Development of Saturation Flow Rate Model for Heterogeneous Traffic at Urban Signalized Intersection

T. B. Rajgor[1], Prof. A. K. Patel[2], Prof. (Dr.) P. J. Gundaliya[3]
[1]*P.G. Student, Civil Engineering Department, L. D. College of Engineering, Ahmedabad.*
[2]*Lecturer, Civil Engineering Department, Government Polytechnic, Ahmedabad*
[3]*Professor, Civil Engineering Department, L. D. College of Engineering, Ahmedabad*

***Abstract* – A rapid growth in automobile vehicles is being experienced in recent years in India, which is having heterogeneous traffic like other developing countries. It has made a very complex job for the research professional to understand the traffic behaviour, in the context of transportation engineering with the virtue of its heterogeneity. Urban intersections are always been the most vulnerable point of the transportation networks and the traffic situations becomes worst and chaotic there. Hence, it is of prime requisite to improve the traffic management and facilities available at traffic intersection. Saturation flow rate is the most important parameter to examine the delay, capacity and level of service at intersection. The Highway Capacity Manual (HCM) has provided the equation to calculate the saturation flow rate but it can't fit well the mixed traffic of developing countries. This paper suggested a new linear model based on the width of approach road to calculate the saturation flow rate of urban traffic intersection for heterogeneous traffic and it predict the saturation flow rate fairly good.**

I. INTRODUCTION

As 'greening' of all dimensions of human activities becomes dominant or mainstream, transportation science is also increasingly focused around sustainability. In developing countries like India, urban area is having both types of traffic namely, motorized and non-motorized. The concentration of non-motorized traffic however, is being low. Yet, the situation at vulnerable nodes in transportation network becomes worst. Besides, the heterogeneity of vehicles available on the links plays dominant 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 calculation 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.

II. SATURATION FLOW RATE

The most significant parameter that can influence the design of signal plan is the "saturation flow rate". As per the highway Capacity (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)".

Saturation flow rate is a macro performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under ideal conditions. Ideal conditions (TRB, 2000) assume the following:

- 3.6 meter lane width;
- No heavy vehicles;
- Flat gradient;
- No parking or bus stops near the intersection;
- Uniform movement type, i.e. only straight movement or only turning movement; and
- No pedestrians or cyclists.

The Highway Capacity Manual (TRB, 2000) prescribes an ideal saturation flow rate of 1900 vehicles per hour per lane. An idealized view of saturation flow at a signalized junction is illustrated in Figure 1, the rectangular model of saturation flow rate (Turner and Harahap, 1993). Note from the figure that as the traffic signal shows green, there is first a very short gap as the first driver reacts to the signal change. The rate of vehicles crossing the stop line increases as vehicles accelerate to the speed determined by the cars they are following. Vehicles soon reach a state where they are following one another at a constant headway. This headway is known as saturation headway.

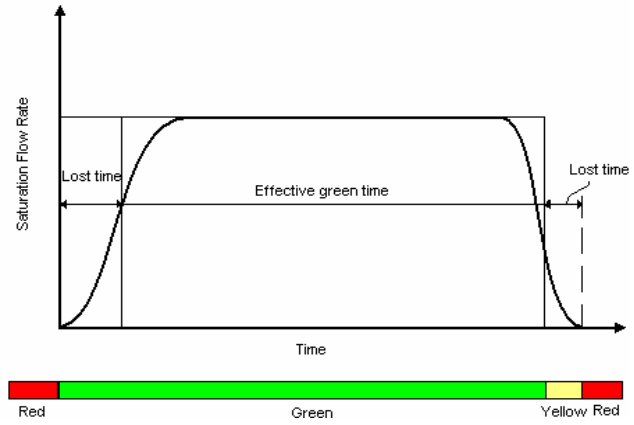

Fig. 1 The flow of traffic during the green period from a saturated approach

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

$$S = 3600/hs$$

Where:

s = saturation flow rate;

hs = saturation headway.

