Performance Evaluation of Uncontrolled Intersection using Microscopic Simulation

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Abstract

Uncontrolled intersections are integral part of the road network in rural and suburban areas. As the speed of the vehicles on major roads are high (130 km/hr) but National Highway had given design speed as 100km/hr in India and the conflict that occur at the uncontrolled intersections result in severe injury. The required gap between vehicles for safe crossing varies with drivers and the type of vehicle that is waiting to enter the intersection area. Video graphic survey was carried out at an uncontrolled T intersection located in a rural area and the accepted/rejected gap to across the intersection area was extracted. The critical gap for the crossing action was estimated and the capacity of the intersection was estimated by US- HCM method and by micro simulation tool. Estimated capacity values by both the methods were nearly same. At the T intersection, three streams of traffic were likely to have conflict. To reduce the waiting time of the crossing vehicles and conflicts, the right turning traffic from minor road were made to take left, travel for some distance and to merge the straight traffic on opposite side after U- turn. The geometric arrangement was similar to J-turn intersection and it was found that with the arrangement, capacity increased by 14.59 % and stopped delay reduced by 72%.

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1. Introduction

Uncontrolled intersections are the most commonly found intersection on rural roads. Uncontrolled intersections seem to be trade-off between safety and delay. The safe gap required to cross becomes an individual judgement and error or misjudgement leads to accident. Being over cautious to cross increases the stopped delay. Delay of traffic at the uncontrolled intersection affects the overall performance of the road network. The estimation of critical gap and capacity at these intersections is one of the grey areas in traffic flow analysis. The capacity of the uncontrolled intersections is required for planning or upgradation of control to avoid accidents and unnecessary delays. The estimation of capacity of uncontrolled intersection in heterogeneous traffic scenario is more complex as the performance of the vehicles varies widely. The speed of vehicle on the major road varies widely and during lean hours, vehicle on major road cross the intersection at higher speeds and gap accepted to cross the stream on major roads tends to be higher. Likewise at higher volume of traffic, the vehicles onminor roads tend to wait for long duration. Longer the waiting time, higher will be the probability of the vehicles to accept shorter gap. Gap estimation is an integral part in capacity estimation of uncontrolled intersection. Even a micro second difference in gap calculation leads to error in capacity estimation (Abhishek Cheeti Sai et al., (2014)).
The critical gaps for different types of vehicles are estimated by methods i.e. Maximum Likelihood method, Clearing Behaviour method (Zondy, 2010 & Satish Chandra, 2011), Ashworth's method, Greenshieldsmethod, Harder's method, Raff method etc. Studies indicate that Maximum Likelihood Method (MLM) is the most accurate method, as it involves iterative process. In this study, the estimated critical gap was used as the parameter for right turning of vehicles and with the aid of microsimulation, the capacity of a T intersection and T intersection after improvement was estimated.

2. Background

The first empirical studies for critical gap estimation were based on regression analysis. An early approach suggested by Greenshields et al.(1947) defined critical gapas theacceptable average minimum time gap as critical gap.Raff and Hart (1950)defined critical gap as the lag for which the number of accepted shorter gaps is equal to the number of rejected longer ones, while analogously Drew (1968) suggested that the critical gap is that for which an equal percentage of traffic will accept a smaller gap as will reject a larger one. More recently, Brilon et al. (1997) benchmarked different sta-

tistical estimation procedures for critical gaps at uncontrolled intersections, reporting more than 30 different ways to define and estimate the critical gap parameter, all leading to different capacity calculations.

