ISSN No:-2456-2165

A Review of Capacity, Critical Gap and Follow-Up Time on an Unsignalised Intersections in Bangalore City

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Abstract:- India, unfortunately ranks at the top with highest number of fatalities with about 11% share in the world. The "Road accidents in India 2018" is an effort of the Ministry to highlight the state-wise data and causes of the accidents and fatalities. The total number of accident related deaths in 2018 stood at 1,51,417 indicate an increase of 2.3% over the figures for 2017. It's generally because of the impatient behavior of the driver. This paper concludes the Capacity calculations, Critical Gap and Follow-up time studied at an unsignalised intersection. The capacity is calculates based on the calculations of IRC SP-41 and the LOS is compared with HCM manual. The Critical Gap and Follow-up time is calculated based on Raff's method.

Keywords:- *Capacity, LOS, HCM manual, Critical Gap, Follow-up time, Raff's Method.*

I. INTRODUCTION

India is a developing country and its cities are undergoing rapid urbanization and modernization as a result there is a rapid growth in the road traffic. Traffic movement in India is very complex due to heterogeneous traffic stream sharing the same carriage way also despite having lane marking, most of the lane discipline is not followed particularly at intersection. Highway capacity manual and other works assume homogeneous and lane best traffic for analysis, which exist in develop country. There is a notable lateral movement at intersection and vehicle tend to use lateral gaps to reach the head of the queue and overtake even during saturated part of green face. Due to this fundamental differences, the standard western relationship for predicting the values of saturation flows and PCU factors are not appropriate for developing countries like India.

This paper describes how the level of service can be as low as the grade "F" even when the capacity is not that much or the traffic flow is not high or congested. The critical gap that is calculated based on Raff's method where the methodology followed is based on accepted and rejected gaps, yet the driver makes some moves that can hold the traffic up at an unsignalised intersection. The Follow-up time is calculated based on critical gap calculated, where the Follow-up time is equal to 0.6 times of critical Gap.

II. LITERATURE REVIEW

Capacity of an unsignalised intersection is an important thing to calculate as accurate as possible. That is important because the design and construction of the changes depends on the capacity of the intersection, for ex: if the capacity of the intersection is less, the design would be much simpler and the construction of the changes would be easier. In a country like India, the traffic and the commotion that takes place due to it is worse than most of the countries out there. With the population of almost 1,380,004,385 people, the traffic can't be any better. More the number of people on the road, more the chances of road accidents. This brings the concept of Critical Gap into the picture. Critical Gap is basically the smallest gap that a driver is willing to accept to merge with the circulating traffic and mainly determines the gap acceptance behavior of the driver. Vehicles making turn to either direction increases the risk of road accident if the gap selected is less than that of Critical Gap. Likewise, the Follow-up time or headway is the mean headway between queued vehicles which move through the intersection during the longer gaps in the major stream.

The capacity and service times at minor streets of uncontrolled intersections rely upon the possibilities to possess enough gap between vehicles of the upper prioritized streams to cross the conflict spaces securely. These possibilities may be a function of vehicle flow rate on the major streams, individual drivers' as well as vehicle characteristics that illustrate each individual gap acceptance behavior.

ISSN No:-2456-2165

III. DATA COLLECTION

A. Capacity Data:

The site selected is an unsignalised 4-legged 2-laned intersection in the city of Bangalore. The exact location of the site is 9th Main, 36th Cross Road, 5th Block, Jayanagar, Bangalore, 560041 as shown below.

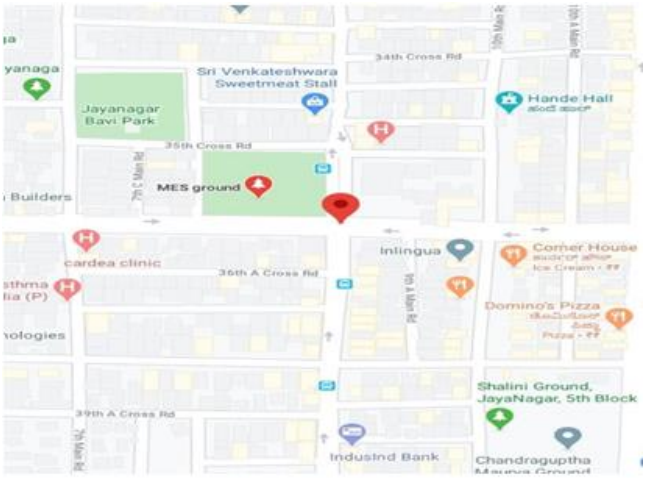


Fig 1:- Location of the studied site.

