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A Dissertation Project Report on

"CAPACITY EVALUATION OF INTERSECTION UNDER MIXED TRAFFIC CONDITION"

Submitted in partial fulfillment for the award of the degree of

BACHELOR OF ENGINEERING IN

CIVIL ENGINEERING

BY

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Certificate

*This is to certify that the project work entitled **"CAPACITY EVALUATION OF INTERSECTION UNDER MIXED TRAFFIC CONDITION"** has been successfully completed by Mr.* SOUGAIJAM HARISH SINGH (USN 1CR15CV084 , Mr. ABHISHEK RAJ (USN 1CR15CV005), Mr. AMOGH J KASTHURIRANGAN (USN 1CR16CV005),Mr. ROMAAN NABI (USN 1CR17CV417)*, bonafide students of CMR Institute of technology in partial fulfillment of the requirement for the award of degree of Bachelor of Engineering in Civil Engineering of the **"VISVESVARYA TECHNOLOGICAL UNIVERSITY",** Belgaum during the academic year 2019-20. It is certified that all corrections indicated for internal assessment has been incorporated in the Report. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said Degree.*

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DECLARATION

We, Mr. SOUGAIJAM HARISH SINGH, Mr. ABHISHEK RAJ ,Mr. AMOGH J KASTHURIRANGAN ,Mr. ROMAAN NABI, bonafide students of CMR Institute of Technology, Bangalore, hereby declare that dissertation entitled **"CAPACITY EVALUATION OF INTERSECTION UNDER MIXED TRAFFIC CONDITION"** has been carried out by us under the guidance of **Dr. Asha M Nair (HOD), Dr. Nipa Chanda (Assistant Professor)**, Department of Civil Engineering, CMR Institute of Technology, Bangalore, in partial fulfillment of the requirement for the award of degree of Bachelor of Engineering in **Civil Engineering** of the Visvesvaraya Technological University, Belgaum during the academic year 2019-2020. The work done in this dissertation report is original and it has not been submitted for any other degree in any university.

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ABSTRACT

Critical gap is an engineering concept generally used for determination of capacity of individual movements at unsignalised intersections. Majority of studies on critical gap estimation are reported from homogeneous traffic conditions where lane discipline and the rule of priority are truly respected. Vehicular interactions and drivers' behavior at unsignalised intersections under mixed traffic are very complex.

The drivers on a minor approach at an unsignalized intersection intending to maneuver are usually at risk because of difficulties in judging if valuable gaps are safe or not any misjudgment may result in collision with major stream vehicles. Drivers should be clear about rejecting small gaps and accepting large gaps but experience dilemmas due to range of gaps. Drivers' inattention, human error and aggressive behavior are often linked with vehicle crashes.

It has been reported in past studies that drivers in india are more aggressive and often accept very small gaps creating dangerous situations. Drivers's behaviour intending to cross a major street is modeled as binary decision, i.e to accept or reject a gap. Most of the intersections in a city are not signalized because of low traffic volume on some approaches and the cost of installing signals.

This paper is related to similar kind of unsignalized intersections which is controlled Manually .This research studies how major road drivers respond to the aggressive maneuvering of the minor road drivers at unsignalized intersections. The study was also designed to investigate the effect of distracted driving (engaged on handheld phone) on driving performance. The major road driver behavior is evaluated with reference to three variables: response time before possible conflict (RTPC). Average speed while approaching intersection and at the intersection, and deceleration rate.

