e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

# A Study and Analysis of Capacity at UN Signalized Interestions

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***Abstract:***

Unsignalized intersection is implemented to regulate low volume of traffic flow. The gap-acceptance method is the common approach to assess the performance of the intersection. However, among the drawbacks of the gapacceptance method are the non-compliance to the right of way, and the heterogeneous traffic condition. Conflict method is developed to overcome these shortcomings. Surveillance equipment is used to obtain the required data, such as traffic volume and occupation time. The occupation time of vehicle is used to calculate the capacity of vehicular movements for each conflict group. The control delay and level of service of the vehicular streams are evaluated according to the procedures in HCM 2000. Result comparison is made between the conflict method and the HCM 2000. The relationship between the occupation time and critical gap is discovered. The results of the conflict method are found to be comparable with the HCM 2000 using field data.

## I.INTRODUCTION

An intersection is a node, and usually it is a bottleneck for traffic flow in highway network. Capacity of a intersection affects the total capacity of highway network due to all types of turning movements. For actions of conflicting, merging and diverging caused by traffic flow, the traffic characteristics of intersection are more complex than those of road mid block section. Traffic stream in developing countries comprises of different types of motorized and non-motorized vehicles leads to mixed traffic conditions and lane changing patterns.

Urban roads in India carry different types of vehicles like high speed automobiles, low speed cycles, cycle rickshaws and animal drawn carts. This will lead to complex interaction between the vehicles and study of such traffic behavior needs special attention. The traffic plying on roads in western countries is of characteristics of different vehicles with marginal variation contrary to large variation on Indian roads. This will result in increased interactions between vehicles; then they tend to move in clusters rather than one after the other. Further two or three wheelers such as scooters, cycles, and cycle rickshaws contribute to this because of their easy maneuverability.

The traffic on Indian roads consists of bi-directional freedom traffic such as two or three wheeled vehicles and uni-directional vehicles such as four wheelers. While the above tend to overtake or turning or crossing or turn right even if a small gap is available. Hence, to determine the intersection capacity traffic engineer requires a clear understanding of gaps being accepted or rejected by various modes of traffic.

Besides, in these mixed traffic conditions, users do not usually follow lane discipline and can occupy any lateral position on the road. Under these conditions, capacity of an unsignalized intersection is difficult to be determined and becomes a very interesting field of highway capacity study.
There are several types of capacity analysis models for unsignalized intersections such as empirical model based on regression technique and gap acceptance model based on probability theory. The third approach is the conflict technique which was based on the mathematical formulation of interaction and impact between flows at an intersection.

### 1.1 TYPES OF INTERSECTION CONTROL

As discussed earlier, with increase in complexity of movement, the quantification of the quality of traffic at any intersection is inevitable at every stage of its planning and designing.Based on controls adopted, intersections can be classified as

- Stop and Yield sign control Intersections
- Signalized Intersections
- Roundabouts

The normal practice of selecting a particular control at any intersection is based on arbitrary considerations. Normally signalization is adopted when all approaches have equal priority and vehicular delays are of higher order. Manual control is adopted at priority type intersections where a minor road meets a major road or at three legged junctions where the flow on minor road has to merge with that on major road. At some intersections, no control is adopted due to low volume levels and non-availability of resources. However, due to variations in traffic flow it is quite unclear to evaluate the traffic flow by simple observation. There is an absolute need for rational approach in this regard.

## II.LITERATURE REVIEW

### 2.1 GENERAL

The review of literature deals with various methods and models developed by different researchers to find the capacity of unsignalized intersections. Two general types of capacity analysis models are available for TWSC intersections i.e., gap acceptance methods and empirical methods. Since unsignalized intersections give no positive indication or control to the driver regarding when he or she can enter the intersection by looking for a safe opportunity of gap or headway in the major stream traffic. This is the basis of the gap acceptance process that is used in most analysis methods of capacity and level of service at unsignalized intersections. At TWSC intersections, a driver must also respect the priority of other drivers. Various models have been developed based on the gap acceptance theory and different assumptions of the gap acceptance process. Empirical models were developed using regression techniques.