The data collection was noted manually by counting the vehicles moving in every direction. The readings were taken per hour in peak morning timed from 8:30 am to 10:30 am and from 6:30 pm to 8:30 pm in evening peak hours for two weekdays consecutively. The data has been recorded as correct as possible by counting mixed stream of vehicles moving in every direction mentioned by V1, V2, V3 and such respectively till V12 as shown below in the figure.

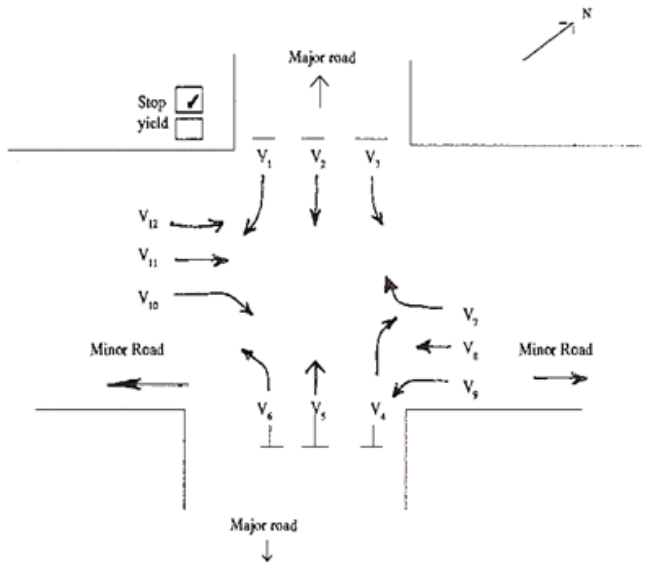


Fig 2:- An unsignalised Intersection with movements taking place in every direction.

Each person stood on one side of the road and counter the respective right, left and through movements happening at the intersection. The data is calculated for the peak hour and is tabulated in VPH(Vehicles Per Hour).

B. Critical Gap Data:

The critical Gap data was noted down manually by using a stopwatch and noting down the time taken by the back of the vehicle and the front of another vehicle following it to cross the stream which was accepted or rejected by the driver trying to merge with that stream. This was done at peak hours too for 2 consecutive days.

C. Follow-up time:

Follow-up time was directly calculated with the help of the basic thumb rule designed for easy calculations

IV. DATA ANALYSIS

A. Capacity Analysis:

The capacity of heterogeneous movement is taken in Volume per hour and this needs to be converted in Passenger Car per hour. Then the Capacities of movements are done based on the critical gap adopted for the respective speeds shown in IRC SP-41. Respectively the LOS is calculated from the Capacity and Volume obtained. Then the Level of Service is compared with that of the HCM manual and the final Level of Service is obtained.

The calculation done to obtain the Capacity and level of service is shown below:

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
Vph-	33	2310	249	44	927	75	63	438	290	13	1778	279
pcph-	27	1848	200	36	742	60	51	351	232	11	1423	224

Fig 3

For V09:

Conflicting Velocity (Vc09): ½ V3+V2
Vc09= .5*200+1848= 1948 vph
Critical Gap (Tc09): 4.8 sec
Potential Capacity (Cp09): 150 pcph
% C09 Utilized (V09/Cp09) : $\frac{232/150}{100}$
% C09 Utilized= 154.56%
Impedance factor (P09): 0.01
Cm09=Cp09= 150pcph

For V12:

Conflicting Velocity (Vc12): ½ V6+V5
Vc12= .5*60+742= 772 vph
Critical Gap (Tc12): 4.8 sec
Potential Capacity (Cp12): 550 pcph
% C12 Utilized (V12/Cp12) : $\frac{224/550}{100}$
% C09 Utilized= 40.73%
Impedance factor (P12): .60
Cm12=Cp12= 550pcph

For V04:
Conflicting Velocity (Vc04): V3+V2
Vc04= 200+1848= 2048 vph
Critical Gap (Tc04): 4.8 sec
Potential Capacity (Cp04): 100 pcph
% C4 Utilized (V04/Cp04) : 36/100
100 100
% C09 Utilized= 36%
Impedance factor (P04): .70
Cm4=Cp4= 100pcph