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CHAPTER 1

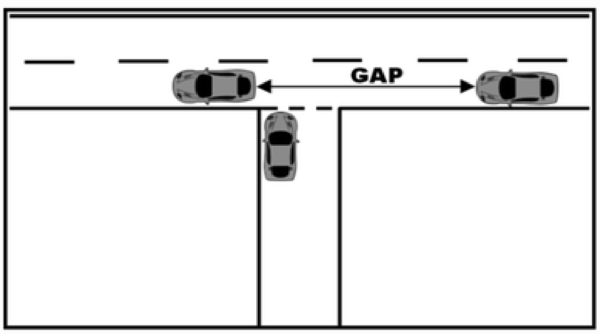
INTRODUCTION

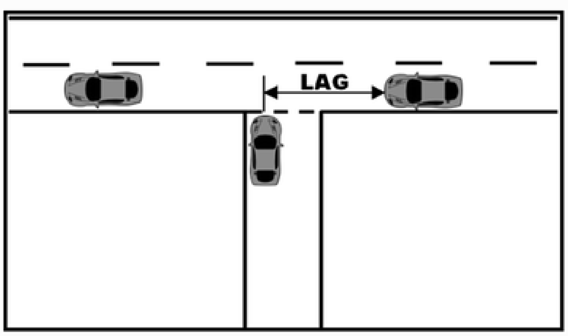
Intersections can be broadly classified into two categories based on traffic control measures signalized intersections (intersections controlled by traffic signals) and unsignalized intersections; they are again classified into (a) uncontrolled intersections, (b) stop sign controlled intersections, (c) yield sign controlled intersection and (d) roundabout. In India, the majority of intersections are uncontrolled. The stop signs are observed at the minor approaches in some intersections. But, in many cases, drivers do not stop or slow down and yield the right of way to the major road traffic. As a result, the major road vehicles are bound to slow down or sometimes even stop to avoid a collision. In these non-standard circumstances, movements at these types of intersections are uncontrolled, so these forms of intersections are also considered as uncontrolled intersections in India.

Gap acceptance is usually considered at junctions where a minor street intersects a major street. If a minor street vehicle has just arrived at the junction, it may clear the intersection while rolling; otherwise, it starts the movement from rest. Drivers intending to perform simple crossing or merging maneuvers are presented with a lag and a series of gaps between vehicles in a conflicting traffic movement. The pattern of arrivals of the major street vehicles creates time gaps of different values.

A gap (Fig. 1) between two vehicles is the distance between the rear bumper of the first vehicle and the front bumper of the following vehicle and is usually measured in seconds. Lag (Fig. 2) is defined as the time interval between the arrivals of vehicles at a stop line of minor road and the arrival of the first vehicle at the upstream side of the conflict zone. An important parameter related to gap acceptance behavior is the ‘critical gap’ which is the minimum acceptable gap to a driver intending to cross a conflicting stream. In this study, the definition used for the critical gap is the gap size that is equally likely to be accepted or rejected by the driver. In other words, the gap duration corresponding to the 50th percentile of the gap acceptance probability distribution is considered as critical gap.

Fig. 1 **Fig. 2**





Schematic diagram of gap Schematic diagram of lag

Critical gap estimation becomes complex in heterogeneous traffic condition. Traffic characteristics under mixed traffic situation vary widely regarding speed, maneuverability, effective dimensions and response to the presence of other vehicles in the traffic stream. Vehicles such as two-wheelers often squeeze through the minimum possible gap and try to clear the intersection in a zigzag manner. A single gap in the major traffic stream may be accepted by more than one vehicle moving one after another even though it is not large enough to let more than one vehicle to clear the intersection. As a result, the major road vehicles are sometimes forced to stop to let the minor road vehicles to clear the intersection. The combined effect of all these issues makes it tough to estimate the critical gap. These situations necessitate a re-look into the factors that influence the gap acceptance behavior at uncontrolled intersections where priority rules are often neglected.

This study is focused on developing logistic regression models suitable for uncontrolled intersections in developing countries like India. The response variable is the gap acceptance or rejection of a right turning vehicle from a minor road (left-hand drive rule followed in India), and the independent variables considered are gap duration, type of interval accepted by the minor street vehicle's driver (gap or lag), forced entry of the minor street vehicles and clearing time (CT). Additionally, the values of the critical gap are estimated using clearing behavior approach and compared with those obtained by logit model.

1.1 CLASSIFICATION OF TRAFFIC CONTROL SIGNALS

Traffic controlled signals are provided with three coloured light glows facing each direction of traffic flow:

Red light indicates STOP; Yellow amber light indicates clearance time for the vehicles which have entered the intersection area, Green light indicates GO.

Traffic Control Signals are classified into the following three types – Fixed time signals, traffic actuated signals, manually operated signals.

Pedestrian Signals:

When vehicular traffic remains stopped by red signal on the traffic signals of the road intersection, these signals give the right way of pedestrians to cross a road during during the walk period.

Special Signals/Flashing Beacons:

These are used to warn the traffic. When there is a red a red flashing signal, the drivers of vehicles must stop before entering the nearest cross walk at the intersection or at the stop line where it is marked. Flashing of yellow signals are used to direct the drivers of the vehicular traffic to proceed with caution.

Fixed Time Signals:

These signals are set to repeat regularly a cycle of red, amber yellow and green lights. Depending upon the traffic intensities, the timings of each phase of the cycle is predetermined. Fixed time signals are the simplest type of automatic traffic signals which are electrically operated.

Traffic Actuated Signals:

In these signals the timings of phase and cycle are changed according to traffic demand.In Semi-actuated signals, the normal green phase of a traffic stream may be extended upto a certain period of time for allowing the vehicles to clear off the intersection.

In fully-actuated signals, computers assign the right of way for the traffic movement on turn basis of traffic flow demand.

Manually Operated Signals:

In these types of signals, the traffic police watches the traffic demand from a suitable point during the peak hours at the intersection and varies the timings of these phases and cycle accordingly.