Chandra et al. (2011) estimated the critical gap by some of the existing methods like Lag, Harder, Logit, Probit, Modified Raff and Hewitt methods and the results showed that values of critical gap estimated are as low as 1.60 seconds and there is a significant variation (12%-38%) among the values estimated by different methods. He has highlighted incapability of the existing methods to address the mixed traffic conditions as rule of priority is not observed and minor street vehicles clear the intersection in zig-zag manner. He indicated that the requirement of gap will depend on two factors i.e. the clearing behaviour of the minor street vehicle and the clearing distance

Sai et al (2014) found that the capacity of any uncontrolled intersection is highly depending on the gap acceptance behaviour. A micro second difference in gap measurement leads to considerable error in capacity estimation. Based on the frequency distribution of the difference in gap measured at entry and exit lines and it can be inferred that the majority of the gaps were between 0 to 2 seconds. Therefore to collect the gap information more accurately authors suggest making a new reference line for measuring these gaps. New reference line is identified based on conflicting area as shown in figure 1.Therefore they developed method for identifying the reference line for measuring gaps which is based on conflicting area considering the observed driving behavior.
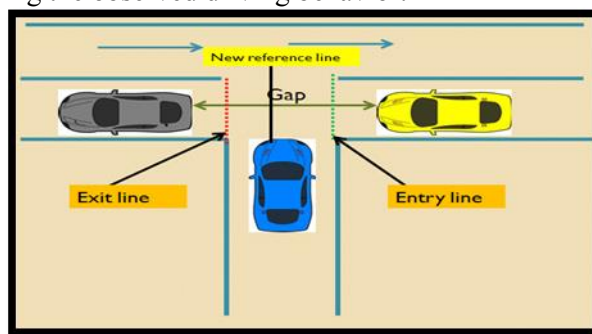

Fig. 1. Diagrammatic representations of new reference line

Viti et al (2013) used microscopic simulation to study the influence of volume on the minimum gap using VISSIM. Jeffrey Sha et al (2014) evaluated J-turn projects in North Carolina using the crash reduction factors for left-turn restrictions from stop approaches to divided highways. The results concluded that there was a 100 percent decrease in crossing conflict and 84 percent reduction in overall total conflict in the J-turn intersection.

3. Methodology

Videography method of data collection was deployed and software application was developed for data extraction of critical gap and follow up time of different vehicles. The critical gap is estimated using Maximum Likelihood methods and average of follow up time was determined. After obtaining critical gap and follow up time, the capacity of uncontrolled intersection is estimated using US-HCM method and it is compared with capacity values of estimated by micro simulation. An innovative intersection improvement was adopted to augment the capacity of the uncontrolled intersection and its capacity was estimated with the aid of microsimulation.

4. Study Intersection

An uncontrolled intersection on inter urban highway NH-45, located at Bukkathurai, 90 Km south of Chennai was selected for the study. It was an ideal intersection. It is free from obstructions, located straight section and on plain terrain. It is a three arm intersection of which the major road connects Chennai with the southern parts of the state, whereas the minor road leads to Uthiramerur, small town in Chennai's outskirts. The layout of the intersection is shown in figure 2. The Major road is a four lane divided road and minor road is a two lane undivided road

Figure 2 Survey Location at Bukkathurai Intersection

5. Data Collection

Videography method of data collection was adopted and the traffic was recorded for 4 hours from 8 A.M to 12 P.M in the day time. Video camera 1 was mounted over a pneumatic mast fitted to a vehicle to capture the traffic from a height of 10m above the ground level and separate camera 2 was deployed at a distance (greater than Safe Stopping Distance) away from the stop line of the intersection to capture the speed of the entering vehicle from the major road as shown in figure 3. Reflective tapes were pasted at stopping line of the intersection and to delineate the intersection area. In figure 3, data collection arrangement and the snapshot of recorded video are shown.

