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HEADWAY COMPRESSION AND QUEUE DISCHARGE CHARACTERISTICS OF MIXED TRAFFIC AT SIGNALISED INTERSECTIONS

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***Abstract*-The assessment and performance of signalised intersections often require the determination of capacity of approach lane or lane group, the intersection clearing speed of queued vehicle during queue discharge. The fundamental element of a signalised intersection is the periodic stopping and starting of the traffic stream. When a signal turns green from red, first of the stopped vehicles (1st vehicle of the queue) starts to move and cross the intersection. Then, the second vehicle in the queue starts to move and so on. The evaluation of capacity at signalized intersection is an important component in the planning, design, operation, and management of transportation system. Presently, the methodologies available for the estimation of capacity of signalised intersections are based on the concept of saturation flow (s). The study describes the headway, and speed characteristics of vehicles during queue discharge after green onset under mixed traffic condition. For the present work data were collected at different signalized intersections in the city of Bhubaneswar, India under highly mixed traffic conditions. It has been found that the queue discharge headways shows an unmistakable pattern of gradual compression as queuing vehicles are discharged in succession. However, contrary to the traditional concept of saturation flow, the discharge rates do not become stable after the fourth queuing vehicle enters the intersection. The average discharge headways become stable from position 6th (sixth) under mixed traffic conditions. The intersection clearing speed of queued vehicles at different queue position was also determined and the speed is in the increasing order. The average time required by vehicles to clear the intersection is also assed and the time decreases as the queue position increases.**

***Keywords*— Saturation flow, signalised intersection, saturation flow region, mixed traffic.**

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I. INTRODUCTION

The primary component of a signalised intersection is the periodic stopping and starting of the traffic stream. When a signal turns green from red, first of the stopped vehicles (1st vehicle of the queue) starts to move and cross the intersection. Then, the second vehicle in the queue and so on. As the queue of vehicles moves the headway measurements with respect to a fixed point or line (say STOP line) are taken. If many queues of vehicles are observed at a given intersection and the average headway is determined, and this average headway tend towards a constant value. The constant headway achieved is referred to as the saturation headway (h_s). Saturation flow is a macro performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under ideal conditions (no gradient, no parking or bus stops near the intersection, no pedestrians or cyclists etc.). However, to determine the saturation flow rate from time measurements taken in the field the following equation is used:

$$S = 3600/h_s \quad (1)$$

Where: S = saturation flow rate;

3600 = number of seconds per hour;

h_s = saturation headway.

This saturation headway (h_s) can be used to determine the maximum number of vehicles that can be released during a specified green time and also to determine the saturation flow rate. The saturation flow rate (s) is an important parameter for estimating the performance of vehicular movement at signalised intersections. Saturation flow rate for a lane group is a direct function of vehicle speed and separation distance. The established concept for the determination of capacity demands the concept of saturation flow (Alcelik-1982; HCM; Teply et al. 1995). On the basis of saturation flow, the capacity of a traffic lane or lane group is determined in HCM as follows:

$$c = s\frac{G+Y-L}{C} \quad (2)$$

Where,

c = capacity of a lane or lane group (vehicles per hour, vph)

s = saturation flow (vph of effective green time)

C = cycle length (s)

G = green interval (s)

Y = signal change or intergreen interval (s)

L = loss time in a single phase resulting from start-up delays and signal change from green interval to yellow warning interval (s).

Intersection clearing speed of queued vehicles is the average speed at which a queue traverses an intersection (from the upstream to the downstream). The intersection clearing speed of vehicles is helpful in judging the efficiency of an intersection. The general trend is that more the clearing speed during queue discharge, more is the capacity of intersection. The understanding in clearing speed with queue position is required to judge the performance of the signalised intersection after the green signal light allocation. Therefore, the present study was undertaken to study the headway, speed, and intersection clearing time characteristics of vehicles during queue discharge at signalised intersections under highly heterogeneous traffic conditions.

Literature on queue discharge characteristics of vehicles at signalised intersections under mixed traffic conditions where large proportion of the traffic does not follow the rules of the road is limited. The design of traffic signal timing and evaluation of intersection performance is done based on the available saturation flow data. Rahman et al. (2005) compared the saturation flow rates at signalised intersections in Yokohama and Dhaka. Lin and Thomas (2005) opined that the saturation flow do not reach stabilized maximum value after the fourth queuing vehicle enters the intersection. Mccoy and Heimann (1990) assessed the effect of driveway traffic on saturation flow rates at signalised intersections. Fujiwara et al. (1994) studied on saturation flow rates at urban signalised intersections in winter season. Lin et al. (2004) studied the variations in queue discharge patterns and their implications in the analysis of signalised intersections in Taiwan. Bhattacharya and Mandal (1982) studied the clearing speed of vehicles at 23 different intersections in Calcutta. Chandra et al. (1996) studied at 19 intersections to determine the clearing speed for different category of vehicles.

