Analysis of Estimating Saturation Flow under Heterogeneous Traffic Condition as against Conventional Techniques

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Abstract— Saturation flow is the most important parameter used to determine the capacity of a signalized intersection which directly influence in determining the phase time of the traffic signal. Most of the existing and popular methods available to determine saturation flow rate are established under homogeneous traffic condition where cars are the predominant users and lane discipline is strictly followed. Queue length should be known to the last vehicle to calculate the saturation flow using the traditional average saturation headway method. But it is difficult to measure the queue length during peak hours when long queue is formed. In heterogeneous traffic condition the base saturation flow considered in HCM 2010 cannot be an ideal one, since it depends on the vehicle flow rate, cycle timing, driver perspective, approach volume etc. IRC:SP:41-1994 also have explained a relationship between saturation flow and capacity. By the use of these conventional methods under Indian condition, the saturation flow rate is either over estimated or under estimated due to the heterogeneity of traffic. This study aims at determining saturation flow as per ground scenario under heterogeneous traffic condition considering a four arm fixed time signalized intersection using Root Mean Square (RMS) method. It also aims to compare the study method with equations explained in HCM 2010 and IRC:SP:41-1994.

Key words: Saturation flow rate, signalized intersection, cycle time, root mean square

I. Introduction

The saturation flow rate represents the maximum rate of flow for a traffic lane, as measured at the stop line during the green indication. Saturation flow rate in controlled flow is more complex to analyse than in uncontrolled flow. Traffic signals are the most common and significant source of controlled flow. Average saturation headway method and saturation flow rate equation described by Highway Capacity Manual (HCM), capacity and saturation flow relation by Indian Road Congress (IRC):SP:41-1994 are the frequently used methods to determine saturation flow. Average Headway method explains that after the fourth vehicle in queue, the successive vehicles will have constant headway until the last vehicle in the original queue has passed. With long queue especially during peak hours, it becomes difficult to count the queued vehicles even through the video recording survey otherwise aerial survey techniques should be used which are much costlier. HCM 2010 [5] describes an equation to compute the adjusted saturation flow rate per lane for the subject lane group where a base saturation flow rate of 1900 veh/hr/lane is considered along with 10 adjustment factors. The selection of this base saturation flow rate itself is an assumption with geometric and traffic conditions that correspond to a value of 1.0 for each adjustment factor. IRC:SP:41-1994 [10] explains a relationship between capacity, saturation flow, cycle time and green time of the signalized intersection.

In developing countries where two wheelers play a major role in vehicular composition and nearly little lane discipline is followed, the above methods turn out to be a theoretical agreement. Presence of heavy vehicles in the vehicular flow may result in longer headways when compared to passenger cars. On the contrary presence of two wheelers may result in lesser headway. These methods can result in an over-estimated or under-estimated saturation flow rate value when used for heterogeneous traffic conditions. Many studies have pointed out the need to determine field saturation flow rate in developing countries rather than following the traditional methods. The purpose of this paper is to study the saturation flow based on the ground scenario for a fixed time four arm signalized intersection in India using Root Mean Square (RMS) method under heterogeneous traffic condition. The study also compares the field result with HCM 2010 and IRC:SP:41-1994 for saturation flow.

II. Literature Review

"Saturation Flow rate is the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced" – HCM 2010.

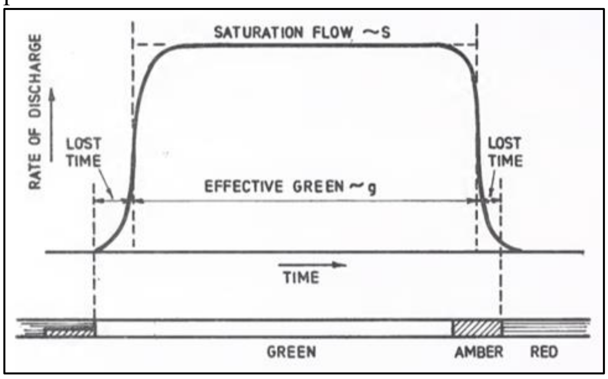

Fig. 1: Saturation Flow and Lost Time graph

Chang-qiao Shao and Xiao-ming Liu [3] explained with 11 surveyed signalized intersections in Beijing that the traditional estimation of saturation headway does not accurately reflect the true value of headway. As a result, the traditional estimation would underestimate saturation flow rate. C. J. Bester and W.L. Meyers [2] found out that the effects of speed limit, gradient and number of through lanes on the saturation flow rate are much greater in Stellenbosch, South Africa, than in the USA. Partha Pratim Dey et.al. [13] explains saturation flow rate is a value that varies cycle by cycle depending on the variation of users and site condition.