Fig. 3. Snapshots of data collection

6. Data Extraction

The acceptance and rejection behavior of two movements were considered for the analysis. The movements analysed are shown in figure 4. They are gap accepted by vehicles taking right turn from minor road to major road (movement 1), gap accepted by vehicles taking right turn from major road to minor road (movement 2)
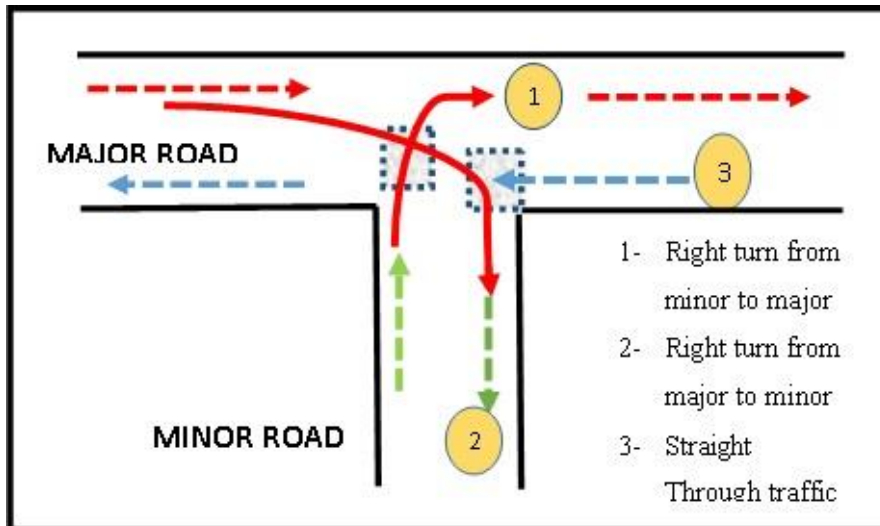
Fig. 4. Vehicle's right turning movement in uncontrolled intersection

Fig. 5. Snapshot of data extraction using software

The recorded video was processed with multimedia software tool to draw lines at the intersection boundaries. With a developed data extraction software, the time of vehicles at movement1 reaching stop line on minor road, the time when they exit the intersection area were recorded. Similarly on

movement 2, the time vehicle at stop line on the major road and the time when they start and exit time from the intersection area were recorded. Accepted snapshot of software application is shown in figure 5 and the data extracted is shown in figure 6.

| Sr. No. | Major to Minor (Right turning movement) | | | | Major Road (Straight Movement)-lead | | | | Accepted / Rejected |
	Vehicle Type	Time when vehicle stops at entry line	Time when vehicle starts again from entry line	Time when vehicle reached to exit line	vehicle Type	Time of ENTRY	Time of Clearance of intersection area	Gap	
1	TWO WHEELER	03.0.24.280	03.0.26.840	03.0.30.840	SMALL CAR	03:00:02.560	3:00:22.720	00:00:02.280	REJECTED
					SMALL CAR	03:00:25.000	3:00:25.160	00:00:01.560	REJECTED
					SMALL CAR	03:00:26.720	3:00:26.880	00:00:01.840	REJECTED
					TWO WHEELER	03:00:28.720	3:00:28.840	00:00:03.640	ACCEPTED
2	BIG CAR	03:01:07.120	03:01:12.640	03:01:20.440	SMALL CAR	03:01:10.960	3:01:11.200	00:00:00.120	REJECTED
	SMALL CAR	03:01:18.280		03:01:22.640	TWO WHEELER	03:01:11.080	3:01:11.240	00:00:05.280	REJECTED
					TWO WHEELER	03:01:16.520	3:01:16.680	00:00:00.600	REJECTED
					TWO WHEELER	03:01:17.280	3:01:17.480	00:00:04.160	ACCEPTED
3	THREE WHEELER	03:01:27.520	03:01:30.520	03:01:34.120	BUS TRUCK	03:01:28.640	3:01:29.120	00:00:00.520	REJECTED
	TWO WHEELER	03:01:30.680		03:01:35.360	TWO WHEELER	03:01:29.640	3:01:29.800	00:00:08.400	ACCEPTED
4	SMALL CAR	03:01:59.000	03:02:16.960	03:02:22.200	LCV	03:02:01.200	3:02:01.760	00:00:00.520	REJECTED