### 2.2 GAP ACCEPTANCE CAPACITY MODELS

The theory of gap-acceptance is the predominant concept for unsignalized intersection analysis. This method is based on critical gap acceptance and follow up times of vehicles from the minor road. Some of the methods developed based on this concept are presented below.

### 2.2.7 HCM METHOD

The analysis procedure for two-way stop controlled and yield-controlled intersections contained in HCM (1985), is based on one developed in Germany in the early 1970's. Some modifications were made to the previous German method including those based on a limited number of validation studies in the United States as well as the addition of the LOS criteria.

The HCM method determines minor road capacity based on the availability of gaps in the major traffic stream to vehicles crossing or turning through that stream. Depending on the type of minor movement being, made a critical gap is chosen based on a number of criteria. The gap is used to extract the potential capacity from a family of curves. The procedure requires a determination of priority traffic volumes and the potential capacities for each movement, adjustment of potential capacities based on impedance factors and a calculation of reserve capacity and to measure the identify the level of service.

## III.METHODOLOGY

### 3.1 General

Different methods to analyze the capacity at unsignalized intersections are suitable for traffic characteristics prevailing in developed countries and these are not applicable for countries like India due to mixed traffic conditions. HCM (2000) is unable to model the behaviour such as of very short gap acceptance (less than 2 seconds), a large number of non–motorized vehicles which have varying speeds, no lane discipline where the chances of more conflicts. Therefore, in such a case of mixed traffic flow at unsignalized intersections the capacity is difficult to measure, when the flow is not in saturated condition. Two methods (gap acceptance and empirical approach) of capacity are used in the saturated traffic and difficult to apply for mixed traffic.

Evidence shows that a relationship between speed and flow was found in every case of mixed traffic at a certain segment of road. This relationship might be more complex (linear to nonlinear) if vehicles of all types (heavy, medium and light vehicles) and the percentage of slow moving vehicles were taken into account. This idea of a relationship between speed and flow was used for further experiments. Data has to be collected for speed and flow for each vehicle type in each stream. However, for the first step, each stream should be grouped based on its conflict pattern. The capacity by conflicting technique is as follows.

- Identification of conflicting groups for a three leg unsignalized intersection
- Formulation of relation between speed and flow for each conflicting group
- Estimation of maximum flow for each conflicting group
- Capacity estimation by minimum of all maximum flow conflicting groups

### 3.2 Conflicting Stream Description and Conflict Group

General scheme of vehicle streams at three–leg unsignalized intersections were defined to construct the conflict streams. Many researchers have taken the scheme for capacity analysis purposes. Kimber and Coombe (1980) applied this technique for three–leg intersections, however, they have not defined the conflicts at any point instead of group streams: left turning ($C_{B\text{-}C}$, $C_A\text{-}_B$) right turning road stream ($C_{B\text{-}A}$, $C_{C\text{-}B}$) as shown in Figure 3.1. Effects of geometric features of an intersection were considered. Flow of different types of vehicles was also considered but only for light and heavy vehicles (LV and HV). By this approach, for a saturated flow the capacity would take if all road flows were zero and rule of priority was applied. However, under mixed traffic flow, intersections were difficult to be saturated since traffic keeps moving under all circumstances.