The saturation flow rate depends directly on width of approach. It also depends on, allowed turning movements, traffic composition, gradient of approaches, road side activities, and lane utilization.

III. LITERATURE REVIEW

Literature has been studied regarding to intersection traffic behaviour in terms of saturation flow, vehicle distribution and discharge headways.

Budi and Yanto have worked on the saturation flow rate in Indonesia. The equation S = 600W is commonly used there to find out the saturation flow rate. They observed that for the approaches having small to medium width (say 3m, 4m, and 5.9m), the observed saturation flow rate and that by the equation are closed to each other. But for the approaches having large (say 9m, 10m, 11m, and 12m) width have significant differences. Chang qiao Shao and Xiao Ming liu studied the stochastic nature of discharge headways and its representative value to find out saturation flow rate. It has come to know that the average value of queue discharge headway is greater than the median value. This suggest that more than 50 per cent drivers will keep smaller headways than average one, tends to underestimate the saturation flow. They observed some intersections with lognormal headway distribution and some with normal distribution. Raval N.G. and Gundaliya P.J. has developed linear models to calculate the saturation flow rate from approach width for Indian condition instead of that provided by HCM for homogeneous conditions. They also considered vehicle composition to calculate the saturation flow rate. Huayan Shang et al. have studied saturation flow rate for 36 intersection of Beijing city and developed linear model to express base saturation flow for the Beijing city for right turn lane, left turn lane, through lane, through-right and through-left lane. S. Chand et al. also developed a linear regression model to analyze the saturation flow rate. They developed correlation between the saturation flow rate and the approach width of intersection, as well as with the percentage of two wheeler and percentage of cars of all approaches. Bhattacharya and Bhattacharya (1994) had also developed a regression model to calculate the saturation flow rate from the approach width. IRC also suggested to use the equation given by HCM to calculate the saturation flow rate.

It is come to know, from previous research, that much efforts has been done to infer the model that can be utilized to calculate the saturation flow rate for mixed traffic in India and other developing countries. Somehow, the results from the suggested models retains variations from the actual saturation flow rate. In this paper also, effort has been made to develop a model that can best suit the complex condition of the traffic intersection.

IV. DATA COLLECTION AND ANALISYS

Study Area

The choice of intersections is made on the basis of keeping in mind that intersections have to be signalized one, obey the traffic signals regularly, doesn't have serious complexity in their geometry. Various intersection proposed for this study are as follows;

(1) Income tax intersection
(2) Memco cross roads
(3) Vijay cross roads

Vehicular Data

The various types of vehicle available on roads are categorized into seven categories as all types have different static and dynamic characteristics. They are represented by applying PCU factors to them to eliminate the effect of heterogeneity. The PCU factors for various types of vehicle categories suggested by IRC SP 41 is used here and shown in the table below.

TABLE I
Passenger car units as per IRC SP 41-1994

Sr. no	Vehicle type	PCU factors
1	Car	1
2	2W	0.5
3	3W	1

4	LCV	1.5
5	HCV	4.5
6	Bus	3
7	cycle	0.5

Intersection geometry and Signal timings

The approach width at each intersection is critical in calculating the saturation flow rate. Therefore, the width of approach on each leg is measured directly and noted down. At Income tax intersection and Vijay cross roads, there is provision of separate lane for left turning traffic whereas at Memco cross road, the whole approach width is utilized by traffic moving right, through and left. For each intersection, Cycle length, green and amber time for particular leg are noted down. The following tables shows the approach width for each intersection with their signal timing.