He also explains the traditional concept of saturation flow may not realistically represent the actual queue discharge characteristics. Subhash Chand et.al. [18] describes how the heterogeneity and homogeneity of traffic affects the saturation flow values. More the presence of two wheelers in the vehicular composition results increase in saturation flow per meter width. Md. Mizanur Rahman et. al. [12] does a comparative study on saturation flow in Yokohama, Japan and Dhaka, Bangladesh. The study shows that the HCM procedure overestimated the saturation flow rates for the observed intersection approaches, for few intersections as high as 4.4%. Abdulai Abdul Majeed et.al. [1] compares the HCM base saturation headway 1.9s with the observed headway obtained from intersections in Huntsville, Birmingham and Montgomery cities of Alabama. This study explains the significant difference between the discharge headway observed and HCM recommended and highlights the need for field investigation of saturation flow. Yi Zhao et.al. [21] attempted to calibrate the saturation flow rate and start up lost time when developing signal timing. This study started from headway distribution and attempted to specify the relationships between headway and vehicle position directly. Stephen M. Remias et.al. [20] has proposed slightly enhanced methods to determine saturation flow rate and saturation flow rate reliability after reviewing the traditional methods to estimate saturation flow rate. Partha Pratim Dey [14] demonstrates contrary to the traditional concept of saturation flow that the discharge rates do not become stable after the fourth queueing vehicles but from the 6th position under heterogeneous condition. Rafael I. Perez-Cartagena and Trako [16] based on studies discovered the reduction in saturation flow rate by 8% for medium size town and 21% for small towns as compared to the large towns.

III. STUDY LOCATION AND DATA COLLECTION

Pattom junction – at grade fixed time four arm signalized intersection, the study intersection, is located at Thiruvananthapuram, the capital city of Kerala. Kerala is a state in the southwestern coast of India. Pattom intersection is one of the busiest junctions in the city characterised by two schools, one hospital and several office and residential buildings in the vicinity. Over one lakh vehicles cross Pattom Junction everyday (92,150 vehicles per day as per 2010-11, as per the Annual Report by NATPAC). The critical approach arm considered for this study provides straight, right and left turning traffic movements, with provision of zebra crossing at the mouth of the junction.

Videography survey was conducted at the study intersection covering peak hour traffic volume data. Video camera was fixed at a suitable vantage point from where the stop line of the approach arm and maximum queue length can be seen. Since the queue extends to more than 75 m, the last vehicle in the queue was not captured in the video recording. The study intersection is shown in figure 2.

Fig. 2: Study Intersection_Pattom Junction, Thiruvanathapuram, Kerala, India
Source: Primary Survey

IV. ANALYSIS AND RESULTS

Vehicular data is coded for different modes comprising of two wheelers, three wheelers, car, LCV, HCV, mini bus, bus and bicycle. Stop line at the study approach arm is considered as the base point of traffic flow. Vehicles crossing this stop line in a time span of 5 seconds are noted down. The approach arm with maximum peak hour traffic volume at the intersection is considered for further analysis to determine saturation flow. This approach arm is further called as the critical approach arm in this study as shown in figure 3. Figure 4 shows the vehicular composition of the critical approach arm in percentage; showing that two wheelers and three wheelers shows a significant presence in the traffic pattern.

Fig. 3: Critical approach arm_Pattom Junction, Thiruvanathapuram, Kerala, India
Source: Primary Survey

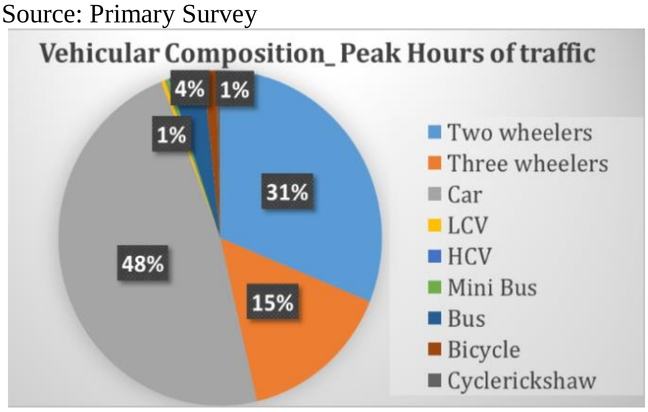

Fig. 4. Vehicular Composition of Critical approach arm_Pattom Junction, Thiruvanathapuram, Kerala, India
Source: Primary Survey

Relation between green time and vehicular flow in PCU are determined per 5 sec per cycle time per direction of flow considering straight, right and left moving traffic in the critical approach arm. Figure 5 shows data of straight moving traffic for a green phase time. These values are then interpolated to get a much smoother graph. Saturation flow rate is determined for interpolated data values of straight moving traffic flow using Root Mean Square (RMS) method as in equation (4.1).

