

A Comparative Study on Saturation Flow at Signalized Intersection and Signal Designing: Surat

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ABSTRACT: Due to increase in the population growth, there is also an increase in the demand for the transport facilities such as Cars, Motorcycles, Trucks, Buses, etc, which result in severe traffic congestion at signalised urban intersections. As a result various traffic characteristics at urban intersections are becoming complicated. Therefore, need arises to study the saturation flow at urban intersections, Surat. Saturation flow is a very important road traffic performance measure of the maximum rate of flow of traffic. Also saturation flow is important for estimating signal green time. In this research, an effort has been made to find the reliable saturation flow at signalized urban intersection and a comparative study is done to find the amount of variation in saturation flow of various urban intersections by comparing it with IRC recommended formula and various models from research journals. A considerable variation is observed in the values which can have an enormous impact in designing of traffic signal. Considering this variation attempt has been made in this paper to design a new cycle length for existing traffic signal for the trouble-free movement of traffic at signalized intersection, Surat. This study may help in redefining the new guidelines or formula for saturation flow in IRC and other generalized models, also in redesigning of existing signals which are incapable to carry traffic effectively.

KEYWORDS: Saturation flow, Heterogeneous traffic, Intersection, Passenger car unit, Effective green time, Signal designing.

I. INTRODUCTION

In developing countries like India, urban area is having both, motorized and non-motorized traffic. The concentration of non-motorized traffic however, is being low. Yet, the situation at vulnerable nodes (i.e. at intersection) in transportation network becomes worst. Besides, the heterogeneity of vehicles available on the links plays major role in the movement of it in transportation network. Urban signalized intersection is being the most chaotic and vulnerable node of the transport network. It has been observed from the past researches that the effectiveness and efficiency of traffic control of signalized intersections strongly depends upon the accurate estimation of Saturation flow rate, particularly when demand approaches capacity. Hence it is of prime requirement to understand the traffic behaviour of the intersection and to predict saturation flow rate that can be utilized in traffic management strategies. In India, where two wheelers play a major role in vehicular composition and nearly little lane discipline is followed, the different 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 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 compare the saturation flow based on the ground scenario with the actual models implemented by IRC and suggest necessary improvements in it; designing of a signal at a non-signalized intersection.

A. SATURATION FLOW RATE

Saturation flow can be defined as "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." As per IRC-41, it is expressed as:

$$S = 525w \text{ where, } w = \text{width of approach}$$

As per the Highway Capacity Manual (Manual HCM 2010), “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 is called saturation flow rate (veh/h/ln)”.

To determine the saturation flow rate from time measurements taken in the field the following equation is used:

$$S = \frac{3600}{hs} \text{ where, } S = \text{Saturation flow rate}$$

$$hs = \text{Saturation headway}$$

B. TRAFFIC VOLUME COUNT

It is essential to know the magnitude of traffic data required or to be collected, which will then determine its quality and type of vehicle classification to be adopted. Traffic counting falls in two main categories, namely;

- (a) Manual method
- (b) Automatic method

C. METHODS FOR SIGNAL DESIGNING

The following methods are commonly used for the design of traffic signals:

- (a) Trial cycle method
- (b) Webster’s minimum delay method
- (c) IRC method

II. OBJECTIVES

1. Obtaining the reliable saturation flow values.
2. To compare observed saturation flow values with the alternate Saturation flow rate models and IRC formula.
3. To observe the effect of vehicle composition on saturation flow.
4. To design a signal with effective green time using IRC signal designing method.

III. METHODOLOGY

A. Selected study area

Surat city is located 284 km south of the state capital, Gandhinagar, on the south of Tapi river, the center being around 22 km from the river’s mouth. Surat is located at 21°10’N 72°50’E. Surat had a population of 6.77 million at the 2019 census, making it the second largest city in the state of Gujarat, after Ahmedabad. The city is connected to the National Highway 8, through a 16 km Connector Highway. Selected intersections are:

1. Patel Pragati Samaj Wadi Ground Intersection (Surbhi Dairy Intersection), Honey Park, Surat.
2. Mahavir Chowk Intersection, Ring Road, Surat.

