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Saturation Flow Rate Measurement on a Four Arm Signalized Intersection of Ahmedabad City

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***Abstract*— Intersection is the most crucial element of road network as it affects the performance and productivity of the whole network significantly. The intersection performance is usually measured via delay and saturation flow rate particularly on signalized intersections. This research work determines the maximum departure flow rate and saturation flow rate in the context of non-lane based heterogeneous traffic condition existing on Vijay Cross-road of Ahmedabad city. The analysis is based on video graphic data collected during peak hours at the selected intersection. Volume conversion is carried out by adopting Justo and Tuladhar (1984) and IRC (1994) recommended PCU values. It has been observed that maximum departure flow rate calculated for 3 second interval is higher than 6 second interval. The analysis shows that maximum saturation flow rate (SFR) observed using IRC suggested PCU values varies between 933W to 1283W, whereas for the Justo and Tuladhar suggested PCU values the maximum saturation flow rate varies between 636W and 821W, where W is width of approach in meter.**

Keywords*— Saturation Flow Rate; PCU; Signalized intersection.

I. INTRODUCTION

As the number of vehicles is increasing, the problem of congestion is also increasing simultaneously on the urban road network. Congestion at the intersection is the most crucial element of road network as it affects the performance and productivity of the whole network. Intersection is the location where vehicles moving in different direction want to occupy same space at the same time. In addition, the pedestrians also seek same space for crossing. For the signalized intersection, design of optimum signal cycle requires demand flow rate (i.e. arrival rate and pattern), geometry of intersection, and service flow rate (i.e. saturation flow rate). Determination of saturation flow rate is very crucial as it depends on several parameters. Saturation Flow Rate (SFR) is perhaps the most important parameter in signalized intersection control strategy. Despite its central importance it is extremely difficult to accurately measure the SFR at current stage of research. Even the HCM suggests eleven different adjustment factors to estimate SFR and gives default value of 1900 pcu/hr/ln. Indian Road Congress (IRC) in its Special Publication (SP-41, 1994) suggests empirical formula 525W to estimate SFR.

Accurate measurement of saturation flow is possible by videography, in which continuous departures from stop line during green interval can be measured accurately. In the peak flow time, when green time is fully utilized by continuously departing vehicles with almost constant headway, saturation flow rate can be obtained in the prevailing traffic condition. When the vehicles move with lane discipline, saturation flow rate can be determined easily from measuring time headway. But, when the vehicles do not follow lane discipline and small vehicles occupy the gaps from right or left side, cross the stop line at a time without following lane discipline, constant time headway cannot be obtained. This condition generally prevails in Indian traffic. Due to advancement of automobile technology, nowadays vehicles move with higher peak up and quicker acceleration. That has increased the saturation flow rate. In the starting of green interval, group of vehicles with very close spacing standing near the stop line immediately cross the stop line. So, for the short duration, maximum departure flow rate can be obtained, which is quite greater than the saturation flow rate found during continuous steady flow condition.

Looking at the above preamble, this study is aimed to measure the saturation flow rate and maximum departure flow rate on the signalized intersection during the peak traffic flow condition. This study will give a clue that at present how much saturation flow rate can be estimated for a given approach width in meter and how much departure flow rate on average can exist on approach for mixed traffic condition without lane discipline. For this purpose, Vijay cross road signalized intersection of Ahmedabad city is selected.

II. REVIEW OF LITERATURE

Many researchers have worked to find the saturation flow rate. Saturation flow rate (S) is 'The maximum rate of flow of vehicles that can pass through the intersection per unit time of effective green expressed in pcu/hr or pcu/sec'. This is a service flow rate. It depends directly on width of approach. It also depends on allowed turning movements of vehicles on given approach, opposing flow of traffic, composition of traffic, approach gradient, parking activity on approach, blocking effect of bus stop etc. (Varia, 1995). Saturation flow rate (S) can be obtained by: (i) using models, (ii) field measurements (by measuring time headway or by measuring flow rate).