1.2 STUDIES IN 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 .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 ."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.

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). 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. 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 ,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.

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 LogNormal distribution for finding the critical gaps (Tc) .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. 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. 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.

MIXED TRAFFIC PROBLEMS IN INDIA: 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 .Smaller size vehicles often squeeze through any available gap between large size vehicles and move into the influence area in haphazard manner. 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. 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

1.3 OBJECTIVES FOR THE STUDY

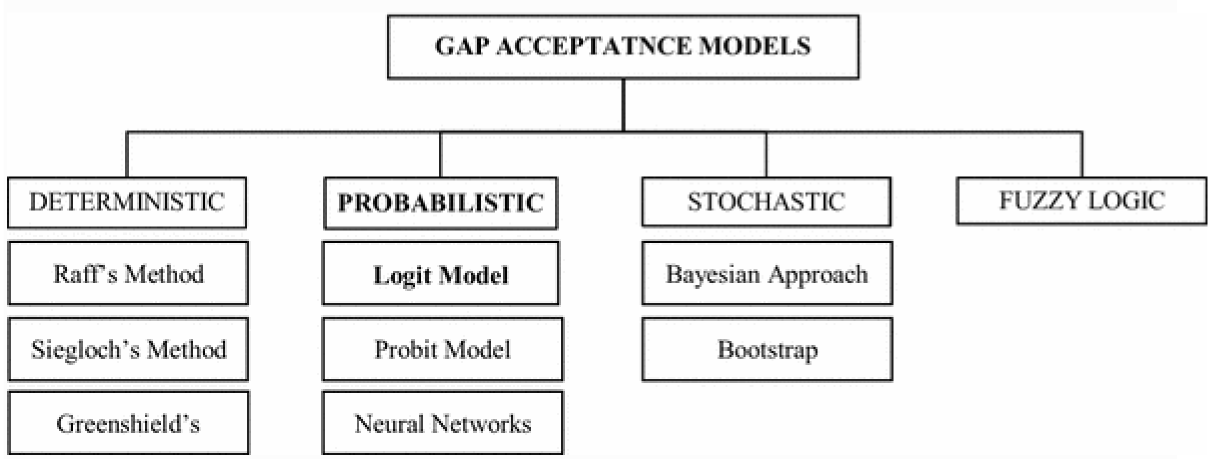
- ❖ To analyse the intersection by doing survey.
- ❖ To analyse the gap acceptance of vehicles.
- ❖ Investigate the traffic performance at unsignalized intersection under mixed traffic conditions, e.g speed, flow and intersection occupancy.
- ❖ Investigate parameters that can be used to describe maximum flow(capacity).
- ❖ Developed new procedure of capacity measurement which can be taken into account for mixed traffic flow at unsignalized based conflicted streams.
- ❖ Look on suitability of the method to measure the capacity compared to other methods that have been widely used

CHAPTER 2

LITERATURE SURVEY

2.1 GAP ACCEPTANCE MODELS

Several methods have been developed by researchers during the past decades on gap acceptance and most of these methods assumed the drivers to be consistent. Moreover, those studies have been done under homogeneous traffic conditions. Various methodologies that have been developed so far can be broadly classified as shown in Fig below. A brief literature review of the past relevant studies is presented in the subsequent paragraphs. The review is grouped into studies focussing on probabilistic approach, and analysis conducted under mixed traffic condition.



2.2 BACKGROUND

Maneuvering in unsignalized intersection involves some risks. Gap acceptance

behaviour plays a critical role and maneuvering through such intersection safely. Many studies have been conducted to understand drivers and pedestrians gap decisions and the impact of various parameters (characteristics of drivers and pedestrians, gap size, geometry, traffic characteristics weather conditions etc)
The main intention of researchers was to understand the drivers gap acceptance behaviour in order to evaluate the highway capacity and to understand its effect on highway design policy
Most of the research focuses on finding the critical gap-the minimum gap size acceptable per population of drivers (Daganzo 1981., Mahmaassani & sheffi 1981., Hamed Ct Al 1997., Gattis & Law 1999., Guo & Lin 2011., Patel& Pawar 2014., Brilon Et Al 1999) Gap and overview of different approach for estimating of critical gap value. Different methods are well described for both saturated as well as unsaturated traffic flow conditions
For saturated conditions, the seigloch method is presented, and for unsaturated, the gap cumulative method, lag method , Ashworth method, Harder method, Logit procedures, probit procedures ,Hewitt method, and maximum likelihood methods are presented.