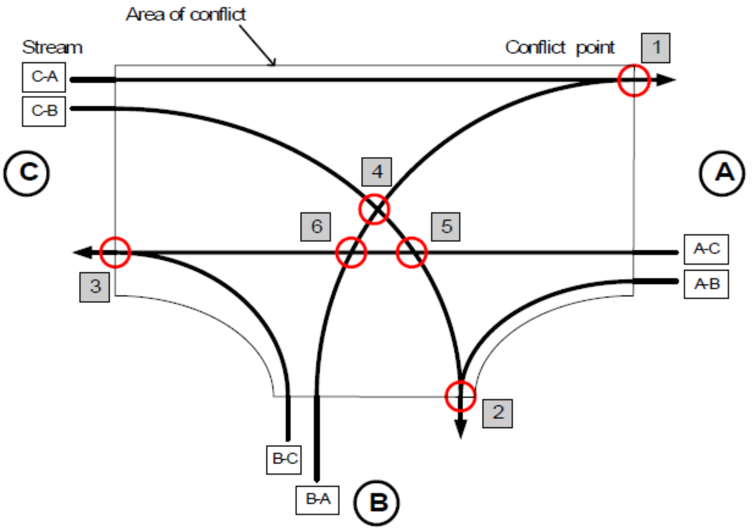



**Fig 3.1: Scheme of Conflict of Traffic Streams**

Recent analyses were based on interactions between streams which include parameters of journey speed, flow and road occupancy (Prasetijo, 2007). Due to these circumstances, each of the parameters for each stream has to be analyzed related to other streams included. The scheme for three legged intersection consists of six (6) streams (C – A, C – B, B – C, B – A, A – C, A – B) and six (6) conflict points (1, 2, 3, 4, 5, 6). Furthermore, it was proposed to have six (6) groups of conflicts (I, II, III, IV, V and VI) which include all streams' conflicts and each group has its own subject stream (presented in Table 3.1). Because this study does not use any of the priority rules, six subject streams have to be defined for further analysis. Each stream (C – A, C – B, B – C, B – A, A – C, A – B) remains the subject stream of its conflict group. Each of them should be considered further in order to find their maximum flow. In general, the conflict groups were defined as the subject stream which leads to conflicting with other streams. In case of the subject stream, C – A has only met one conflict movement with stream B – A, but subject stream B – A would meet more streams (C – A, C – B and A – C).

**Table 3.1: Interaction of Traffic Streams of Each Conflict Group**

| Group of Conflict | Subject Stream | Conflict Point | Streams Involved |
|---|---|---|---|
| I | C – A | 1 | C – A, B – A |
| II | C – B | 2,4,5 | C – B, B – A, A – C, A – B |
| III | B – C | 3 | B – C, A – C |
| IV | B – A | 1,4,6 | B – A, A – C, C – B, C – A |
| V | A – C | 3,5,6 | A – C, C – B, B – A, B – C |
| VI | A – B | 2 | A – B, C – B |

Further analysis of speed and flow of each stream always relies on this description. Investigations of conflict groups were conducted in terms of flow and speed in each flow stream and its portion based on total flow of its group was counted.

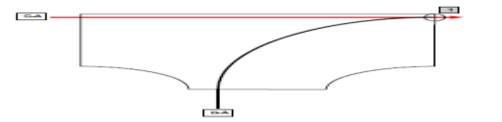
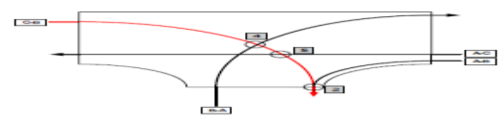
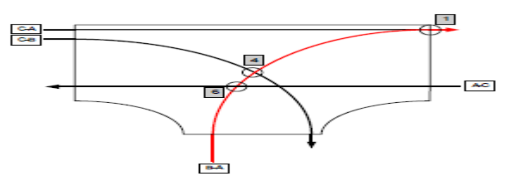
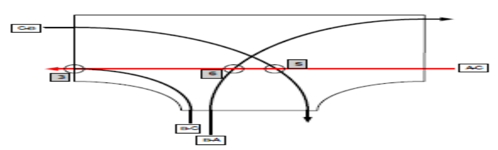
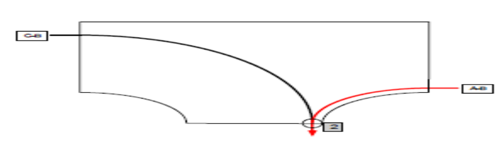
It is difficult to compare speed data of one intersection with remaining intersections as they differ in composition of vehicles and geometric features. Therefore, the study also found difficulties to analyze the general relationship between flow and speed of each stream which can represent the relationship for all intersections due to the above mentioned dissimilarities.