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The famous models are given as follows:

(i) Road Research Laboratory (U.K.) Model-Widths from 5.5m to 18m:

$$S = 525W \quad \text{..... (1)}$$

Where, S = Saturation flow rate (pcu/hr)
W = Width of approach road in m at stop line

(ii) HCM model:

$$S = So*N*fw*fHV*fg*fp*fbb*fa*fRT*fLT \quad \text{,..... (2)}$$

Where,
So = Ideal saturation flow rate per lane (1800 pcphgpl)
pcphpgpl = passenger cars per hour green per lane
N = number of lanes in the lane group,
Fw = adjustment factor for lane width (12' lane is standard)
fH = adjustment factor for heavy vehicles in the traffic stream
fg = adjustment factor for approach grade
fp = adjustment factor for the existing parking activity in that lane
fbb = adjustment factor for the blocking effect of local buses stopping
fa = adjustment factor for area type
fRT & fLT = adjustment factor for right and left turns in the lane group

For the Indian conditions, Sarana and Malhotra (1967) have given

$$S = 431.7W + 103.5 \quad \text{..... (3)}$$

Bhattacharya and Bhattacharya (1982) have given

$$S = 490W - 360 \quad \text{..... (4)}$$

Chandra (1994) has given

$$S = 293W + 1241 \quad \text{..... (5)}$$

Saturation flow rate (S) can also be obtained by field measurements:

- By Measuring Headway

$$S = 3600/h \quad \text{..... (6)}$$

Where, h = saturation flow rate headway (sec/veh)
= constant headway achieved once a suitable moving queue is established

- By Measuring Flow rate

No. of departures shall be recorded against short duration of green time like 3 to 5 sec at stop line (by videography). Figure 1 illustrates this method. Here,

$$G + A = g + (l1 + l2) \quad \text{..... (7)}$$

Where, G = Green time (sec)
A = Amber time (sec)
G = Effective green time (sec)
$l1$ = Starting lost time (sec)
$l2$ = Clearance lost time (sec)

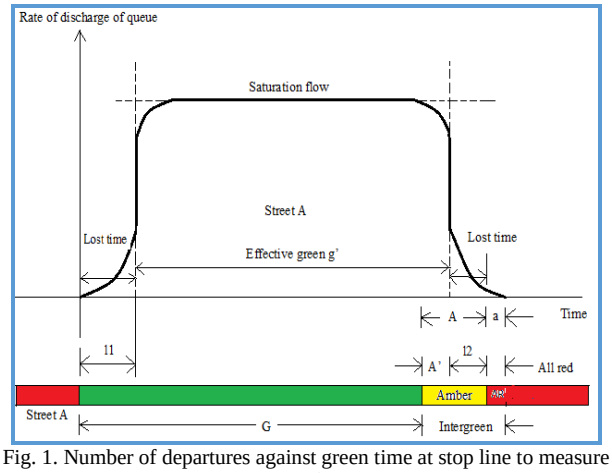

Fig. 1. Number of departures against green time at stop line to measure saturation flow rate

Arasan and Vedagiri (2007) have estimated S of heterogeneous traffic using computer simulation and given a range of saturation flow rate between 610 to 660 pcu/m for width of approach 3.5m to 14m. They have established significant increase in S with increase in width of approach road. Verma et al. (2013) have shown that S does not depend only on width of approach, therefore empirical formula suggested for Indian condition in IRC (SP-41, 1994) is inappropriate for obtaining S. While measuring S in their study they have assumed start-up lost time 5 second for Indian condition based on past studies. However, from the field observation carried out in their study, practically no initial start-up lost time is observed. Table I summarizes the previous studies on saturation flow rates. (pc/h/ln = passenger car per hour per lane).

TABLE I. PREVIOUS STUDIES ON SATURATION FLOW RATE

Study	Country	Mean (pc/h/ln)	Sample Size
Webster & Cobbe	UK	1800	100
Kimber et al.	UK	2080	64
Miller	Australia	1710	-
Branston	UK	1778	5
H.E.L.Athens	Greece	1972	35
Shoukry & Huizayyin	Egypt	1617	18
Hussain	Malaysia	1945	50
Coeyman & Meely	Chile	1603	4
Bhattacharya & Bhattacharya	India	1232	20
De Andrade	Brazil	1660	125

III. SITE SELECTION

For the proposed study, Vijay cross-road signalized intersection of Ahmedabad city is selected. Its location map is shown in Fig. 2. It has four approaches of varying width, University approach (9 m), Darpan approach (10.2 m), Gurukul approach (8 m) and Commerce college approach (7.1 m). The intersection has pre-timed signal control system. Its snap shot for geometric details is shown in Fig. 3.

