raff's Method

Table 8 Critical Gap Values by Modified Raff Method

Opposing Volume (vph)	Critical gap (sec)			
Range	2w	3w	Car	SUV
1000-1500	1.50	2.90	2.40	-
1500-2000	2.80	2.40	3.00	2.40
2000-2500	1.90	2.50	2.80	1.80
2500-3000	1.75	1.70	2.30	2.90
3000-3500	1.90	1.85	2.20	3.25
3500-4000	2.00	1.70	2.25	2.50
4000-4500	1.75	2.00	2.50	2.30
4500-5000	1.60	1.75	2.50	2.25

There is a decreasing trend of the critical gap with respect to opposing through volume increase.

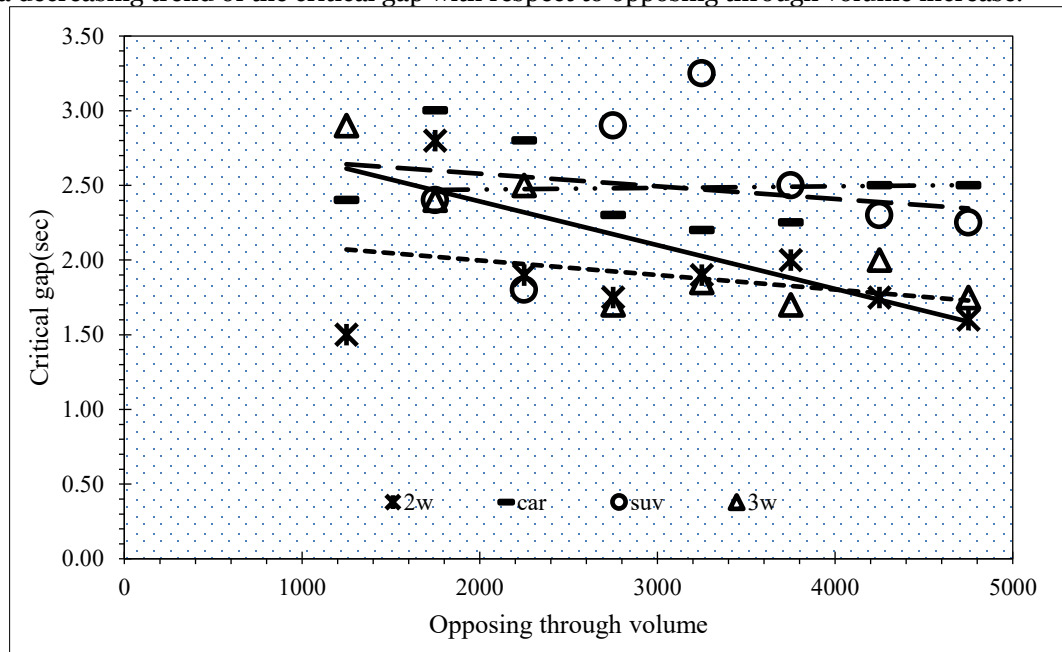


Figure 9 Effect of Opposing Traffic Volume on Critical Gap Estimated by Modified Raff Method

6.1 Effect of Opposing through Traffic on Critical Gap of U-turns

The effect of opposing through traffic (conflicting vehicles) on the critical gap of different categories of vehicles has been studied by increasing the traffic volume of opposing traffic on 4 different categories of vehicles (2W, 3W, car, and SUV). The influence of opposing through traffic volume on t_c has been studied. The relationship between drivers' critical gap and the opposing Volume has been studied in this paper. The relationship has been studied for 4 categories of vehicles (2W, 3W, car, and SUV), and the following trend has been obtained, as shown in Figure 2. It has been studied that the t_c is being influenced by opposing traffic volume. The variation in the critical gap at different traffic volumes has been observed, and the trend for different categories of vehicles (2W, 3W, SUV, and car) is shown in Figure 2. Comparing the critical gap values in the table, the critical gap value for 2W is less than that for 3W, SUV, and car. In the case of 2W, there is no trend of critical gap value with respect to volume increase. The reason behind this type of trend is that due to the small dimensions of the two-wheeler vehicle (2W), there is a tendency to accept very small gaps. In the case of a three-wheeler (3W), there is a decreasing trend of the critical gap value with an increase in the through Volume. The tendency is consistent with through traffic volume, as when the through traffic volume is low, U-turning drivers have the opportunity to reject some larger gaps since there are many available large gaps, so the critical gap increases. When a major road has high traffic volume, drivers are inclined to accept smaller gaps due to the smaller size of 3W and due to the professional driver's aggressive nature. In the case of a car, no specific trend is obtained. This is due to the fact that most car drivers are the vehicle's owners, so they are more cautious and likely to accept a large gap. Additionally, the age of car drivers varies from 22 to 65 years, resulting in a significant variability in driver behavior.