For V01:
Conflicting Velocity (Vc01): V6+V5
Vc01= 60+742= 802 vph
Critical Gap (Tc01): 4.8 sec
Potential Capacity (Cp01): 530 pcph
% C1 Utilized (V01/Cp01) : 27/530
100 100
% C09 Utilized= 5.1%
Impedance factor (P01): 0.97
Cm1=Cp1= 530pcph

For V08:
Conflicting Velocity (Vc08):
½ V3+V2+V1+V6+V5+V4
Vc08 = 2534 vph
Critical Gap (Tc08): 5.1 sec
Potential Capacity (Cp08): 100 pcph
% C8 Utilized (V08/Cp08) : 351/100
100 100
% C09 Utilized= 351%
Impedance factor (P08): 0
Cm9= Cp8*P1*P4= 100*.97*.70= 68 pcph

For V11:
Conflicting Velocity (Vc11):
½ V6+V5+V4+V3+V2+V1
Vc11= 2883 vph
Critical Gap (Tc11): 5.1 sec
Potential Capacity (Cp11): 100 pcph
% C11 Utilized (V11/Cp11) : 1423/100
100 100
% C09 Utilized= 1423%
Impedance factor (P11): 0
Cm11= Cp11*P1*P4= 68 pcph

For V07:
Conflicting Velocity (Vc07):Vc08+V11+V12
Vc07= 2534+1423+224= 4181 vph
Critical Gap (Tc07): 5.6 sec
Potential Capacity (Cp07): 100 pcph
% C07 Utilized (V07/Cp07) : 51/100
100 100
% C09 Utilized= 51%
Impedance factor (P07): 0
Cm7=Cp7*P1*P4*P11*P12= 0pcph

For V10:
Conflicting Velocity (Vc10): Vc11+V5+V9
Vc10= 2883+743+60= 3685 vph
Critical Gap (Tc10): 5.6 sec
Potential Capacity (Cp10): 100 pcph
% C10 Utilized (V10/Cp10) : 11/100
100 100
% C09 Utilized= 11%
Impedance factor (P10): .95
Cm10= Cp10*P1*P4*P8*P9= 0pcph

Los Calculations For This Intersection Is Shown Below:

Reserve Capacity(pcph)	Level of Service	Expected delay to Minor street traffic
>400	A	Little or no delay
399-300	B	Short traffic delay
299-200	C	Avg. traffic delay
199-100	D	Long traffic delay
99-00	E	V. Long traffic delay
0	F	Stops and starts

Table 1:- LOS classification on the basis of Capacity

Minor street approach movements 07, 08, 09

MOVEMENT	V(pcph)	Cm(pcph)	LOS(Cm(pcph)-(Vpcph))
7	51	0	-51 = F
8	351	68	-283 = F
9	232	150	-82 = F

Fig 4

Minor street approach movements 10, 11, 12

MOVEMENT	V(pcph)	Cm(pcph)	LOS(Cm(pcph)-(Vpcph))
10	11	0	-11 = F
11	1423	68	-1355 = F
12	224	550	326 = B

Fig 5

Major street Right Turn movements 1, 4

MOVEMENT	V(pcph)	Cm(pcph)	LOS(Cm(pcph)-(Vpcph))
1	27	530	503 = A
4	36	100	64 = D

Fig 6

Comparision of LOS with HCM manual is shown below:

Level of Service	Volume-Capacity ratio
A	<0.15
B	0.16-0.35
C	0.36-0.55
D	0.56-0.80
E	0.81-1.00
F	>1.00

Table 2:- LOS calculation according to HCM manual

Movements	Volume/Capacity	Level of Service
V01	27/530	A
V04	36/100	C
V07	51/0	F
V08	351/60	F
V09	232/150	F
V10	11/0	F
V11	1423/60	F
V12	224/550	C