### 3.3 Speed and Flow Relationship of Each Stream

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

Despite the speed and flow relationship between each type of vehicle from each stream, the relationship between the flow of each stream ($Q_{C-A}$, $Q_{C-B}$, $Q_{B-C}$, $Q_{B-A}$, $Q_{A-C}$, $Q_{A-B}$) of each conflict group (I, II, III, IV, V, VI) and the speed of each stream ($V_{C-A}$, $V_{C-B}$, $V_{B-C}$, $V_{B-A}$, $V_{A-C}$, $V_{A-B}$) was also developed, because further capacity calculations would be based on each stream performance of every conflict group. Table 3.2 shows the relationship adopted for each conflict group and also its nature of conflicting process. From the table, it can be seen that the *red line* remains the subject stream and dark-black colour represents the streams included in a conflict group.

**Table 3.2: General Functions and Scheme of Speed- Flow Relationship at Conflict Group**

| Group of Conflict | Function | Scheme |
|---|---|---|
| I | $V_{C-A} = a_{C-A} - b_{C-A}Q_{C-A} - b_{B-A}Q_{B-A}$ |  |
| II | $V_{C-B} = a_{C-B} - b_{C-B}Q_{C-B} - b_{B-A}Q_{B-A} - b_{A-B}Q_{A-B} - b_{A-C}Q_{A-C}$ |  |
| III | $V_{B-C} = a_{B-C} - b_{B-C}Q_{B-C} - b_{A-C}Q_{A-C}$ |  |
| IV | $V_{B-A} = a_{B-A} - b_{B-A}Q_{B-A} - b_{A-C}Q_{A-C} - b_{C-A}Q_{C-A} - b_{C-B}Q_{C-B}$ |  |
| V | $V_{A-C} = a_{A-C} - b_{A-C}Q_{A-C} - b_{C-B}Q_{C-B} - b_{B-C}Q_{B-C} - b_{B-A}Q_{B-A}$ |  |
| VI | $V_{A-B} = a_{A-B} - b_{A-B}Q_{A-B} - b_{C-B}Q_{C-B}$ |  |

## IV.DATA COLLECTION AND ANALYSIS

### 4.1 GENERAL

The study of traffic behavior is useful for traffic engineers to design intersections, for developing traffic control warrants, traffic signal timings, vehicle storage lanes. Data is needed for analysis and understanding of the traffic conditions. The data can be collected by manual method or mechanical method or photographic methods.

### 4.2 DATA REQUIREMENTS

The main objective of this study is to find the capacity of unsignalized intersection using conflict technique. For this the following field observations are necessary.

- Travelled distance for each movement on each approach
- Times of arrival and departure at reference lines for each vehicle from each stream
- Approach speed of the vehicles
- Volume at unsignalized intersection movement-wise

### 4.3 DATA COLLECTION METHODS

The methods available for collecting the data at the intersection are

1. Manual Methods
2. Mechanical Methods
3. **Photographic Techniques**

### 4.3.1 MANUAL METHODS

Manual counts are typically used when

- Small data samples are required
- Automatic equipment is not available, or the effort and expense of using automated equipment are not justified
- The count period is less than a day

Manual counts are typically used to gather data about the following:

- Vehicle classifications

- Turning movements
- Direction of travel
- Pedestrian movements
- Vehicle occupancy

The number of people need to collect data depends on the length of the count period, type of data being collected, number of lanes or cross walks being observed, and traffic volume.

**4.3.2 MECHANICAL METHODS**

Automatic counting methods were used to gather large amounts of traffic data over an extended period of time. Counts are generally collected for 1-hour interval in 24-hour period. Automatic counting methods are generally used to determine traffic patterns and trends. The following information can be determined using automatic counts:

- Hourly traffic patterns
- Daily or seasonal variations
- Growth trends
- Annual traffic estimates

Observers can use portable or permanent automatic counters.

**Portable counters** consist of automatic recorders connected to pneumatic road tubes. They are typically used to collect the same kind of data collected in manual counts, but for longer periods, usually 24 hours.

**Permanent counters** are sometimes built into the pavement and used for long-term counts. The equipment is expensive, and relatively few jurisdictions have access to it. They are typically used to collect the continuous data for longer periods.