B. Study methodology

The systematic flow chart of methodology of this research work is depicted in figure (a).

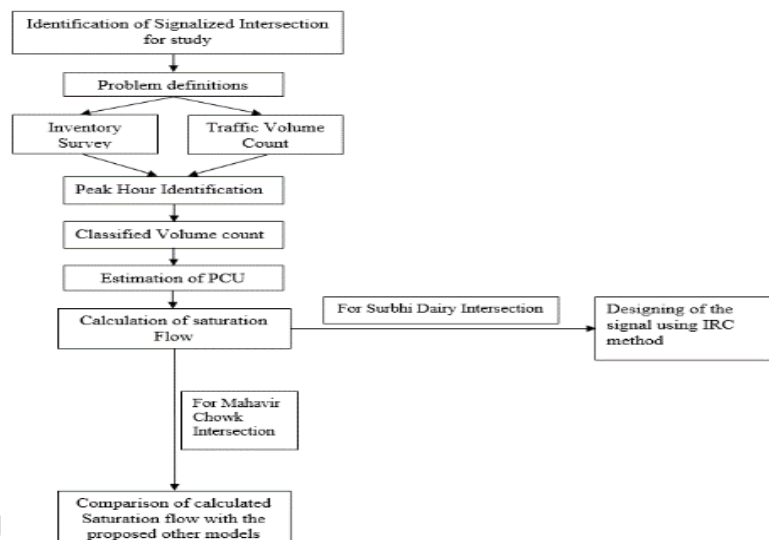


Fig 1. Flow chart showing methodology for the proposed work

IV. DATA COLLECTION AND DATA ANALYSIS

1. Data collection

For the data collection, two processes are needed to be done for obtaining the results:

- (a) Road Inventory Survey
- (b) Traffic Volume Count by videography method

The survey was conducted at both the intersections for half hour according to the recording capacity of the camera. The time taken for the survey was during the peak hour, i.e. 10.00-10.30(morning) am and 05.15-05.45 pm(evening) on 06-12-2019(Surbhi Dairy Intersection) and 09-12-2019(Mahavir Chowk Intersection).

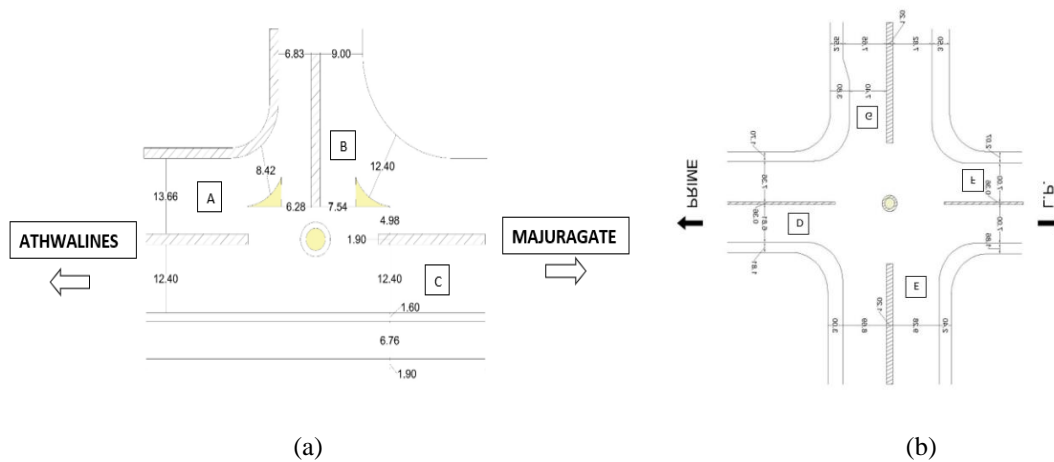


Fig 2. Plan showing (a) Layout of Mahavir Chowk Intersection (b) Layout of Surbhi Dairy Intersection