Although the critical gap has been defined primarily in the context of highway capacity estimation, it has also been used for some highway safety consideration. Preston Et Al (2004) stated that poor rejection of unsafe gap in traffic has resulted in crash rate on role express intersection .Further investigations also reveal that drivers inability to recognise the intersection and therefore running at the stop sign was the reason for only small fraction of right angle passage. Recently Pawar Et Al (2016) analysed it and quantified the Dilemma zone for crossing pedestrians at high speed uncontrolled mid-block crossing using an empirical approach .At a signalised intersection paragraph one of the many reasons considered in defining the cost of accidents is the drivers confusion about what action to take when the signal is changed from green to yellow. Drivers who are unable to see before the stop light and unable to cross the intersection before the end of yellow time are in confusion or Dilemma. Gazqs Et Al (1960) first proposed the concept of dilemma zone poor signalised intersection by studying the drivers decision making process in response to the yellow light page, and distribution of dilemma zone was formulated by the Gazis Herman Maradubin (GHM) model.

The dilemma zone for signalised intersection is modulated using different approach, one of them is probabilistic approach based on the probability of the drivers decision to stop in response to the yellow indication. Zegeer (1977) defined the dilemma zone as the road signal were more than 10% and less than 90% of the drivers would choose to stop. In this study the authors are following similar concept for defining the dilemma zone at unsignalized intersection. The authors did not find any study on drivers dilemma at unsignalized intersection, this is the focus on current paper. The authors believed such study will help to improve the safety of minor road vehicles

2.3 Gap events and Dilemma zone

Dilemma zones analysis is the present study base on the concept of gap acceptance. A gap is a time and space separating two consecutive vehicles on major road approaching the intersection. The lack is the time and space separating a vehicle on a minor road from the first vehicle (the conflicting vehicle) approaching from the right of the minor road vehicles. Gap or lack can be expressed either a distance or time. As per Pawar and Patel references (2014) critical gap as defined in many studies is a minimum gap that the driver accepts while crossing., as per this definition, drivers accept all gaps greater than the critical gap and reject all gaps lower than the critical gap. However the actual behaviour observers is different and clearly shows that there are some drivers who accepts gaps that or slower than critical gap and reject that greater large than critical gap. Drivers are clear about rejecting small gaps and accepting large gap. The dilemma zone can be expressed with respect to either time or distance. In this study the author have study distance dilemma. Thus the authors defined the dilemma zone as a major road way signal or which if a vehicle is present with a certain speed the dilemma is created for minor road vehicles regarding the maneuring. When a conflicting vehicle is in this zone minor road vehicles may make a incorrect decision and such unsafe behaviour may need to crashes at other intersection. This observation lays to the evaluation the upper limit of accepted and rejected gaps.

CHAPTER 3

METHODS USED

3.1 METHODS TO BE USED

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.

HARDERS METHOD

Harders (1968) have developed a method for 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. $\Delta t = 0.5$ 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. 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.

INAFOGA METHOD

INAFOGA (Influence Area for Gap Acceptance) which has 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.

3.2 METHODOLOGY

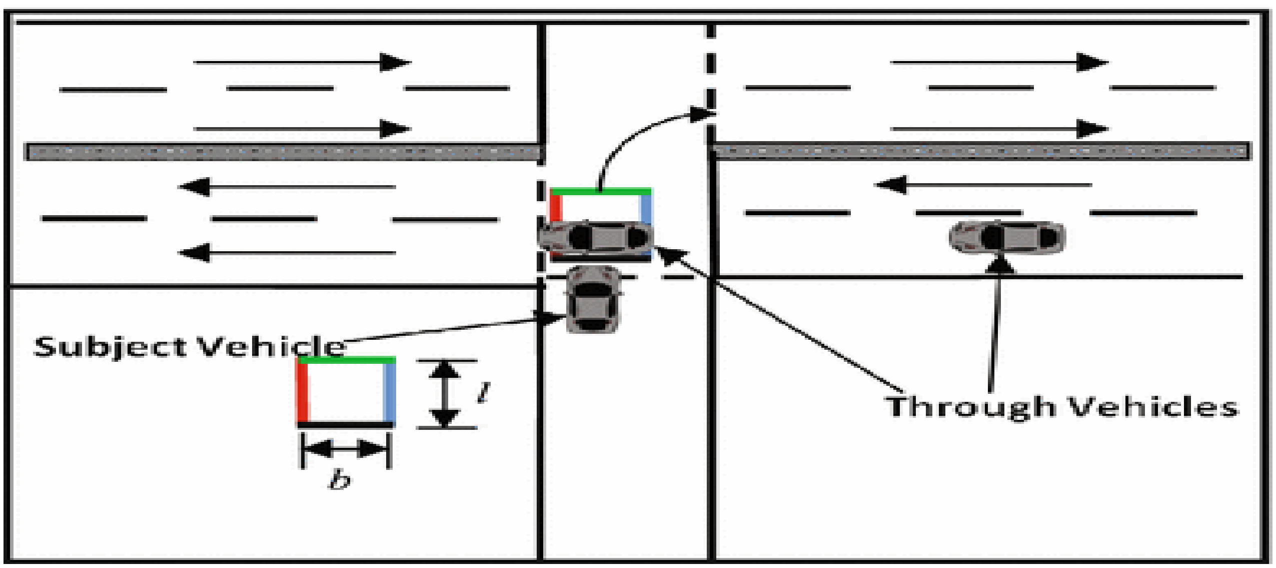
The following brief methodology is proposed for the experimental study:

- Video graphic survey will be carried out for data collection.
- Video recording will be done during peak hours (10:00 am–12:00 noon).
- The video camera will be so placed that all movements of the vehicles could be recorded.

- The available modes at those intersections were two-wheelers, auto rickshaws, and four-wheelers.

- After the video shooting of the uncontrolled T-intersections, extraction of relevant decision variables were carried out based on the concept of 'INAFOGA' as given by Ashalatha and Chandra in their theory of gap acceptance under mixed traffic conditions in India.

- The figure shown below represents the schematic diagram of an uncontrolled T-intersection on a 4-lane divided carriageway representing the 'INAFOGA' method.



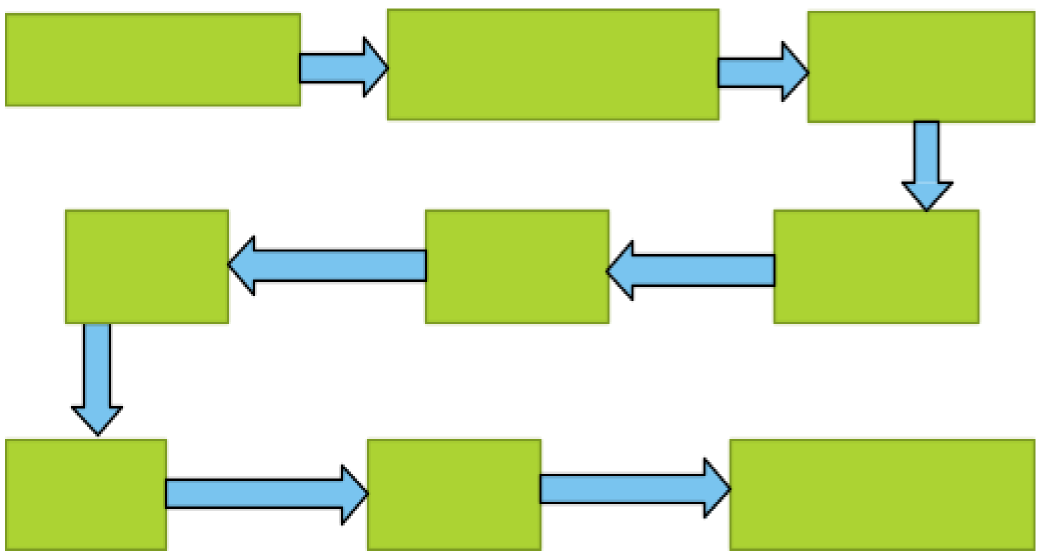
- The INAFOGA of a right turning vehicle is the rectangular area bounded by the red, green, blue and black lines. The black line represents the stop line of the minor road vehicle while the blue and red lines form the upstream and downstream ends of 'INAFOGA'.

- The length (*l*) of the area measures 3.5 m (lane width), while the breadth (*b*) is almost 1.5 times the width of the crossing vehicles.

- Data are extracted from the video, and a set of observations have been recorded for all the selected study area.

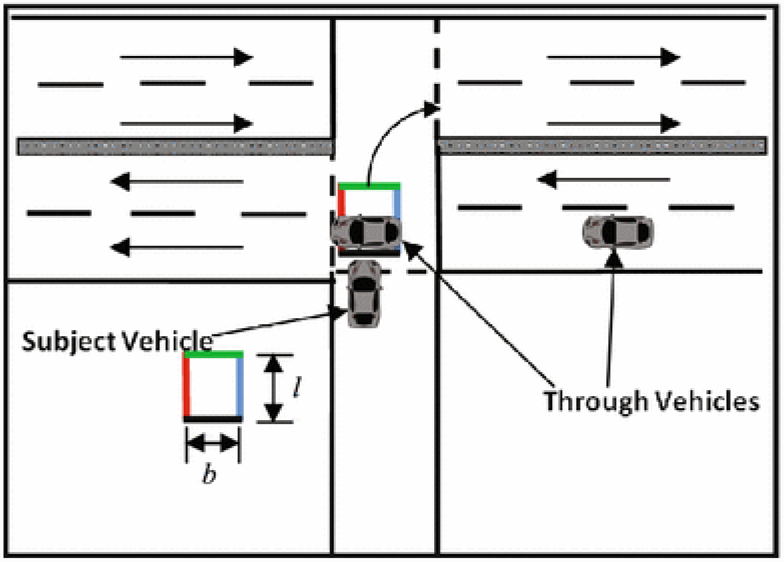
- Out of these, the accepted gap/lag data are used to understand the aggressive behaviour of the minor street drivers and a statistical summary is presented in Table 1.