Figure 6 Snapshot of extracted data

7. Traffic Flow Characteristics

The hourly variation of traffic flow at Bukkathurai intersection is shown in Figure 7. Peak hour flow was observed found between 9 am and 10 am. The right turning volume from major road was 1083 Vehs/Hour, straight traffic on major road was 1283 Vehs/Hour/Dir and from minor road 261 Vehs/Hour/Dir turned right. The compositions of vehicles observed at the intersection are shown in figure 8. The percentage of two wheeler and car were 33% and 38% respectively. It was found that heavy vehicle viz. Truck and buses were also were in significant percentage.
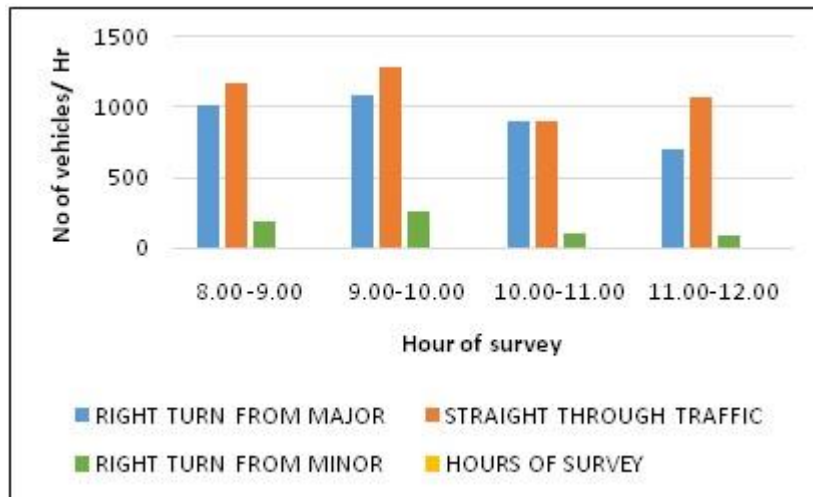
Fig. 7. Hourly traffic flow on Bukkathurai intersection

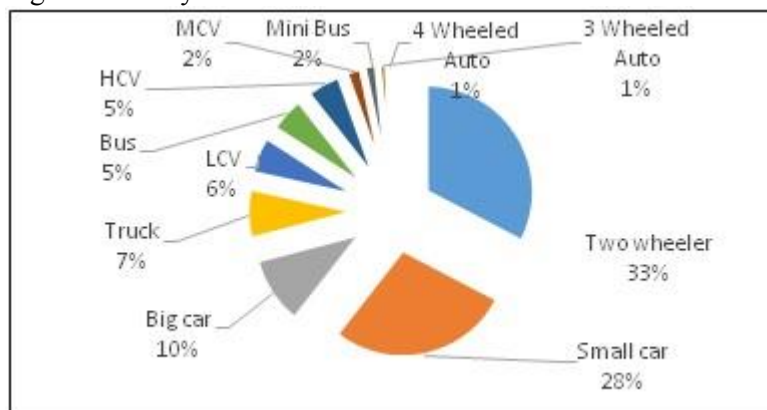Figure 7 Hourly Traffic Flow on Bukkathurai Intersection

Fig. 8. Composition of vehicle on Bukkathurai intersection

The cumulative plot of speed of the vehicles as shown in figure 9.The speed of the cars at the intersection was maximum and truck at low speed whereas two wheeler and bus, the speed varied from 30 kmph to 100 kmph
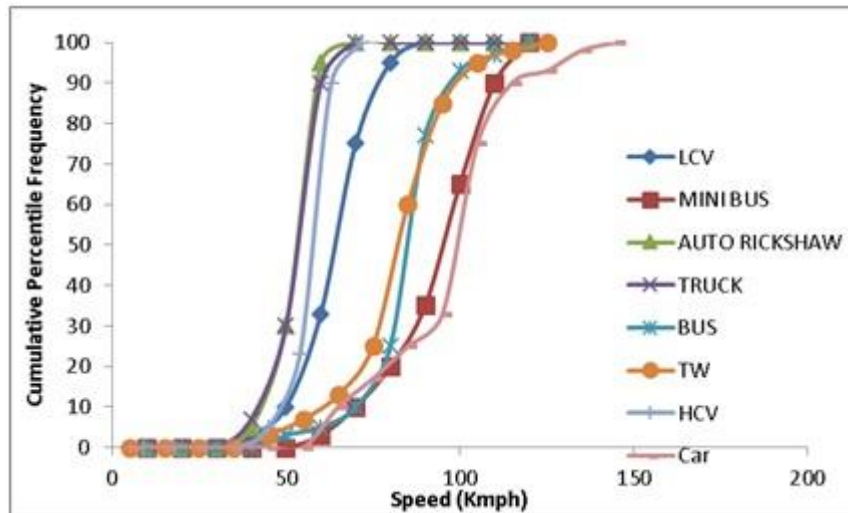
Fig. 9. Cumulative distribution of speed