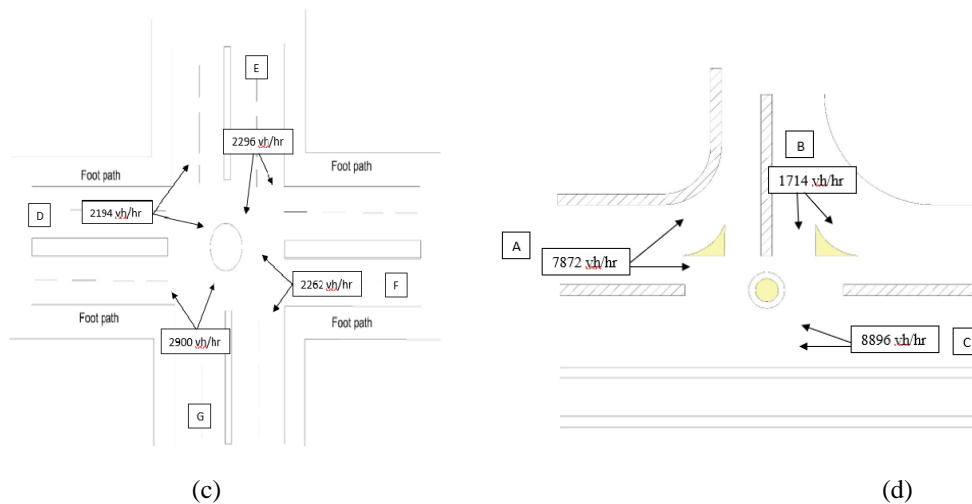


Fig 3. Vehicular traffic flow from the approach leg of (c) Surbhi Dairy Intersection (d) Mahavir Chowk Intersection

2. Data Analysis

2.1 Mahavir Chowk Intersection

Videography survey has been carried out on Mahavir chowk intersection. After the videography survey the readings were noted down. The half hour reading were converted into an hour to get the data in PCU/hr. Following are the tables showing the maximum saturation flow at the signalized intersections during the morning and the evening peak period.



The observed highest PCU value (Mahavir Chowk Intersection) obtained along the routes are:

1) Morning survey data:

Table 1. Observed Saturation Flow during morning peak period

Route	A	B	C
PCU	5415	819	5436
Time headway: $H_T = \frac{\text{Total cycle length}}{\text{PCU}}$ (sec-hr/PCU)	0.37	0.85	0.44
Saturation Flow: $S = 3600/H_T$	9279.70	4215.46	8181.80

2) Evening survey data:

Table 2. Observed Saturation Flow during evening peak period

Route	A	B	C
PCU	5415	819	5436
Time headway: $H_T = \frac{\text{Total cycle length}}{\text{PCU}}$ (sec-hr/PCU)	0.37	0.85	0.44
Saturation Flow: $S = 3600/H_T$	9279.70	4215.46	8181.80

2.2 Surbhi dairy intersection.

For intersection no.2, which is shown in figure (b) and (c) above, the intersection is not sufficient to carry the traffic efficiently and effectively. So a try has been done to redesign a signal, for effective passing of saturation flow.

Signal Design using IRC method

Taking the highest PCU values from the morning and the evening peak hour data:

Road-1(G)=1668 PCU/hr

Road-2(D)=1308 PCU/hr

Road-3(E)=1389 PCU/hr

Road-4(F)=1507 PCU/hr

Pedestrian green time for:

Assuming walking speed=1.2 mt/sec

Initial walking time=7.0 sec

$$\text{Road-1} = \frac{15.22}{1.2} + 7 = 19.683 \text{ sec} = 20 \text{ sec} \text{ [Road width=15.22 mt]}$$

$$\text{Road-2} = \frac{14.17}{1.2} + 7 = 18.8083 \text{ sec} = 19 \text{ sec} \text{ [Road width=14.17 mt]}$$

$$\text{Road-3} = \frac{17.97}{1.2} + 7 = 21.9750 \text{ sec} = 22 \text{ sec} \text{ [Road width=17.97 mt]}$$

$$\text{Road-4} = \frac{14.00}{1.2} + 7 = 18.6667 \text{ sec} = 19 \text{ sec} \text{ [Road width=14.00 mt]}$$