Fig 3.1 Flowchart showing the methodology of the project



The figure shown below represents the schematic diagram of an uncontrolled T-intersection on a 4-lane divided carriageway representing the 'INAFOGA' method (Fig. 8). The INAFOGA of a right turning vehicle is the rectangular area bounded by the red, green, blue and black lines. The black line represents the stop line of the minor road vehicle while the blue and red lines form the upstream and downstream ends of 'INAFOGA'. The length (*l*) of the area measures 3.5 m (lane width), while the breadth (*b*) is almost 1.5 times the width of the crossing vehicles.

Fig. 8



Schematic representation of INAFOGA for minor road right turn movement
The time frames chosen during data extraction are as follows:

1. (a) T_0: the time instant when the front bumper of the subject vehicle touches the black line of the INAFOGA.

2. (b)T_1: the time instant when the front bumper of the first through traffic vehicle after the arrival of the subject vehicle touches the upstream end of INAFOGA (blue line).

3. (c) T_n: the time instant when the back bumper of the nth through traffic vehicle after the arrival of the subject vehicle touches the upstream end of the INAFOGA.

4. (d)T_{n+1}: the time instant when the front bumper of the $(n + 1)$th through traffic vehicle after the arrival of the subject vehicle reaches the upstream end of INAFOGA.

5. (e)T_p: the time instant when the back bumper of the subject vehicle touches the green line of the INAFOGA.

The time frames extracted from survey video were then compiled and entered into an MS Excel spreadsheet and the following decision variables were calculated:

1. (a)Gap/lag: $G = T_{n+1} - T_n (n = 0,1,2,...)$. When $n = 0$, $G = T_1 - T_0$ is the lag; when $n = 1,2,3....$, G is the gap.

2. (b)Clearing time: $T_c = T_p - T_0$.

3. (c)Forced entry: If a minor road vehicle clears the intersection by slowing the major road vehicles, it is considered to be a forced entry, represented by a dummy 1, otherwise 0.

Preliminary data analysis

Data are extracted from the video, and a set of 1414 observations have been recorded for all the selected study area. Out of these, the accepted gap/lag data are used to understand the aggressive behavior of the minor street drivers and a statistical summary is presented in Table 1.

Intersection A			
	Aggressive drivers (%)	**Non-aggressive drivers (%)**	**Total (%)**
Total observations	37	63	100 (200 observations)*
Distribution by mode			
Two-wheeler	13	41	54
Auto rickshaw	11	12	23
Car	13	10	23
Distribution by number of rejected gaps			
0	27	48	75
1	7	12	19
2	2	2	4
3	1	1	2
Type of gap			
Gap	10	18	28
Lag	27	45	72
Intersection B			
	Aggressive drivers (%)	**Non-aggressive drivers (%)**	**Total (%)**
Total observations	35	65	100 (238 observations)*
Distribution by mode			
Two-wheeler	13	45	58

Auto rickshaw	7	8	15
Car	15	12	27
Distribution by number of rejected gaps			
0	18	38	56
1	5	13	18
2	4	7	11
3	2	3	5
4	3	1	4
5	1	1	2
> 5	2	2	4
Type of gap			
Gap	17	27	44
Lag	18	38	56
Intersection C			
	Aggressive drivers (%)	**Non-aggressive drivers (%)**	**Total (%)**
Total observations	36	64	100 (198 observations)*
Distribution by mode			
Two-wheeler	8	36	44
Car	28	28	56
Distribution by number of rejected gaps			
0	11	26	37
1	16	10	26
2	1	9	10
3	1	6	7
4	3	3	6
5	2	3	5
> 5	2	7	9
Type of gap			
Gap	24	40	64
Lag	12	24	36

The primary statistics obtained from Table 1 are as follows:

(a)The percentage of two-wheelers at intersection A was 54%, whereas intersection B had 58% two-wheelers and intersection C had 56% four-wheelers.

(b)The percentage of vehicles showing aggressive behavior is found to be quite high (Table 1). 24% two-wheelers at intersection A, 22% two-wheelers at intersection B and 18% four-wheelers at intersection C are found to have shown aggressive behavior. A new parameter 'forced entry (F)' is introduced to address the aggressive behavior of the minor street drivers.