**4.3.3 PHOTOGRAPHIC TECHNIQUES**

Several problems are encountered when collecting traffic information by conventional methods and which leave scope for the development of more comprehensive techniques. Data collection and analysis made by manual and mechanical methods are proving to be increasingly cumbersome and inadequate to pursue the complex interactions among man machine, environment, time and space. The sophistication in instrument has now reached a high degree aided by the developments in electronics and computers. Photographic techniques fall into this category of useful instruments. The different methods involving the principle of photography in traffic studies are:

- Continuous stereoscopic strip photography
- Stereo camera photos from stationary object on the ground
- Conventional air photography
- Time-lapse photography
- Video graphic technology

Among all these techniques, the latest development in the field of instrumentation from the traffic studies is the video graphic technique.

**Video graphic Technique**

The video system can be mounted on a car, at a stationary point by the side of a road or at an elevated point. The instrument consists of the following components:

- Video camera to record the video of traffic from moving vehicles
- Video recorder and player to record the images taken from the camera on to the videocassettes and to play back the record cassettes at anytime later.
- Monitors (TV screens)

The greatest advantage with this system is its versatility. Views from the separate cameras can be brought out simultaneously on the screen, the top half representing the view from one camera and the bottom half from another.

This technique can be used for gap and lag studies, speed-volume studies, speed-fuel consumption, overtaking and crossing studies. For getting the data at three-legged intersections one video camera is required for recording the traffic approaching from all legs. Care must be taken in recording video such that there are no obstructions for traffic data collection.

**4.4 INVENTORY OF INTERSECTION**

For the present study, four T-shaped 3-legged intersection in Warangal city were identified. The intersections were chosen such that one road has the priority over the other the traffic at the intersections is not controlled either manually or by signalization and there is a reasonable traffic on both major and minor road. The identified intersectionand the details are listed in table 4.1. There is no gradient.

**Table 4.1 Details of geometric design of intersection**

| S.NO. | INTERSECTION NAME | APPROACH WIDTH |
|---|---|---|
| 1 | FATHIMA JUNCTION | A=7.5, B=6.5m,C=7.5m |

**4.5 ADOPTED SURVEY METHODOLOGY**

**4.5.1 Video graphic Survey**

The field data was collected by video graphic technique. The data collection was carried out using a video camera (Model No. HDR-PJ260VE).

For intersection data for speed, traffic volumes at the minor road and at the major road, geometric details of the intersections, roadside activities and type of environment (commercial, residential, limited access). These parameters were monitored by video camcorders and were manually extracted from the videos by playback.Every stream was observed by using video camera which is placed at the edge of the road near thecorners of the intersection. From these points the traffic movements could be observed very clearly. Each intersection was investigated during two hours either in the morning (08.00 – 10.00) or in the afternoon (4.30 – 6.30). These periods were considered as the peak period times.

Data were counted from the recorded cassettes by using monitors. First, data from the recorded cassettes had to be transferred to the DVD's. Viewing the monitor, time instants when the vehicles arrive at specified points of the intersections were noted. Times of arrival and departure were recorded for each vehicle from each stream. Based on the arrival and departure time as well as the travelled distance of each movement, the speed of each vehicle is found out. Travelled distance for each movement were measured based on reference lines which were drawn at each approach and which could also be seen at the monitor (cassette recorded). Furthermore, speed and volumes were aggregated in 1–minute interval.

**4.6 TRAFFIC FLOW MEASUREMENTS**

The traffic flow parameters considered in this study are major street speed and volume. For collecting data for speed, a 20 m stretch away from the intersection area was taken. The time of entry and time of exit for each type of vehicle was noted down and the speed was calculated. The $50^{th}$ percentile speed was taken as the maximum approach speed of the vehicles to the intersection. The format given in table 4.2 was used for the speed data collection from the video.

**4.7 ANALYSIS OF DATA**

The analysis of collected data was carried out as per the methodology explained in Section 3.5. The data collected for intersection is listed in Table 4.3. Each sample represents the average speed and flow value for all observed 1-minute intervals. Mean speeds have been determined for each stream at its conflict group. This was counted on the total average speed in a stream. The traffic composition details of intersection are presented in table 4.3. The speed details are presented in table 4.10. Correlation between speed and flow were developed using simple regression analysis. A linear model for the relationship was found to have $R^2$in the range of 0.5 – 0.9. Various levels of correlation were found for the relation between subject stream and group conflict flow. If the correlation level is low, it was assumed that the stream faced more conflicts and lower number of vehicles than other streams. The bar chart and graphs for a flow of each group of conflict showed that the proportion of speed has followed the flow variation.