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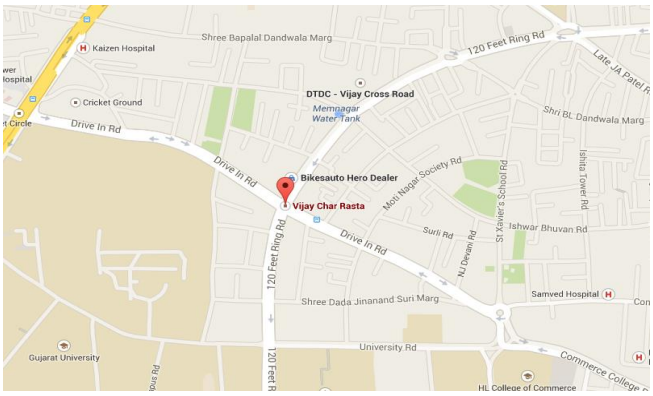

Fig.2. Location map of Vijay cross road intersection

The selected intersection passes heavy traffic flow in the morning and evening peak hours. Long queues are found on the approaches during rush hours. The traffic movement in Ahmedabad is more complex due to the heterogeneous characteristics of the traffic stream using the same right of way with high percentage of motorcycle. Another striking feature of the road traffic operating condition in Ahmedabad is that, most of the times lane discipline is not followed. Hence,

Fig.3. Snap shot of selected intersection

it is unwise to use the standard western relationships for predicting the values of saturation flows, lost time, PCU factors and delay. Traffic studies were conducted at the selected junction to collect the following data:

- Classified traffic volume with rurning movements using video camera;
- Intersection geometry; and
- Saturation flow.

IV. DATA COLLECTION

The data necessary for this study are described below:

a) Road Geometry

It includes number and width of the Lane, parking condition, length of Storage bay if any, etc.

b) Traffic data

It includes vehicle count during the Saturation flow period for the determination of saturation flow. Video camera is used to capture all traffic movements during morning peak hour.

c) Signal data

It includes the type of signal, cycle length and the green time for each lane. Geometric and operational attributes of the intersection are given in Table II.

TABLE II. GEOMETRIC AND OPERATIONAL ATTRIBUTES OF THE JUNCTION

Junction Name	Existing Cycle Length (sec)	Approach Name	Green Time + Amber Time (sec)	Movement	Approach Width (m)
Vijay Char Rasta	155	University	34+2= 36	Through and right turners	9
		Darpan	30+2= 32		10.2
		Gurukul	48+2= 50		8
		Commerce College	35+2= 37		7.1

The width of each lane under consideration was measured using the tape. The cycle time and green time for each lane group was measured using stopwatch. The data was collected at the site during peak hour. It was decided to use a video recording technique for data collection by placing it at vantage point to cover the traffic flow over the entire approach. The data for traffic flow was recorded and later analyzed. The data for finding the saturation flow rate was collected using a video cassette player by calculating the vehicle departures from stop line at every 3 second.

V. DATA ANALYSIS

Data was collected during the morning peak between 10:00 to 12:00 AM on 11thDecember 2014 (Thursday). For data extraction an observation point is selected by playing a video clip recorded for the particular approach of the intersection. The observation point is normally the stop line. Start of the green is noted down from the video camera timer. A conventional stop watch timer is used to measure time in seconds. The video clip is paused at the moment the signal turns green, and the stop watch is set to zero. The video is played for 3 sec and again paused to count the vehicles crossed the stop line. This procedure continued until the signal turns red.

PCU value depends on the factors such as vehicle characteristics, roadway characteristics, climatic conditions, control conditions etc. In India, many researchers/ organizations have worked out the PCU values at urban as well as for rural roads and intersections. No comprehensive guideline for PCU values still prepared in Indian mixed traffic condition which takes into account all these influential factors. The study uses two different sets of PCU values have been selected for the volume conversion. The selected values are shown in the Table III. The overall vehicle composition is shown in figure 4.

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TABLE III. PCU VALUES USED FOR CALCULATION

Serial Number	Class of Vehicle	PCU as per Justo and Tuladhar (1984)	PCU as per IRC SP-41-1994
1	Two Wheeler	0.3	0.5
2	Three Wheeler	0.4	1.0
3	Four Wheeler	1.0	1.0
4	Bus	2.8	3.0
5	Cycle	0.4	0.5

In order to estimate the saturated green time, all vehicles passing an approach are counted for every three-second and at every six-second interval. They are converted into passenger car unit as per values selected and shown in Table III. The following figure 5 represents saturated cycle during data analysis considering 3 second interval. Here, saturated green time observed is 27 second and total PCU served is 59 as per IRC recommended PCU values. The sample calculation of saturation flow rate values for this cycle is shown here. Figure 6 shows the same cycle departures for 6 sec interval. As the green time is fully utilized by the vehicles, the saturation flow rate obtained same for the 3 sec and 6 sec interval plot.