Table 3:- Volume/Capacity to calculate HCM

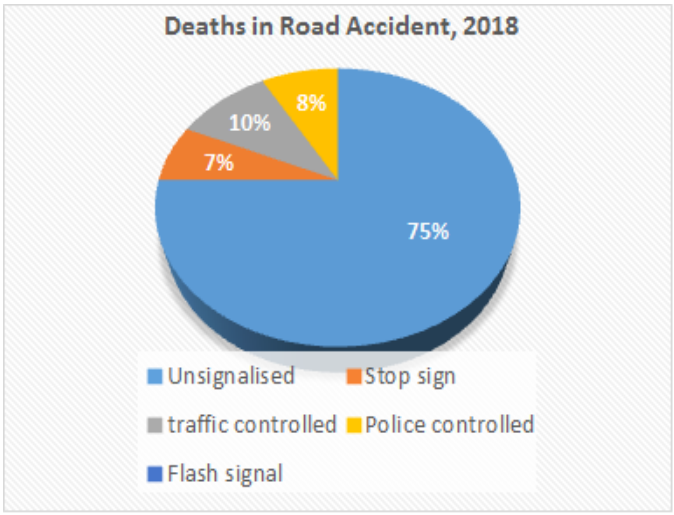
The Level of Service here in HCM manual is calculated by the formula Volume/Capacity that was obtained during the calculation. The level of service defines how easy transportation process would be through the intersection. The calculations done for it is defined next. Some of the movements such as V09, V01 and V12 had a better Level of Service as per the calculations done on the basis of HCM manual and yet many of the movements remained same and nothing as such in change was seen in them. This, as said is because of the impatient behavior of Indian drivers who barge into the main stream with gaps less then critical gaps, risking the lives of others and themselves, making commotion and slowing down the traffic to this extent that the Level of Service drops down to the least possible. This makes the traffic move to STOP and START, increasing the travel time through the intersection.

B. Critical Gap

A gap is the time interval between two successive vehicles measured from the rear end of the leader to the front end of the follower across a line of reference. The critical gap is the smallest gap that a driver is willing to accept to merge with the circulating traffic and mainly determines the gap acceptance behavior of the driver. The critical gap is not directly observable. Only gaps that drivers have accepted or rejected are observed.

Traffic operations at a TWSC intersections occur through gap acceptance process and the vehicle in the non-priority stream should wait for suitable gaps in the major traffic stream to complete the desired maneuver. Normally a driver will reject all gaps which are less than critical gap and accept the rest.

However, Accidents in India are a normal talk to have, and it's has not been any better in these couple of years. India, unfortunately ranks at the top with highest number of fatalities with about 11% share in the world. The "Road accidents in India 2018" is an effort of the Ministry to highlight the state-wise data and causes of the accidents and fatalities. The data collected from all the States and Union Territories has been compiled in the Publication. The total number of accident related deaths in 2018 stood at 1,51,417 indicate an increase of 2.3% over the figures for 2017. About 85% of the accident related deaths happen in the most productive age group of 18-60. Road accidents deaths not only cause severe trauma to the family of the victim but they also result in huge economic loss to the Nation.



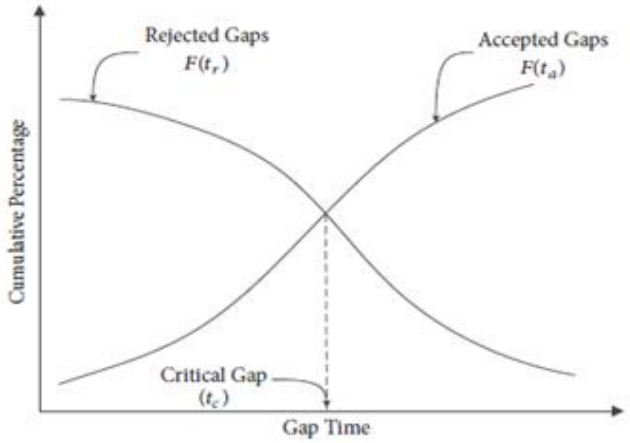
Graph 1:- Deaths in Road Accident, 2018

The study location is same as that of the Capacity calculation:

- *9th Main, 36th Cross Road, 5th Block, Jayanagar, Bengalure, 560041.*

Raff's method**:** This is based on macroscopic model, and it is the earliest methodology for estimating the critical gap which is employed in several countries due to its simplicity. According to Raff method, a critical gap is the time at the sum of the cumulative number of accepted gaps F_a and rejected gaps F_r is equal to 1. The original Raff theory uses solely lag data.

ISSN No:-2456-2165



Graph 2:- Critical Gap based on Raff's method.

Here, t_a and t_r are accepted and rejected gap times and $F(t_a)$ and $F(t_r)$ are commulative distribution functions (CDFs) of accepted and rejected gaps.