"The RMS value of a quantity or a continuous-time waveform is the square root of the arithmetic mean value of the squares of values of the quantity taken over an interval" [6][7]. In the case of a set of n values $\{x_1, x_2, \ldots\ldots, x_n\}$, the RMS value is determined as in equation (4.1). Here x denotes the vehicular flow rate and x_{RMS} denotes the saturation flow rate.

$$x_{RMS} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + \cdots + x_n^2)} \quad (4.1)$$

In this study location, two wheelers from the back of the queue sneaks their way into the front of the queue near the stop line. As a result, when the signal turns green phase there occurs a major discharge of two wheelers for the first few seconds. This initial discharge gives a significant variation in the saturation flow rate. The higher value for vehicular flow rate in initial 5 seconds of green phase as shown in figure 5 is due to the heavy volume of two wheeler traffic generated in the front of the queue. Due to the influence of this heavy discharge in the initial seconds, saturation flow rate value significantly changes. Also the last seconds of the green time shows a substantial decrease in the flow of traffic affecting the saturation flow calculation.

Figure 6 shows the discharge pattern and saturation flow rate after disregarding the first and last 5 seconds of the green phase due to the difference in traffic flow pattern. The shaded portion under the saturation flow rate steady line provides the saturation flow value for the given green time of the signalized intersection. To conclude, saturation flow is estimated for the whole approach arm per cycle time. This is obtained by multiplying the combined saturation flow rate of all direction of flow to the signal green time for each cycle during the entire analysis period.

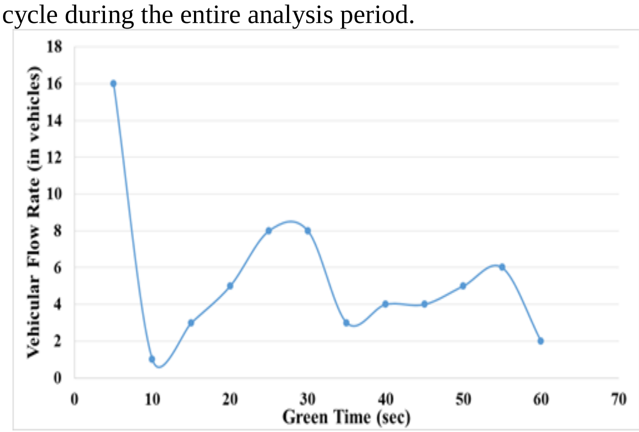

Fig. 5: Vehicular flow for green time per 5 second interval for straight moving traffic.
Source: Primary Survey Analysis

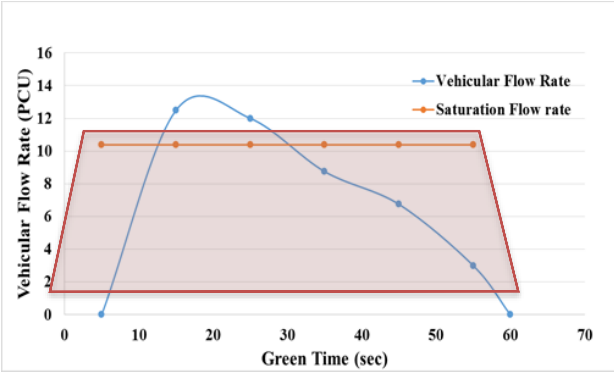

Fig. 6: Interpolated vehicular flow in PCU for green time per 10 second interval and saturation flow rate disregarding initial 10 seconds in the start of green time.
Source: Primary Survey Analysis

RMS value / Saturation Flow Rate disregarding the initial and last 5seconds of green time is obtained as 10.38 vehicles / lane. The study intersection - fixed time signalized intersection; has 30 number of cycles for peak hour traffic flow. Saturation flow for each cycle time is analysed separately as per ground flow condition. The vehicles are converted in PCU values for the analysis of saturation flow rate. The PCU values considered for this study is from IRC:SP 41-1994 [10] for intersection design as shown in table 1. Table 2 shows the combined saturation flow along with vehicular flow.

Type	PCU Equivalency
Two Wheeler	0.5
Three Wheeler	1
Car	1
LCV	1.5
HCV	3
Mini Bus	1.5
Bus	3
Bicycle	0.5

Table 1: PCU Equivalency for intersection design.