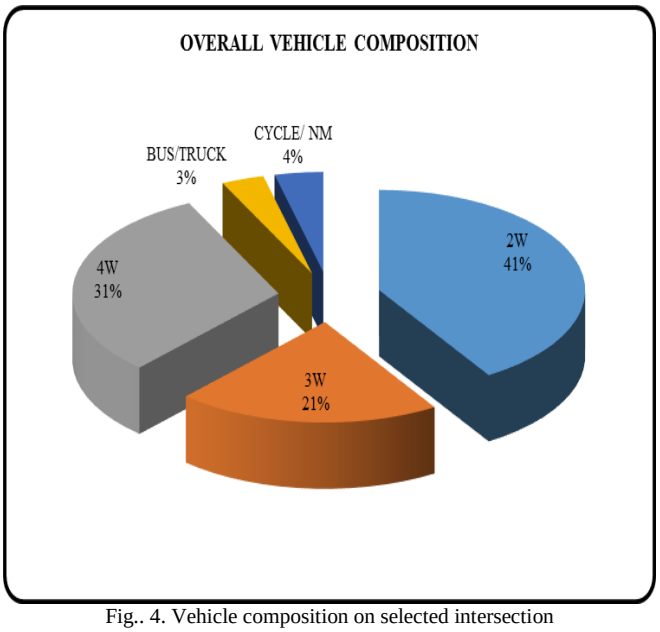

Fig.. 4. Vehicle composition on selected intersection

Saturation flow rate = total pcu departed/ Time interval (sec)

S = 59/27
=2.185pcu/sec
= 2.185*3600
= 7866 pcu/hr/approach width
Or

S = (2.185*3600)/9
=874 pcu/hr/meter width of approach

Similarly all the cycles are analyzed and saturation flow rate of all the fully utilized green period (saturated) cycles of all approaches for the 3 sec and 6 sec intervals are calculated. It is observed that saturation flow rate comes same for the 3 sec and 6 sec time interval for the fully utilized green time cycles. The obtained maximum saturation flow rate for all the approaches is presented in tabular format in table IV (PCU values as per IRC-1994) and table V (PCU values suggested by Justo and Tuladhar).

It is observed that saturation flow rate using IRC PCU values are quite higher than it is obtained using PCU values suggested by Justo and Tuladhar. In both the cases saturation flow rate is quite more than 525W suggested by RRL (UK). It seems that due to recent development of automobile technology, departures are quicker compare to previous condition.

It is also observed that the small vehicles (2W and 3W) do not follow lane discipline and occupies the small gaps on the approach road and departed quickly in bunch gives sudden rise in departure flow rate for small time intervals in starting of green, which may be more than saturated flow rate. These types of maximum departure flow rates are calculated for 3 sec and 6 sec time intervals and typical cycle is shown in figures 7 (PCU values as per IRC-1994) and 8 (PCU values suggested by Justo and Tuladhar). The maximum departure flow rates observed on all the approaches are presented for 3 sec and 6 sec time intervals in table VI (PCU values as per IRC-1994) and table VII (PCU values suggested by Justo and Tuladhar). It has been observed that maximum departure flow rate for 3 sec time interval is higher than that for the 6 sec time interval.

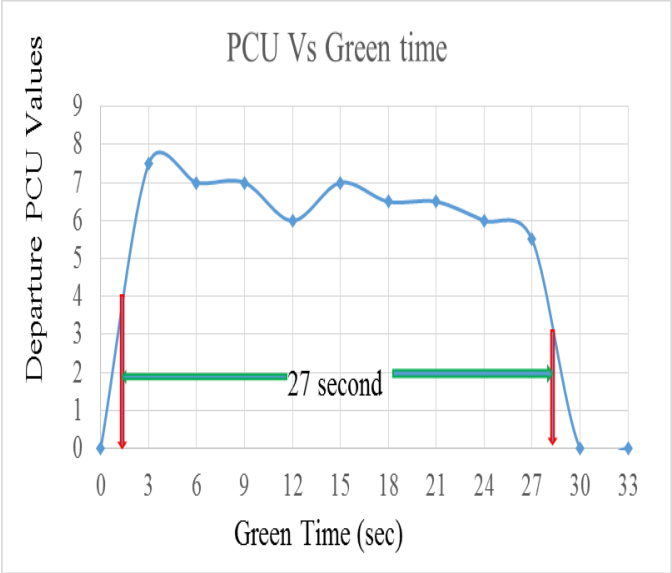

Fig. 5. Saturated cycle observed at University approach (3 sec interval)