(c)The percentage of aggressive drivers forcing themselves through in the first available gap (i.e., lag) at intersections A, B, and C are 73%, 53% and 31%, respectively.

(d)The percentage of aggressive drivers who had to reject three or more than three gaps (which includes the lag) at intersection A, B and C are 4%, 23%, and 22%, respectively.

Based on the statistics mentioned above, the following conclusions (1–4) are drawn:

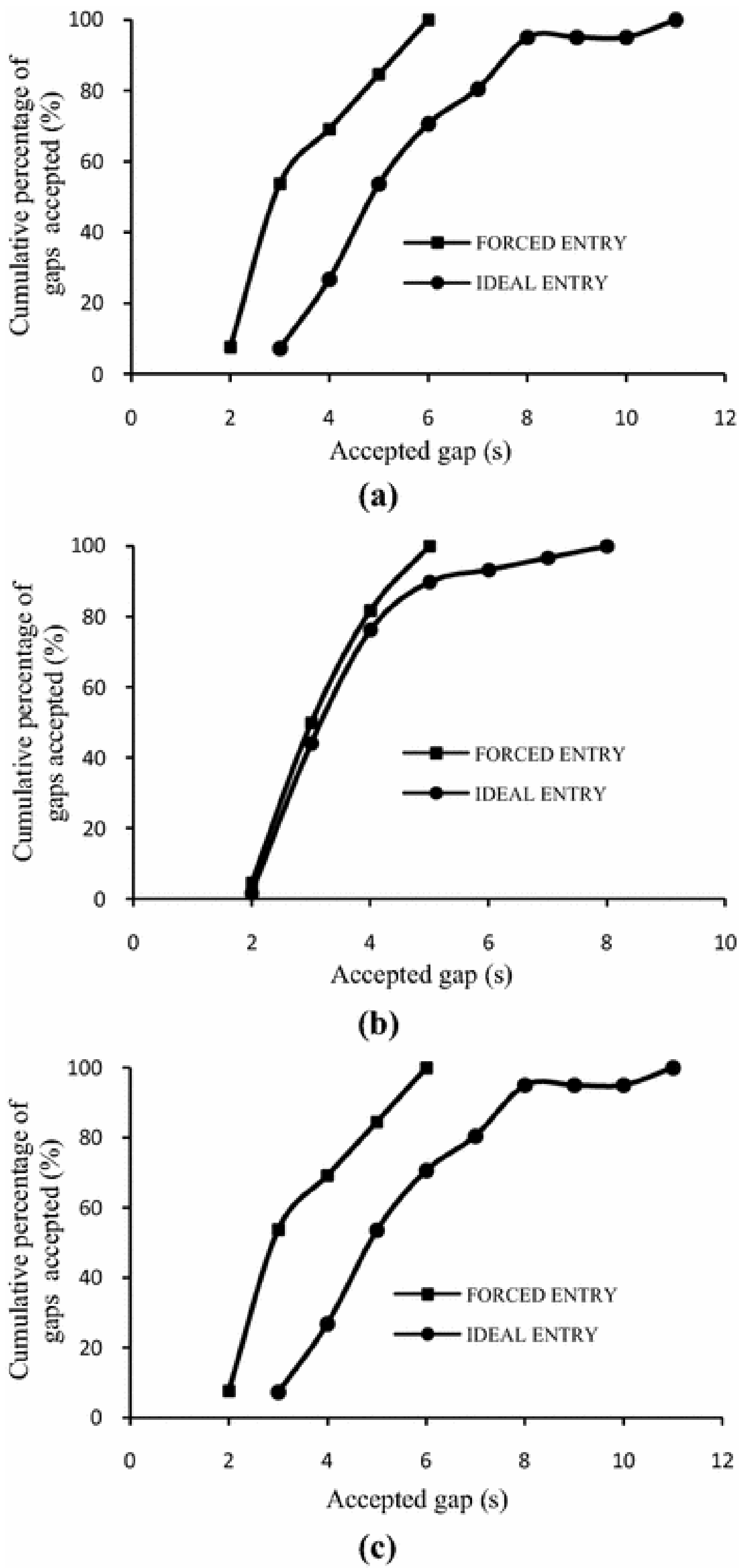
- Only the vehicle categories with higher proportion have been selected for each intersection; i.e., two-wheelers at intersections A and intersection B and four-wheelers at intersection C.

- No direct relation between aggressive behavior and the number of rejected gaps is evident from the data as the maximum forced entry occurs with zero rejected gap (i.e., lag) at all the intersections. It can be said that the minor street drivers behave aggressively not because they have to wait for a long time, but because of their lack of respect for traffic rules.

- A significant amount of vehicles (37%–75%) are found to be entering the intersection forcibly or ideally at the first available gap, i.e., lag, so, a separate parameter 'gap/lag (I_{GL})' is taken which indicates whether the driver has accepted a gap or lag.