TABLE II
Approach width and signal timing for Income tax intersection (Cycle time 220 sec)

Approach (Leg)	**App. Width (m)**	**Green Time (sec)**	**Amber time (sec)**
Usmapura (A)	10.55	45	4
Gandhi bridge (B)	9.7	54	4
Nehru bridge (C)	9.55	60	4
Rajiv Gandhi Underbridge (D)	9.7	45	4

TABLE III
Approach width and signal timing for Memco cross roads (Cycle time 186 sec)

Approach (Leg)	**App. Width (m)**	**Green Time (sec)**	**Amber time(sec)**
Bapunagar (A)	11.5	35	4
Memco BRTS (B)	9.5	35	4
Overbridge (C)	11.5	32	4
Naroda (D)	8.0	68	4

TABLE IV
Approach width and signal timing for Vijay cross roads (Cycle time 168 sec)

Approach (Leg)	**App. Width (m)**	**Green Time (sec)**	**Amber time (sec)**
LD (A)	9.0	32	4
Gurukul (B)	8.0	53	4
Darpan (C)	10.2	32	4
Commerce college (D)	7.1	35	4

Traffic Composition Data

The vehicle composition is found out at each intersection and the proportion is measured for the peak hour. For this, vehicle passing the stop line at every 5 minutes of interval are calculated for the peak hour with their relative directional movements. It is noticed that, at all the intersection under study, traffic mainly consists of 2W, 3W and Car dominantly. The traffic composition approach-wise is given in the figures below for each intersection. The proportion of each category of vehicles are also tabulated below.

INCOME TAX INTERSECTION

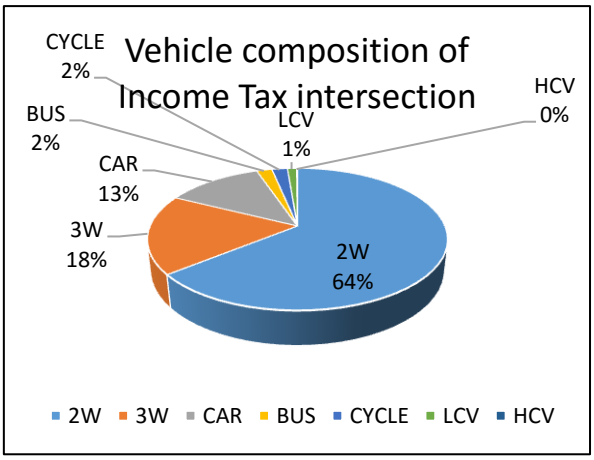

Fig. Vehicle composition of Income Tax intersection

MEMCO CROSS ROADS

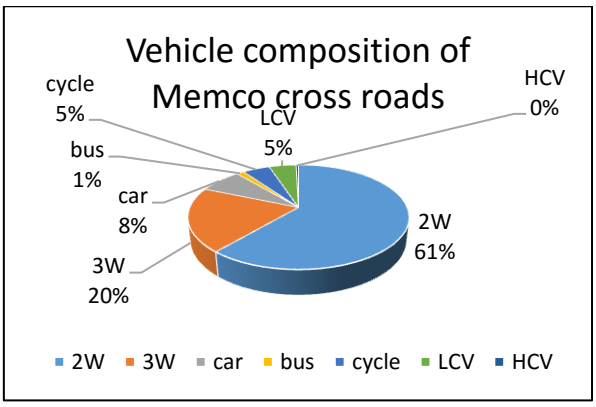

Fig. Vehicle composition of Memco cross roads

VIJAY CROSS ROADS

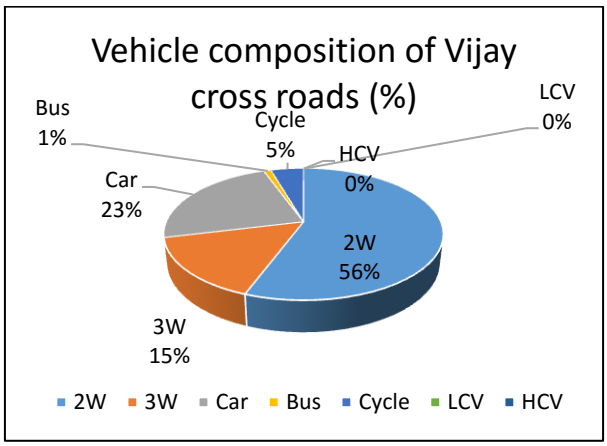

Fig. Vehicle composition of Vijay cross roads

Observed Saturation Flow rate Data

Traffic flows of varied composition was captured by videography and later, the number of vehicles crossing the stop line at approach for through and right turning movement were extracted from the video file. The data were extracted for the interval of 3 sec from the start of the green time of any approach till the termination of the green for that approach or up to end of the queue. The observed saturation flow rate for each of the intersection is as follows.