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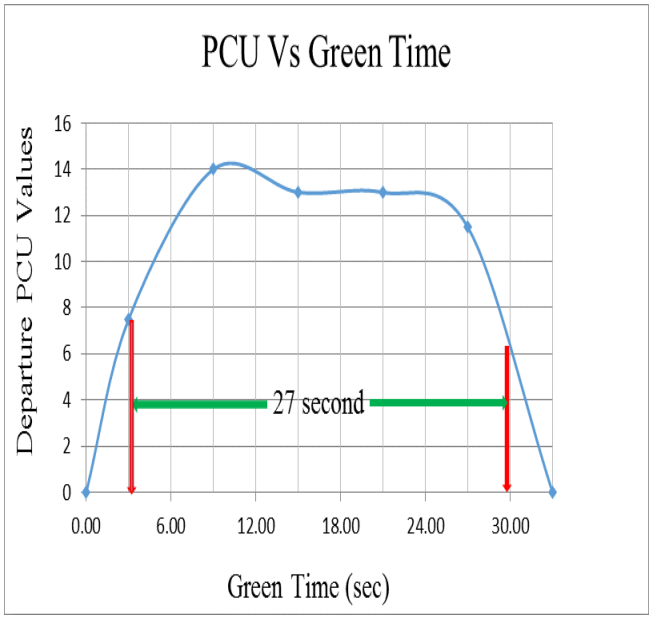

Fig. 6. Saturated cycle observed at University approach (6 sec interval)

TABLE IV. SATURATION FLOW RATE OBTAINED ADOPTING IRC (1994) PCU VALUES

Approach Name	Width W (m)	Saturation Flow Rate	
		PCU/hr/approach width	PCU/hr/meter
University	9	8397	933W
Darpan	10.2	11781	1155W
Gurukul	8	9320	1165W
Commerce College	7.1	9109	1283W

TABLE V. SATURATION FLOW RATE OBTAINED ADOPTING PCU VALUES SUGGESTED BY JUSTO AND TULADHAR (1984)

Approach Name	Width W (m)	Saturation Flow Rate	
		PCU/hr/approach width	PCU/hr/meter
University	9	5724	636W
Darpan	10.2	7201	706W
Gurukul	8	6176	772W
Commerce College	7.1	5829	821W

It is obvious that these maximum departure flow rates are higher than the saturated flow rates obtained on fully utilized green cycles.

In the calculation of signal cycle time, generally saturation flow rate of fully utilized green time is considered, which may under estimate the actual maximum departure capacity of approach particularly in mixed traffic condition having no lane discipline like in India.

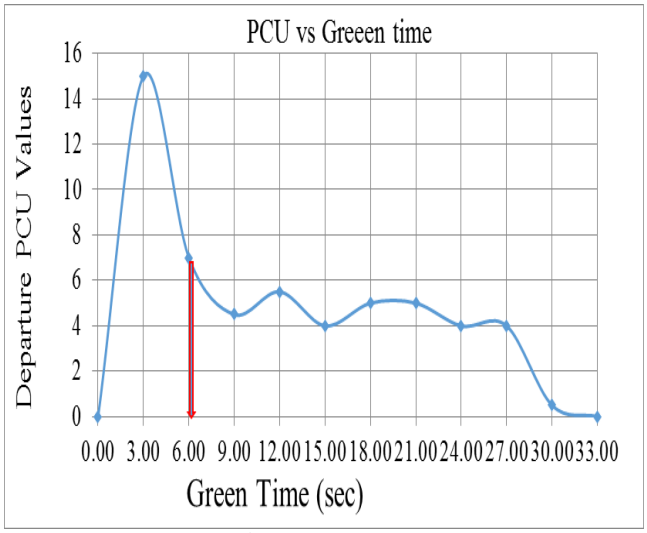

Fig. 7. Maximum departure flow rate observed at University approah (cycle 14) for 3 sec interval