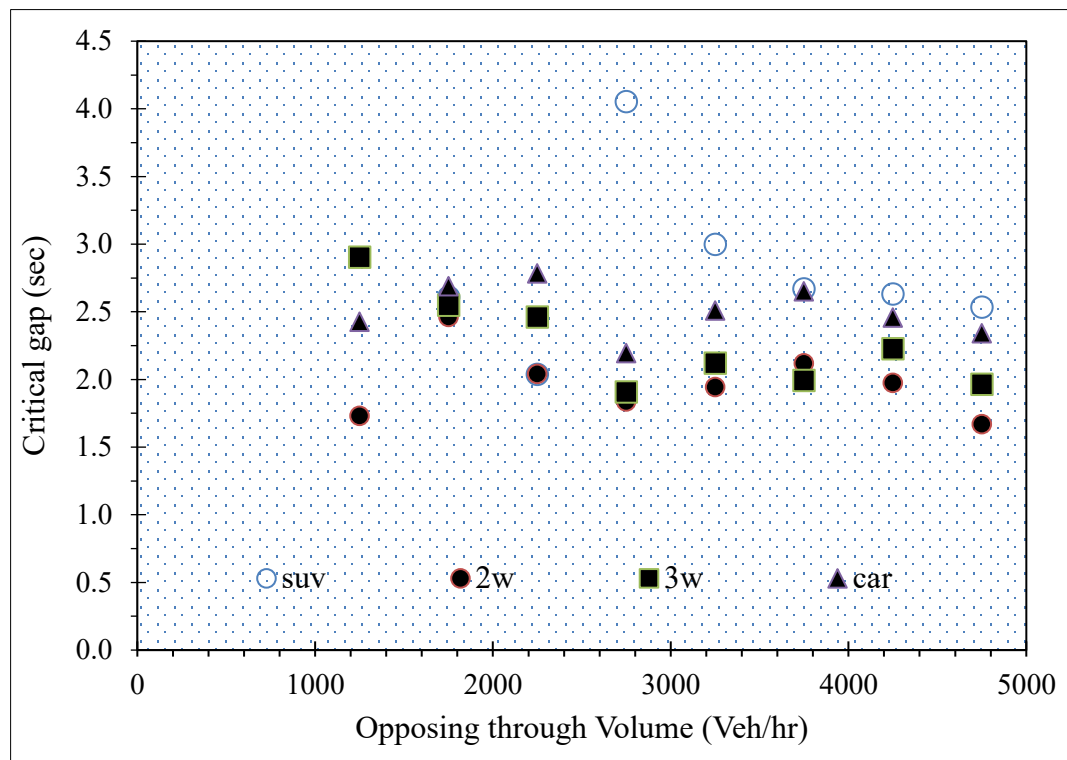


Figure 10 Effect of opposing through traffic on critical gap using the MLM method

The maximum likelihood method yielded biased results under low traffic volume, as at lower volume levels, most gap acceptance behaviors are lag acceptance cases, resulting in a zero rejected gap. Therefore, the maximum likelihood method gives biased results. Vasconcelos et al. (2013) reported obtaining biased results under lower traffic volumes. It gave lower results compared to other methods (ref 12). It gave similar results to the modified Raff method. Bunker J. (2012) has also reported getting fluctuating results at very low traffic volume (ref 11). Chancey et al. reported changes in the critical gap for right-turning drivers as they varied the opposing traffic volume, and the results are as follows. Per this data, minor street volume plays a larger role in affecting the critical gap acceptance than major street volume.

7. Comparison and Conclusion

Both the maximum likelihood and the modified Raff method are reliable for calculating the critical gap of a conflicting stream. Both use all accepted and rejected gaps of the driver in spite of the major flow condition and recording time. One necessary condition for the maximum likelihood method is that for reliable calculation, it requires a large no of input data. The variation in critical gap at different traffic volumes has been observed, and the trend for different categories of vehicles (2W, 3W, and car) is shown in Figure 5. Comparing the critical gap values in the table, the critical gap value of 2W is less than that of 3W and the car. In the case of 2W, there is no trend of critical gap value with respect to volume increase. The reason behind this type of trend is that due to the small dimensions of the two-wheeler vehicle (2W), there is a tendency to accept very small gaps. In the case of a three-wheeler (3W), there is a decreasing trend of the critical gap value with an increase in the through Volume. The tendency is consistent with through traffic volume, as when the through traffic volume is low, U-turning drivers have the opportunity to reject some larger gaps since there are many available large gaps, so the critical gap increases. When a major road has high traffic volume, drivers are inclined to accept smaller gaps due to the smaller size of 3W and due to the professional driver's aggressive nature. In the case of a car, no specific trend is obtained. As in the case of SUV drivers, a similar trend was obtained, but the decreasing trend is more pronounced in the case of 3w as compared to SUV. This is due to the fact that most car drivers are the vehicle's owners, so they are more cautious and likely to accept a large gap. Additionally, the age of car drivers varies from 22 to 65 years, resulting in a significant variability in driver behavior. There is a decreasing trend in the critical gap as the volume increases. Guo et al. in their study found that the critical gaps obtained by the M3 definition, Ashworth's method, Raff's method, and Revised Raff's method exhibit a trend of decrease with an increase in flow rate. (Ref 8) They varied the flow rate from 0.05 to 0.45 vehicles/sec (180 vehicles/hour to 1,620 vehicles/hour). In our study, we varied the opposing traffic Volume from 1000 to 5000 vehicles per hour (.347 to 1.319 vehicles/sec). They have varied the flow up to 1600 vph only, but we have taken a wide range of variation from 1000 to 5000 vph. Although the decreasing trend we obtained is not as steep a decrease as Guo et al have obtained in their study. The maximum likelihood method and Raff's method give

similar values for heterogeneous traffic conditions, as both methods consider the same input values, such as maximum rejected gap and accepted gap, for estimation purposes.

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