TABLE V
Observed Saturation flow rate

Intersection	Approaches	Saturation flow rate (PCU/hr)
Income Tax intersection	Usmapura	9040
	Gandhi bridge	9833
	Nehru bridge	6789
	Rajiv Gandhi Underbridge	9857
Memco cross roads	Bapunagar	7250
	Memco BRTS	6050
	Overbridge	7472
	Naroda	5765
Vijay cross roads	LD	7145
	Gurukul	7767
	Darpan	8618
	Commerce college	7650

V. VARIOUS OTHER MODELS FOR SATURATION FLOW RATE

1. IRC SP 41 (S=525*W)

The IRC SP 41 suggested the equation based on width of approach to calculate the saturation flow rate as,

S=525*W,

Where, W = width of approach (m)

2. Bhattacharya and Bhattacharya (1994)

They suggested the model to calculate the saturation flow rate as under;

S = 490w-360,

Where, w = width of approach (m)

3. Raval N.G. and Gundaliya P.J. (2012)

They suggested the values of saturation flow rate for Ahmedabad city with two models as follows.

Model 1: S=626w+268,

Where, w = width of road approach (m)

Model 2: S = 647w+709tw+270b+702auto-1568car-1552bic,

Where, w = width of road approach (m)

tw = proportion of two wheeler in percentage

b = proportion of bus in percentage

auto = proportion of auto-rickshaw in percentage

car = proportion of car in percentage

bic = proportion of bicycle in percentage

4. S. Chand et al.

They developed a regression model between the saturation flow rate and the approach width. The developed model is as under.

Saturation flow rate, S = -63w2 + 2093w – 7043

Where, S = saturation flow rate (PCU/hr),

W = width of approach.

VI. DEVELOPMENT OF SATURATION FLOW RATE MODEL

From the previous study, it has come to know that the saturation flow rate is largely depends upon the width of approach lane. As greater the width of approach lane, greater number of vehicles can pass through the intersection, hence ultimately greater will be the saturation flow rate. Here, the width of approach is selected as dependent variable and saturation flow rate is selected as independent variable. The model is developed using regression analysis. Following model is developed to estimate the saturation flow rate for heterogeneous traffic flow for Indian condition using regression analysis.

Saturation flow rate S = 805.09*w,

Where, w = width of approach road

VII. COMPARISON OF OBSERVED SATURATION FLOW RATE AND THAT GIVEN BY DEVELOPED MODEL

Intersection	Approaches	Observed SFR (PCU/hr)	SFR from developed model
Income Tax intersection	Usmapura	9040	8494
	Gandhi bridge	9833	7809
	Nehru bridge	6789	7689
	Rajiv Gandhi Underbridge	9857	7809
Memco cross roads	Bapunagar	7250	9259
	Memco BRTS	6050	7648
	Overbridge	7472	9259
	Naroda	5765	6441
Vijay cross roads	LD	7145	7246
	Gurukul	7767	6441
	Darpan	8618	8212
	Commerce college	7650	5716

VIII. CONCLUSION

From the above study, it is come to know that the model developed give the saturation flow rate fairly well and can be used to predict the saturation flow of any urban signalized intersection. The saturation flow measured on the field is counted after three seconds of green time initiation. The developed model for saturation flow rate is based on the traffic behaviour and geometric conditions of Ahmedabad city. The model can be checked for another cities of India having similar conditions. It is also recommended that large number of such intersections can be covered under study to develop the base saturation flow rate model. The model developed gives better results than the previously developed models for saturation flow rate.

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