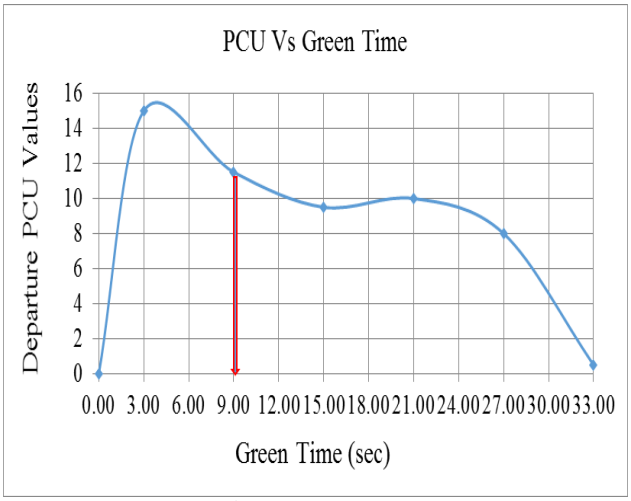

Fig. 8. Maximum departure flow rate observed at University approach (cycle 14) for 6 sec interval

TABLE VI. MAXIMUM DEPARTURE FLOW RATE OBTAINED ADOPTING IRC (1994) PCU VALUES

Approach Name	Width W (m)	Maximum Departure Flow Rate (Considering 3 sec Interval)		Maximum Departure Flow Rate (Considering 6 sec Interval)	
		PCU/hr/ approach width	PCU/hr/ meter	PCU/hr/ approach width	PCU/hr/ meter
University	9	13203	1467W	10602	1178W
Darpan	10.2	11801	1157W	11801	1157W
Gurukul	8	9480	1185W	9480	1185W
Commerce College	7.1	13199	1859W	12603	1775W

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TABLE VII. MAXIMUM FLOW RATE OBTAINED ADOPTING PCU VALUES SUGGESTED BY JUSTO AND TULADHAR (1984)ON

Approach Name	Width W (m)	Maximum Departure Flow Rate (Considering 3 sec Interval)		Maximum Departure Flow Rate (Considering 6 sec Interval)	
		PCU/hr/ approach width	PCU/hr/ meter	PCU/hr/ approach width	PCU/hr/ meter
University	9	7083	787W	5733	637W
Darpan	10.2	10078	988W	8517	835W
Gurukul	8	6768	846W	6544	818W
Commerce College	7.1	8443	1192W	7881	1110W

The maximum departure flow rate for 6 sec time intervals may give good estimate for service flow rate of given approach in existing conditions, because 3 sec intervals, i.e. small time intervals show more fluctuations and quite higher side estimates. This service flow rate may be considered for designing optimum signal cycle time. Due to higher values of service flow rates, ratio Y of normal flow (q) to saturation flow(s) and volume to capacity ratio (v/c) may not increase more than 1. Looking at the present vehicular characteristics and mixed traffic condition, saturation flow rates shall be considered more than 525W pcu/hr/m.

VI. FINDINGS

- The values suggested by Webster and adopted by IRC for saturation flow rate is 525W but in this analysis saturation flow rate values observed is quite higher than the suggested values.
- It has been observed that shorter time interval (3 second) for calculation of maximum departure flow rate gives higher values than longer time interval (6 second). Every single cycle analyzed has recorded PCU in first 3 second interval. It reveals that startup lost time as suggested by HCM 2010 is not valid in Indian condition.
- The variation of SFR values for different width of approach is not following the general trend that an increase in width of approach leads to increase in SFR values. This depict that there are other factors also that affect the saturation flow rate.
- The analysis reveal that maximum saturation flow rate (SFR) observed by IRC suggested PCU values varies between 933W to 1283W. Whereas, for the Justo and Tuladhar suggested PCU values the maximum saturation flow rate values varies between 636W and 821W. Where, W is approach width in m.
- It has been observed that maximum departure flow rate of cycle is quite higher than the calculated saturation flow rate of the saturated cycles. As per IRC suggested values it varies between 1157W to 1775W for 6 sec time interval observations. Whereas, for the PCU values suggested by Justo and Tuladhar, it varies between 637W to 1110W for 6 sec time interval observations. Where, W is approach width in m. It shows that for small amount of cycle time the clearing capacity of intersection approach is more than the saturation flow rate.
- The study has considered only one intersection and the results are based on very limited number of observations (Morning peak hour) considering old PCU values. So, there is a need of extensive data collection and analysis before arriving at any tangible conclusion.

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