**FATHIMA JUNCTION**

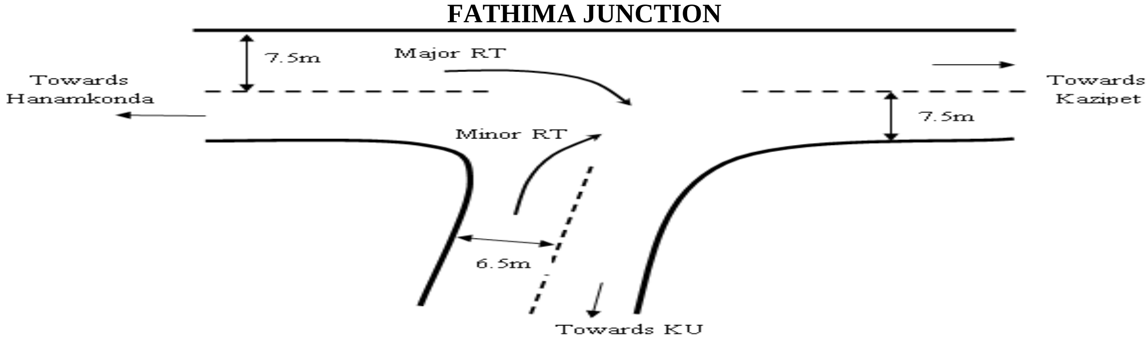



Fig 4.1: Scheme of turning movements at Fatima junction

**Table 4.3: Traffic Composition of Each Stream at Fathima Junction**

| Type of Vehicle | Streams | | | | | |
|---|---|---|---|---|---|---|
| | C-A | C-B | B-C | B-A | A-C | A-B |
| | Percentage Vehicle Composition | | | | | |
| Motor Cycles (MC) | 4.7 | 8.6 | 8.2 | 6.6 | 4.7 | 4.4 |
| Autos (A) | 11.4 | 5.0 | 3.4 | 4.1 | 10.6 | 4.7 |
| Cycle Rick. & Other Slow Veh. (OT) | 0.4 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 |
| Car | 0.7 | 1.1 | 0.4 | 0.7 | 0.5 | 0.5 |
| Cycles (CY) | 1.2 | 0.7 | 1.2 | 1.0 | 0.5 | 0.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Buses (B) | 0.7 | 0.0 | 0.2 | 1.1 | 1.2 | 1.4 |
| Tractors and Tractor Trailers (TT) | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 |
| Light Commercial Vehicles (LT) | 0.9 | 1.8 | 0.5 | 1.5 | 0.5 | 1.3 |
| Two Axle Trucks (HT) | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.2 |
| Multi Axle Trucks (MT) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | **Percentage Movement** | | | | | |
| | 20.0 | 18.0 | 14.5 | 15.6 | 18.2 | 13.7 |

## V. CAPACITY ESTIMATION USING HCM PROCEDURE

Capacity analysis at TWSC intersections depends upon a clear description and understanding of the interaction of drivers on the minor or stop-controlled approach with drivers and vehicles on the major street. The input values for capacity estimation such as turning volume, gradient and vehicle composition are collected from field. The critical gap and follow-up time values were taken as per HCM (2000). Table 5.8 shows the total volume and Proportion of Heavy Vehicles.

**Table 5.1 Vehicle Volumes and Adjustments for Intersection**

| **Movement** | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Volume (pcu/h)** | 1267 | 152 | 268 | 384 | 1102 | 401 |
| **Proportion of Heavy Vehicles** | 0.01 | 0 | 0 | 0.03 | 0.01 | 0.03 |

The critical gap can be estimated from the expression (2.16) provided in Chapter 2. Table 5.2 shows the critical calculations after applying the different adjustments. Table 5.3 shows the critical calculations for follow up time after applying the different adjustments.