- The percentage of aggressive drivers accepting 'lag' is the highest at intersection A. This suggests that a vast number of the minor road drivers clear the intersection area as soon as they reach the intersection. The vehicles approaching from the minor road pay less attention to the major road traffic and do not wait for a suitable gap to clear the intersection safely. Thus, if we compare these three intersections, the major road gets the least priority at intersection A (73%) and the highest priority at intersection C (31%).

The gap acceptance behaviour of two-wheelers (intersections A and B) and four-wheelers (intersection C) at forced and ideal entry situations are graphically shown below.



Cumulative percentage of gap acceptance for aggressive and non-aggressive drivers of **a** intersection A, **b** intersection B and **c** intersection C

The cumulative percentage of gap acceptance of aggressive and non-aggressive drivers is plotted with respect to gap duration. All the aggressive drivers are found to have accepted a gap less than or equal to 6 s, whereas non-aggressive drivers accept gaps as high as 11 s. Additionally, it is evident from the graph that for a given gap, a higher percentage of aggressive drivers accept the gap than the non-aggressive drivers. It indicates that the aggressive behavior of drivers affects their gap acceptance decision.

Based on the results obtained by preliminary analysis of the data and field observations, the following utility explanatory variables are considered in this study to address the traffic condition prevalent in Indian roads (Table 2).

Variable	Symbol	Description
Gap/lag time (s)	G	Lag or gap duration in seconds
Clearing time (s)	T_c	Time taken in seconds by the minor street vehicle to clear the intersection area
Gap or lag	I_{GL}	Type of interval presented to the driver, represented by a dummy = 1 for gap and 0 for lag
Yield	F	Forced entry of minor street vehicles, represented by a dummy = 1 if major street vehicle yields (stopped or speed is reduced) and 0 if not
Accept or reject	O_{AR}	Driver accepted or rejected the gap/lag, represented by a dummy = 1 in the case of acceptance and 0 in the case of rejection

CHAPTER 4

SUMMARY AND CONCLUSION

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 Kadubeesanahalli intersection in Bengaluru. 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 maneure 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.

In this paper, gap acceptance behavior analyses of two-wheelers and four-wheelers at uncontrolled T-intersections are presented. The videographic survey was carried out at three uncontrolled intersections with the help of video camera—two in Silchar, and one in Guwahati. The purpose was to model gap acceptance behavior of drivers and to find the critical gaps which are widely used in the intersection operational analysis and capacity estimates. Erratic maneuvers in the intersection area and aggressive driving are two common behavior of drivers observed at these intersections. Preliminary analysis of the data revealed that the gap accepted by two-wheelers follow Dagum distribution, whereas, in the case of four-wheelers, it follows Dagum (4p) distribution. It was also concluded by analyzing the data that drivers behave aggressively because of their lack of respect for traffic rules, rather than due to drivers losing his patience because of unavailability of a suitable gap.

Binary logit models were developed for two-wheelers at intersections A and B and four-wheelers at intersection C, to predict the probability of accepting or rejecting a given gap or lag. The manner in which a driver clears the intersection is not consistent at these intersections, thus affecting the value of critical gap. Apart from considering the gap duration which is an obvious factor, the variables considered in the models are clearing time and aggressive nature of drivers (forced entry). The variable, 'forced entry' of minor street vehicles, which had not been introduced in previous studies under mixed traffic condition, was found to be significant in the models. The model analyzes yielded critical gap in the range of 2.93–4.79 s for non-aggressive drivers, whereas the values are in the range of 2.02–2.40 s for aggressive drivers. The critical gaps were also obtained using logit model without considering the aggressive behavior of drivers. The values were in the range of 2.80–4.09 s. Clearing behavior approach was also used to determine the values of critical gap at these intersections. It is found that the results obtained by the proposed method help in differentiating between aggressive and non-aggressive drivers at an uncontrolled intersection.

The data extraction procedures and the analysis presented in this study can be implemented at uncontrolled intersections in countries where mixed traffic condition exists. Moreover, the methodology adopted in this study addresses the aggressive behavior of drivers. Considering the scarcity of studies on the aggressive behavior of drivers, this approach can be a valuable reference for similar studies at uncontrolled intersections where rules of priority are often neglected. Further studies are underway to analyze how the speed and type of oncoming vehicles affect a driver's decision-making. In this study, only minor street right turning movement at T-intersections has been considered; the procedure can be extended to analyze the gap acceptance behavior of major street right turning vehicles as well. Studies on four-legged intersections and effect of other parameters such as geometric features, side friction, driver's characteristics can be taken into account to gain further understanding of traffic behavior at uncontrolled intersections.

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