Green time for vehicles on road-2(i.e. pedestrian green time for road-1)

$$G_2 = 20 \text{ sec}$$

$$\text{Green time for vehicles on road-2, } G_1 = \frac{1668}{1308} \times 20 = 25.5046 \text{ sec} = 26 \text{ sec.}$$

Adding 2.0 sec each towards clearance amber and 2 sec inter green period for each phase

$$\therefore \text{Total cycle time} = (2+20+2) + (2+26+2) = 54 \text{ sec}$$

Table 3. 2-phase signal time diagram for road-1 and road-2

Road	Green	Amber	Red	Cycle
Road-1	26	2	2 + 24	54
Road-2	26	2	2 + 30	54



Similarly, for road-3 and road-4,

Table 4. 2-phase signal time diagram for road-3 and road-4

Road	Green	Amber	Red	Cycle
Road-3	21	2	2 + 26	51
Road-4	22	2	2 + 25	51

The extra 2.5 sec per cycle may be added to the green time of road-1,2,3,4

$$\therefore G_1 = 26 + 0.625 = 21.625 \text{ sec} = 27 \text{ sec}$$

$$\therefore G_2 = 20 + 0.625 = 20.625 \text{ sec} = 21 \text{ sec}$$

$$\therefore G_3 = 21 + 0.625 = 21.625 \text{ sec} = 22 \text{ sec}$$

$$\therefore G_4 = 22 + 0.625 = 22.625 \text{ sec} = 23 \text{ sec}$$

Vehicles arrival per lane cycle on road-1 = $\frac{1668}{54} = 30.8889 \text{ PCU}$

The vehicles will take approximately 6 sec. and subsequent vehicles will be cleared at the rate of 2.0 sec.

Minimum green time for clearing vehicles on road-1

$$\begin{aligned} &= 6 + (30.8889 - 1) \times 2 \\ &= 65.778 \text{ sec} \\ &= 66 \text{ sec.} \end{aligned}$$

Vehicle arrival per lane cycle on road-2 = $\frac{1308}{54} = 24.2222 \text{ PCU}$

Minimum green time for clearing vehicles on road-2

$$\begin{aligned} &= 6 + (24.2222 - 1) \times 2 \\ &= 52.4444 \text{ sec} \\ &= 53 \text{ sec.} \end{aligned}$$

Taking the maximum value, $G_1 = 66 \text{ sec}$, $G_2 = 53 \text{ sec}$

Similarly, taking maximum value, $G_3 = 59 \text{ sec}$, $G_4 = 63 \text{ sec}$

Cycle time = $(2 + 66 + 2) + (2 + 53 + 2) = 127 \text{ sec}$

Signal time may conveniently be set in multiple of 5 secs.

\therefore Cycle time = 130 sec

Proportioning the cycle time, i.e. splitting the extra 3 secs in G_1 and G_2 respectively.

$$\therefore G_1 = 66 + 1 = 67 \text{ sec}$$

$$\therefore G_2 = 53 + 2 = 55 \text{ sec}$$

$$\therefore G_3 = 59 \text{ sec}$$

$$\therefore G_4 = 63 \text{ sec}$$

Lost time per cycle = [amber time + inter green time + time lost for initial delay of first vehicles] $\times 2$ phases