II. FIELD STUDY AND DATA COLLECTION

For the present study data were collected at different signalised intersections of Bhubaneswar city, Odisha. The intersections were free from the effect of bus stops, parked vehicles and pedestrian movements. Data were collected on different weekdays on all the intersections. In all, 467 cycles of traffic data were collected at different signalised intersections. Queuing vehicle refer to those vehicles that are stopped by the red light and those join the stationary queue of vehicles. As the queue of vehicles moves the headway measurements with respect to a fixed point or line (say STOP line) are taken as follows:

- The first headway is the time lapse between the initiation of green signal and the time that the rear wheel of the first vehicle in the queue cross the stop line.
- The second headway is the time lapse between the time that the first vehicle’s rear wheels cross the stop line and the time that the second vehicle’s rear wheels cross the stop line.
- Subsequent headways are similarly measured.
- During over saturated condition, only the headway of those vehicles that cleared the intersection by using green time of a phase was considered.

Speed data were collected for about 3-4 hours using video recording at each intersections. Only the vehicles in queue and leaving intersection as the signal turns green and going straight were selected for the speed study. For data collection, the stop line at an intersection was used at the first reference mark. The width of the intersection was considered for the calculation of speed. The total width of the intersection was divided into two equal parts. The time required to cover the individual parts by each and every vehicle was extracted from the recorded film and are used to estimate the intersection clearing speed and intersection clearing time. A total of about 650 observations were taken for the speed study.

III. ANALYSIS OF DATA

When the signal at an intersection turns green, the vehicles in the queue will start moving. The vehicle headways can now be described as the time elapsed between successive vehicles crossing the stop line. The first headway will be the time taken until the first vehicle’s rear wheels cross the stop line from the light turns green. The second headway will be the time taken between the crossings of the first vehicle’s rear wheels until the crossing of the second vehicle’s rear wheels over the stop line and so on. In general, the headway value corresponding to the i^{th} vehicle gives the headway between the i^{th} and $(i-1)^{th}$ vehicle. The first driver in the queue needs to observe and react to the signal change at the start of green time. After the observation, the driver accelerates through the intersection from stand-still which results in a relatively long first headway. The second driver performs the same process with the exception that the driver could react and start accelerating whilst the first vehicle began moving. This results in a shorter headway than the first, because the driver had an extra vehicle length in which to accelerate. This process carries through with all following vehicles where each vehicle’s headway will be slightly shorter than the preceding vehicle. This continues until a certain number of vehicles have crossed the intersection and start-up reaction and acceleration no longer have an effect on the headways. From this point headways will remain relatively constant until all vehicles in the queue have crossed the intersection or green time has ended. To provide a better insight into the nature of queue discharge, the headway data are represented graphically in Figure 1. The average discharge headways become stable from the 6^{th} (sixth) position of the discharged queue of vehicles. In aggregate, the average queue discharge headways exhibit an unmistakable trend of gradual compression as queuing vehicles are discharged in succession. Li and Prevedouros (2002) and Lin et al. (2004) also reported that the queue discharge headway tends to compress as the discharge of a queue progresses. Bester and Meyers (2007) reported that saturation headway can start to occur anywhere between the third and sixth vehicle in the queue.

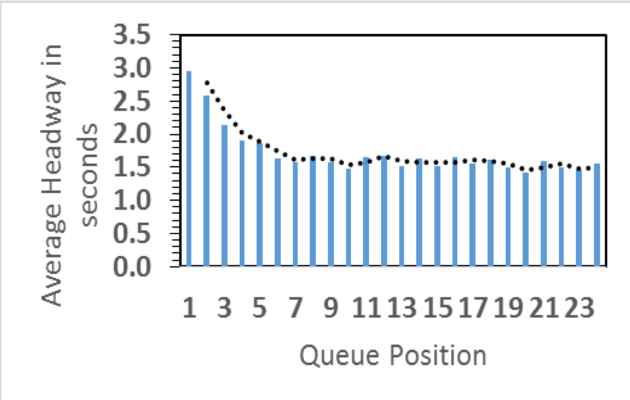

Figure 1: Characteristics of queue discharge headways

The collected data were analysed to calculate speed of vehicle clearing the intersection. The details of average time required by all the queued vehicles during queue discharge are plotted in Figure 2. From the Figure 2 it is clear that, as the queue position increases (i.e. i^{th}, $(i+1)^{th}$ vehicle), the time required to clear the width of the intersection decreases. It is due to the fact that any $(i + 1)^{th}$ vehicle starts to move from the upstream of the stop line. Therefore, the $(i + 1)^{th}$ vehicle attains some speed when it crosses the stop line and obviously time required to clear the intersection width decrease as compared to the previous i^{th} vehicle.