8. Estimation of Critical Gap

Previous studies (Brilon et al. (1997) and Andrea Gavulova (2012)) shows that the Maximum Likelihood Method (MLM) of critical gap estimation yields accurate estimate. Also, this method considers accepted and rejected gaps in pairs. This technique calculates the probability of the critical gap between the largest rejected gap and accepted gap. To estimate this probability the user must specify the general form of the distribution Fc (t) of the critical gaps for the population of drivers and assume that all the drivers are consistent. This technique uses the maximum amount of information without biasing the results by including the effects of a large number of rejected gaps. It also accounts for the effects due to the major stream headway distribution. If all drivers accept the first gap offered without rejecting any gap then the method may yield trivial result

Using Maximum Likelihood technique critical gap was estimated and the statistical parameters are

Standard deviation of critical gap = 0.755

Mean of log critical gap (mu) = 0.999

Standard deviation of log of critical gap (sigma sq) = 0.2639

Mean critical gap = 2.987

9. Estimation of Capacity

Capacity is defined as the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under given conditions with a reasonable expectation of occurrence.

The capacity of uncontrolled intersection was computed using the US-HCM (2000) formula

$$c_{px} = v_{cx} \times \frac{e^{-v_{cx}t_{cx}/3600}}{1 - e^{-v_{cx}t_{cx}/3600}}$$

(1)

cpx is the potential capacity of minor movement x (veh/h),

vcx is the conflicting flow rate for movement x (veh/h),

tcx is the critical gap for minor movement x, and

tfx is the follow-up time movement x.

The observed conflicting flow and the estimated capacity of conflicting flow using equation (1) is given in table 1.

Table 1. Conflicting volume and their capacity

Conflicting Movement	Observed Conflicting Flow In Vehicles/Hour	Estimated Capacity (Vehicle/Hour)
Right turn from major road	1083	1489
Right turn from minor road	261	2193

10. Simulation Model Development

It was attempted to estimate the capacity of the conflicting flow at uncontrolled intersection using microscopic simulation. The development of simulation model involves various steps such as creation of links and connectors, vehicle inputs, definition of speed profiles, definition of vehicle composition, route assignment, model calibration and model validation. The stages of the model development are described below.

Creation of Link/Connectors

Microscopic model of the selected study intersection was developed using VISSIM 6 simulation software. The layout and dimension of the study intersection was measured and given as input as shown in figure 10.

Fig. 10. Layout of three arm intersection

10.1. Vehicle Speed and Composition

The speeds of the vehicles before entering the intersection and while crossing the conflict area were calculated from the extracted data. The cumulative distribution of speed by vehicle category and the composition of the vehicles observed were given as input to the model.

10.2. Vehicle Routing and Critical Gap Parameter

The routing of the vehicles to describe the travel pattern was defined with the help of origin and destination matrix created with the collected data. Totally 6 route combinations and their corresponding volume were given as input. Critical gap was also defined to cross the intersection area.

11. Model Calibration and Verification

The model was calibrated for volume and speed and the final result were compared with the field data values. After calibration, the capacity of the

conflicting movement at uncontrolled intersection was determined from the simulation model. The estimated capacity value obtained from simulation close to that estimated capacity using US – HCM formula and it was nearly 1% as shown in table 2.

Table 2. Comparison of capacity obtained by US HCM method and microscopic simulation software

Intersection	Average Operating speed	Capacity of conflicting movement using US-HCM method	Capacity estimation using Microsimulation Software	Percentage Difference
Bukkathurai intersection	60	3682	3694	1