The critical gap observed based on the raff's methodology is obtained below:

	CRITICAL GAP		
Location	Right turn through major	Right turn through minor	Through Minor
HCM(2017)	3.50	3.80	4.90
Location 1	3.10	2.40	2.20
Location 2	2.20	3.20	3.90
Location 3	1.90	3.50	4.10

Table 4:- Critical Gap for Cars

	CRITICAL GAP		
Location	Right turn through major	Right turn through minor	Through Minor
HCM(2017)	2.90	3.20	3.50
Location 1	2.90	1.90	2.00
Location 2	2.00	3.00	3.50
Location 3	1.90	3.50	4.30

Table 5:- Critical gap for 2-wheelers

Careful analysis of the field situation exposed that more than 60% of right turning from minor stream vehicles forced opposing vehicles to slow down. Hence, major vehicle has to wait up to the time when the movements of lower priorities are clear. As a result, in the majority of case, critical gaps obtained for right turning movements are quite less as compared to through movements. In addition, careful analysis of the field situation revealed that the majority of vehicle accepts the gap in two stages in India. In the majority of cases, drivers were not bothering about the gaps in the far lane when they are exploring the gaps in the near lane. Once, they accept the gaps in the near lane and reach up to the median; they start searching the suitable gaps in the far lane. This condition creates more chaos at median separated uncontrolled intersection.

C. Follow-up time

The follow-up time is the mean headway between queued vehicles which move through the intersection during the longer gaps in the major stream**.** Consider the example of two major stream vehicles passing by an unsignalised intersection at times 1.0 and 20.0 seconds. If there is a queue of say 35 vehicles trying to make a right turn from the minor street, and if 20 of these minor street vehicles depart at 3.85, 5.25, 9,29, 12.13, 13.14 and such, then the headway between the minor street vehicles are 5.25-3.85, 9.29-5.25, 12.13-9.29 and so on. This process is repeated for a number of larger major stream gaps and an overall headway between the queued minor stream is vehicles is estimated. This average headway is the follow-up time, t_f.

At unsignalised intersections, the major road traffic has priority over the minor road. From that perspective, unsignalised intersections cause neither reduced capacity nor delay. When the volumes of cross and turning traffic at intersections with minor roads are small, capacity considerations are usually not significant. A simple rule of thumb in relation to the gap acceptance parameters can be stated as "the ratio of follow-up headway to critical gap is about 0.6". In practice, when a gap acceptance survey is limited to measuring the follow-up headway, the rule about the ratio of follow-up headway to critical gap can be useful for estimating the critical gap as Critical Gap = Follow-up Headway / 0.6. More conservatively, a factor of 0.55 could be used instead of 0.6.

The Follow-up time calculation is shown below:

	FOLLOW-UP TIME		
Location	Right turn through major	Right turn through minor	Through Minor
Location 1	3.10*0.6=1.86	2.40*0.6=1.44	2.20*0.6=1.32
Location 2	2.20*0.6=1.32	3.20*0.6=1.92	3.90*0.6=2.34
Location 3	1.90*0.6=1.14	3.50*0.6=2.10	4.10*0.6=2.46

Table 6:- Follow-up time for Cars

	FOLLOW-UP TIME		
Location	Right turn through major	Right turn through minor	Through Minor
Location 1	2.90*0.6=1.74	1.90*0.6=1.14	2.00*0.6=1.20
Location 2	2.00*0.6=1.20	3.00*0.6=1.8	3.50*0.6=2.10
Location 3	1.90*0.6=1.14	3.50*0.6=2.10	4.30*0.6=2.58

Table 7:- Follow-up time for 2-wheelers

The Critical Gap and Follow up time results are found to be comparatively low with considerable variation among the results obtained as per the HCM manual.

The discrepancy is due to the inborn fault of the methodology to consider for the heterogeneous stream of traffic as it evolved under homogenous stream of traffic conditions.

V. CONCLUSION

The following results were determined by the calculations and comparisions done in this work:

- The capacity calculations were done and the Level of Service were found for the movements.
- Electronic machines that reads and records the speed of a vehicle and the number plate of the vehicles moving should be deployed.
- The Critical Gap found in this study may be erroneous which is calculated by the Raff's method.
- The gaps calculated here shows that the drivers accepted the gaps even if it was difficult to accept them, this shows the aggressive behavior of Indian drivers. Therefore, the standards should also be set according to the worst scenario possible.
- The follow-up time similarly implies that the small amount of gap tends to attract more relative risks at the intersection for accidents.
- This can be reversed if the critical gaps are noted for the highly congested traffic and driver's aggressive behavior.

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