Sl. No:	Green Time (sec)	Combined Vehicular Flow (PCU/ Cycle Time)	Combined Saturation Flow / cycle time for whole approach arm
1	60	86	206
2	60	70	167
3	60	87	179
4	60	83	183
5	60	82	161
6	60	72	170
7	60	87	181
8	60	99	230
9	60	102	224
10	60	78	174
11	60	90	211
12	60	105	223
13	60	90	189
14	60	95	229
15	60	114	243
16	60	109	214
17	60	103	193
18	60	83	181
19	60	103	215
20	60	112	216

21	60	104	220
22	60	97	228
23	60	94	206
24	60	96	217
25	60	90	188
26	60	117	220
27	60	123	225
28	60	115	235
29	60	96	190
30	60	101	210

Source: IRC:SP 41-1994 [10]

Table 2: Saturation Flow per cycle time for Fixed Time Signalized Intersection.

V. Comparison of Saturation Flow with Conventional Equations

Saturation flow obtained from the field survey data for the critical approach arm of the intersection is compared with the conventional equations stated in HCM 2010 and IRC:SP:41-1994

HCM-2010 has explained saturation flow rate as shown in equation (5.1).

$$s=s_o\, N\, f_w\, f_{HV}\, f_g\, f_p\, f_{bb}\, f_a\, f_{LU}\, f_{LT}\, f_{RT}\, f_{Lpb}\, f_{Rpb}\, PHF \quad (5.1)$$

Where s = saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (vph); s_o = base saturation flow rate per lane (pcphpl); N = number of lanes in lane group; f_w = adjustment factor for lane width; f_{HV} = adjustment factor for heavy vehicles in traffic stream; f_g = adjustment factor for approach grade; f_p = adjustment factor for existence of a parking lane and parking activity adjacent to lane group; f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area; f_a = adjustment factor for area type; f_{LU} = adjustment factor for lane utilization; f_{LT} = adjustment factor for left turns in lane group; f_{RT} = adjustment factor for right turns in lane group; f_{Lpb} = pedestrian-bicycle adjustment factor for left-turn movements; f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements; and PHF = Peak Hour Factor.

As per the study location the values considered for the above parameters are : s_o=1900 (pcphpl); N=3; f_w=1.0; f_{HV}=1.0; f_g= 1.0; f_p=1.0; f_{bb}=1.0; f_a=0.90; f_{LU}=1.0; f_{LT}=0.952; f_{RT}=1.0;

From IRC:SP:41-1994, the relationship between capacity and saturation flow for signalized intersection is presented in equation (5.2).

$$\text{Capacity, C} = \frac{(g \times s)}{c} \text{ vehicles per hr.} \quad (5.2)$$

Where g is the effective green time in seconds, s is the saturation flow (vehicles per hr.) and c is the cycle time in seconds. Capacity is considered for Indian condition as per the studies for the project "Development of Indian Highway Capacity Manual" [4] (undergoing project, 2016 in India). For the selected case study capacity of a four-lane divided carriage was is taken as 3141 PCUs/hr. Cycle time of the fixed time study intersection is 120 sec, the green time is 60 sec and lost time is considered as 2 sec per cycle time. Table 4 shows the saturation flow value by field survey analysis and by HCM-2010 and IRC:SP:41-1994 after substituting the values for the defined parameters.

	Survey Analysis, 2016	HCM 2010	IRC:SP 41:1994 & Indo-HCM, 2016 (understudy)
Saturation Flow (PCU)/hr/lane	2042	1628	2166

Table 4: Saturation flow values obtained for four arm fixed time signalized intersection by field survey analysis and by conventional methods

From table 4 it is noted that both the convention equations have estimated the saturation flow value showing distinguished variance from saturation flow obtained by field survey analysis. The Highway Capacity Manual has underestimated the saturation flow by 25.43% and IRC:SP 41 has overestimated the saturation flow by 5.72% with respect to the field calculated saturation flow. Usage of these conventional methods to calculate saturation flow which directly influences the capacity and signal time of the intersection will not gratify the requirement of the ground traffic volume.

VI. Conclusion

Due to the heterogeneity of traffic (heavy vehicles to motor bikes commute on the same travel lane) determination of accurate saturation flow becomes a difficult task. Many of the concepts are formulated in developed countries considering cars as the major road user and where lane disciple is strictly followed. But in developing countries where two wheelers play a major role in vehicular composition and nearly little lane discipline is followed an untrue picture is being provided by using those equations. Here the study has focused on the determination of saturation flow through field measures by considering a fixed time four arm signalized intersection. By using Root Mean Square method saturation flow value per cycle time is calculated for peak hour traffic. This calculated value is this compared with the conventional equations to determine the saturation flow value. The result shows that saturation flow value has been underestimated by 25.43% by HCM and overestimated by 5.72% by IRC respectively when compared with the field method.

VII. Limitations

Constrained queue length recording due to limitation in survey method. Data coded per approach arm for every 10 second time span per vehicular composition is a tedious task. Human error can occur in data coding process.

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