12. Proposed **Innovative Improvement**

With this calibrated model, it is assumed that the model predicts the capacity of uncontrolled intersection accurately. One of the improvement measures suitable for the study intersection was attempted using microscopic simulation. By adopting the improvement J-turn intersection, the right turning vehicles from minor road are directed to take free left turn and then U-turn at a distance away from the intersection as shown in figure 12.These configurations were incorporated to the model and the capacity after intersection improvement was determined by simulation.
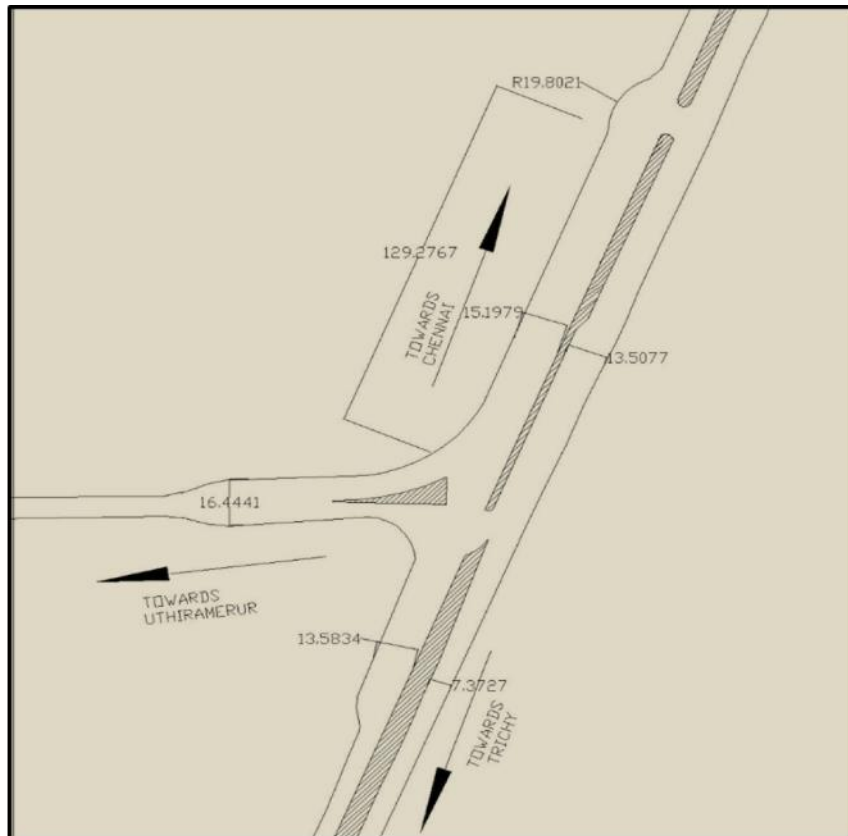
Fig. 12. Layout of J-turn intersection

13. Results and Discussion

Microscopic Simulation studies consider several parameters for the evaluation of scenarios. In the present study, the parameters for evaluation were average speed, average delay, average stopped delay, total stopped delay, total number of stops, and capacity. The comparison of these parameters for the existing intersection and after improvement is shown in table 3.

The results of conflicting movement show that the introduction of J-turn at the selected intersection, improves the performance of the uncontrolled intersection in respects of speed improvement, delay reduction and capacity augmentation. The scenario proves that the average stop delay reduced significantly from 1 sec from 0.28 sec per vehicle. In other words, the total stop delay was reduced from 2401 sec to 669.18 sec.

Table 3. Comparison of performance parameter

Performance Parameter		Base Scenario	J - Turn Scenario
Speed Average (All vehicle)(km/hr)		53.13	72.43
Delaystop Average (All vehicle)(seconds)		1	0.28
Stops Total (All vehicle)		271	133
Delay Stopped Total (All vehicle)(seconds)		2401.35	669.18
Capacity (vehicles/ hour)		3682	4218

Similarly, the speed of the vehicles at the intersection after improvement increased to72.43 kmph from 53.13 kmph for the existing scenario after improvement. This increase in speed is attributed to the elimination of one conflicting movement at the uncontrolled intersection. It is observed that the introduction of J-turn at the intersection, the capacity of the uncontrolled intersection increased to 4218 vehicles per hour from 3682 vehicles per hour.

14. Conclusions

The study demonstrates the method of measuring critical gap for uncontrolled intersection carrying heterogeneous traffic and use of capacity estimation by simulation. The gap could also be used to estimate the capacity enhancement on improvement like J-turn facility.

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