$$L = [2 + 2 + 4] \times 2 = 16 \text{ sec.}$$

Saturation flow for road-1 = $525w = 525 \times 7.40 = 3885 \text{ PCU/hr}$

Saturation flow for road-2 = $525w = 525 \times 6.81 = 3575.25 \text{ PCU/hr}$

Saturation flow for road-3 = $525w = 525 \times 9.28 = 4872 \text{ PCU/hr}$

Saturation flow for road-4 = $525w = 525 \times 7.00 = 3675 \text{ PCU/hr}$

$$\therefore Y_1 = \frac{834}{3885} = 0.21467$$

$$\therefore Y_2 = \frac{654}{3575.25} = 0.18292$$

$$\therefore Y_3 = \frac{694.5}{4872} = 0.14254$$

$$\therefore Y_4 = \frac{753.5}{3675} = 0.20503$$

$$Y = Y_1 + Y_2 + Y_3 + Y_4 = 0.21467 + 0.18292 + 0.14254 + 0.205 = 0.74516$$

$$\text{Optimum Cycle Length} = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 16 + 5}{1 - 0.74516} = 113.7968 \text{ sec}$$

Signal time may conveniently be set in multiple of 5 secs.

\therefore Optimum cycle length = 115 sec



Table 5. Optimum cycle length for the intersection

Road	Optimum cycle length(sec)
Road-1	36.92715 = 37
Road-2	35.49224 = 36
Road-3	33.82082 = 34
Road-4	36.47936 = 37

Therefore, the provided cycle length is safe as the optimum cycle length is less than provided.

V. RESULTS

Results after comparison of the saturation flow at Mahavir Chowk intersection with other models.

Table 6. Morning observed saturation flow comparison

Route	Observed Saturation flow $S=3600/H_T$ (PCU/hr)	Bhattacharya(1994) =490w-360	IRC method	Raval N.G. and GundaliyaP.J.(2012)	
				Model-1=626w+268	Model-2=647w+709tw+270b+702auto-1568car-1552bic
A	9729.70	6333.40	7171.5	8819.16	8758.92
B	4215.46	3334.60	3958.0	4988.04	4943.87
C	8181.80	5716.00	6510.0	8030.40	8245.67

Table 7. Evening observed saturation flow comparison

Route	Observed Saturation flow $S=3600/H_T$ (PCU/hr)	Bhattacharya(1994) =490w-360	IRC method	Raval N.G. and GundaliyaP.J.(2012)	
				Model-1=626w+268	Model-2=647w+709tw+270b+702auto-1568car-1552bic
A	7612.60	6333.40	7171.5	8819.16	8819.71
B	5806.45	3334.60	3958.0	4988.04	4968.26
C	9230.8	5716.00	6510.0	8030.40	8079.50

Based on the calculations done on the PCU values obtained from the traffic survey of the Surbhi Dairy Intersection, the optimum Signal Cycle Length was found to be 130 seconds.

Phase-1:



(e)

Phase-2:



(f)

Fig 4. Cycle Length=130 sec diagram for (e) phase-1 (f) phase-2.

Table 6. Signal timings for different roads

Road	Initial Amber (sec)	Green (sec)	Clearance Amber (sec)	Red (sec)	Cycle Length (sec)
Road-1(G)	2	67	2	59	130
Road-2(D)	2	55	2	71	130
Road-3(E)	2	59	2	71	130
Road-4(F)	2	63	2	63	130

VI. CONCLUSION

- As there seems to be a large variation in the observed calculated values of Saturation flow as compared to the generalized IRC formula and the other proposed research models from various research papers, it can be considered that these formulas are not applicable to all the urban intersections in India (Refer table 6 and 7).
- The variation in Saturation flow for different approaches shows that it does not depend only on the width of the approaches (w); the empirical formula $525w$ suggested for Indian condition in special publication (IRC-SP-41-1994) of the Indian Road Congress is inadequate for obtaining saturation flow at all the intersections.
- Also it was observed from the Traffic Volume Chart data that the vehicular proportion of 2-Wheeler is 60%-70% which is higher as compared to 3-Wheeler and 4-Wheeler vehicular composition, leading to an increase in the saturation flow rate per meter width.
- For intersection 2, (Surbhi Dairy Intersection) the suitable cycle length was found to be 130 seconds for all the phases after obtaining the PCU values at the particular stretch and finding out the traffic flow at the intersection. This cycle length at intersection may be considered for up gradation for better operation of traffic. (Refer figure e and f).

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