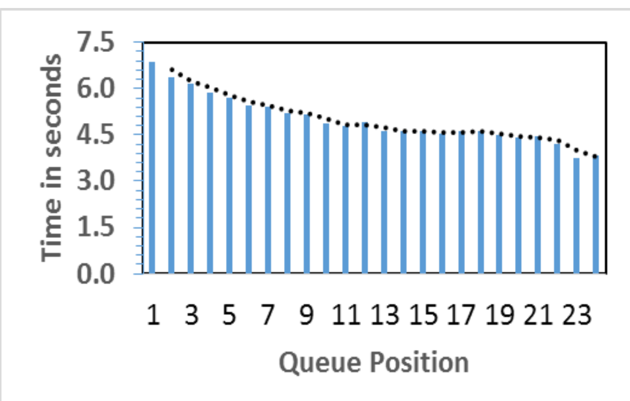

Figure 2: Intersection clearing time v/s position of the vehicle in the queue

The intersection clearing speed of the vehicles was calculated by dividing the intersection width by the time required to clear the width of the intersection. The average clearing speed of vehicles was calculated for the first half and last half of the intersection width for each queue position. The average intersection clearing speed was also calculated and the details are given in Table 1. As may be seen that the clearance speed is varying from 19 km/h to 35 km/h. As the position of the vehicle in the queue increases, the clearing speed increases. The initial vehicles take longer time due to perception-reaction time and additional time required to accelerate to a reasonable speed to cross the intersection. The later vehicles in the queue more or less achieve this reasonable speed during crossing the intersection as they start moving from a distance further upstream from the reference point (say STOP line). Therefore, during crossing the reference line (say STOP line) the speed of initial vehicles is quite low as compared to other vehicles in the queue.

Table 1 : Intersection clearing speed statistics of vehicles during queue discharge

Queue Position	V_1(m/s)	V_2(m/s)	V(m/s)	V(km/h)
1	4.253	7.331	5.379	19.364
2	4.780	7.390	5.802	20.887
3	5.096	7.273	5.990	21.565
4	5.286	7.731	6.276	22.592
5	5.539	7.830	6.485	23.346
6	5.728	8.214	6.746	24.285
7	5.911	8.070	6.821	24.555
8	6.250	8.214	7.096	25.546
9	6.446	8.000	7.137	25.694
10	6.801	8.558	7.577	27.277
11	6.903	8.720	7.704	27.733
12	6.679	8.638	7.531	27.110
13	7.115	9.154	8.004	28.816
14	7.198	9.064	8.022	28.878
15	7.171	9.020	7.987	28.753
16	7.341	9.200	8.164	29.389
17	7.143	9.109	8.004	28.816
18	7.034	9.340	8.022	28.878
19	7.708	8.846	8.237	29.652
20	7.839	9.020	8.386	30.191
21	7.520	9.246	8.292	29.852
22	8.259	9.293	8.744	31.479
23	9.069	10.760	9.840	35.424
24	9.487	9.787	9.634	34.684

Where, V_1 = clearing speed from the reference line to the middle of intersection

V_2 = clearing speed from middle of intersection to the end of intersection

V = Average intersection clearing speed

IV. CONCLUSIONS

The present paper demonstrates the headway, speed, and intersection clearing time characteristics of vehicles during queue discharge at signalised intersections in India. Estimation of accurate saturation flow rate is the fundamental building block in the management of efficient urban traffic control. The ideal saturation flow rate may not be achieved (observed) or sustained during each signal cycle. In most HCM analyses, the value of saturation flow rate is a constant based on the parameters input by the user, but in reality, this is a value that varies depending on the cycle by cycle variation of situations and users. The traditional concept of saturation flow may not realistically represent the actual queue discharge characteristics. For signal designing, it is often necessary to put emphasis on this parameter due to the high degree of fluctuation in this parameter from cycle to cycle. It is also difficult to identify the position of queued vehicle from where the saturation flow region starts or the steady maximum discharge rate of vehicles. The queue discharge characteristics under mixed traffic conditions exhibit a general trend of gradual compression of headways as the queue discharge continues. Contrary to the traditional concept of saturation flow, the discharge rates do not become stable after the fourth queuing vehicle enters the intersection. The average discharge headways become stable from position 6th (sixth) under mixed traffic conditions. The intersection clearing speed was estimated from the field observations and the speed of queued vehicles at different queue position was also determined and the speed is in the increasing order. The average speed for the first vehicle in the queue is 19 km/h whereas it increases to 35 km/h as the queue position increases. The intersection clearing time is also studied and it is observed that the clearing time decreases as the position of the vehicle in the queue increases.

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