**Table 5.2 Determination of Critical gap**

| **Description** | **Movement for** | | |
|---|---|---|---|
| | **Major Right Turn** | **Minor Left Turn** | **Minor Right turn** |
| | 2 | 6 | 5 |
| $t_{c,base}$(s) | 4.1 | 6.2 | 7.1 |
| $t_{c,HV}$(s) | 1 | 0 | 0 |
| $P_{HV}^{*}$ | 0.01 | 0.01 | 0.01 |
| $t_{c,G}$(s) | 0 | 0.1 | 0.2 |
| G* | 0 | 0 | 0 |
| $t_{c,T}$(s) | 0 | 0 | 0 |
| $t_{3,RT}$ (s) | 0 | 0 | 0.7 |
| $t_c^{*}$ (s) | 4.11 | 6.2 | 6.4 |

* Values are obtained from HCM (2000)

**Table 5.3 Determination of Follow up time**

| **Description** | **Movement for** | | |
|---|---|---|---|
| | **Major Right Turn** | **Minor Left Turn** | **Minor Right turn** |
| | 2 | 6 | 5 |
| $t_{f,base}$(s) | 2.2 | 3.3 | 3.5 |
| $t_{f,HV}$(s) | 0.9 | 0 | 0 |
| $P_{HV}$ | 0.01 | 0.01 | 0.01 |
| $t_f$(s) | 2.209 | 3.3 | 3.5 |

## VI.SUMMARY AND CONCLUSIONS

### SUMMARY

Studied were carried by various researchers for analyzing the capacity at unsignalized intersections based on priority, gap acceptance and empirical approaches. Recent advance in capacity analysis is conflict technique and it can be applied for first–in–first–out (FIFO) discipline where this kind of discipline is common in Indian cities. The conflict technique is based on the concept where interactions and impact between flows at intersections is brought through mathematical formulation. The capacity by this technique can be defined as the maximum possible flow of the intersection corresponds to the relationship of speed and flow of streams at each group of conflict. The study was carried for possibility of correlation between speed and flow at selected three–leg unsignalized intersection in Warangal. 2-hour speed and flow values were obtained for each vehicle category in each stream of flow. Six conflict groups were identified and two to four streams are interacting in each conflict group. Combined speed-flow relations were developed for each conflicting group from field observations. From these relations, maximum flow for each conflicting group was arrived. The capacity for intersection is the minimum of all maximum flows for all conflicting groups and minor approach capacity is flows from all streams derived from speed-flow relationships.

## CONCLUSIONS

The following conclusions are drawn from the study:

- Conflict technique is a simple method for calculating capacity of unsignalized intersections where the input data like volume and entry, exit time of each type of vehicle can be easily measured from the field where as for gap acceptance models the input parameters i.e., critical gap and follow up time measurement is very complicated.
- Based on traffic flow and speed measurements, the maximum flow of a stream, the total capacity of an intersection can be calculated and the maximum flow of each stream can also be measured.
- All possible maximum flows at intersections have been calculated by using the model (equation) and use the matrix for simplification.
- The real maximum flow as the capacity of the intersection is the least of all possible maximum flows.
- This study has also calculated the capacity based on the HCM (2000) which was a standard method of comparison for the results obtained by the conflict approach.
- The capacities obtained from the conflict technique are slightly higher values than that obtained from HCM method and final capacities obtained for minor approach from both these methods have 16% deviations.
- The capacities of each movement can also be calculated using conflict technique, where as in HCM procedure there is no such formulas for each movement.

It can be concluded that the conflict approach can be suitable to calculate the capacity of unsignalized intersections under mixed traffic flow, especially for India as an alternative instead of the method by the Highway Capacity Manual (2000).

## SCPOE FOR FURTHER STUDY

The present work can be extended as indicated below

- In this study, pedestrians are not considered, so further study canfocus on pedestrian movements along with vehicle movements.
- The equations developed in this dissertation are to T-junction and the same procedure can also be applied for four-legged intersections.
- It was recommended to extend the two hour study to until the maximum flow of intersections is reached and the real speed can be counted in order to achieve a better prediction.

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