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Study on Geometric Factors Influencing Saturation Flow Rate at Signalized Intersections under Heterogeneous Traffic Conditions

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Abstract

The main objective of intersection design is to facilitate the convenience, comfort, and safety of people traversing the intersection by enhancing the efficient movement of road users. The intersections on urban roads in India generally cater to heterogeneous motorized traffic, along with slow-moving traffic including pedestrians. It is therefore necessary to consider saturation flow for mixed traffic conditions to evaluate the overall operation of signalized intersections. A proper traffic model must consider varying characteristics of all the road users to effectively design and efficiently manage signalized intersections. This paper presents the results of the study on analyses of saturation flow rate conducted at signalized intersections with mixed traffic conditions in the city of Bangalore, India. Studies were carried out at 15 signalized intersections in the city of Bangalore with varying geometric factors such as width of road (w), gradient of the road (g), and turning radius (r) for right turning vehicles. Saturation flow rate computed as per Highway Capacity manual (HCM: 2000), Indonesian highway capacity manual (IHCM), and IRC SP: 41-1994 was compared with the field observations. The geometric factors, which affect the saturation flow, have been considered in this study and accordingly a new model has been proposed for determining saturation flow. It has been shown that by the introduction of the suggested adjustment factors in this paper, the saturation flow rate can give better picture of the field conditions, especially under heterogeneous traffic conditions of an urban area.

Keywords

Saturation Flow, Capacity, Signalized Intersections, Heterogeneous Traffic

1. Introduction

The improvement of intersections normally follows a direction that consists of planning, design, construction, and operations. In developing countries like India, road traffic in general, and urban roads traffic is highly heterogeneous, comprising vehicles of widely varying static and dynamic characteristics. Further, the vehicles have the same road space without separate lanes. Knowledge of basic traffic flow characteristics like traffic volume under such heterogeneous conditions is fundamental, since traffic volume is the basic input variable in planning, designing and operation of roadway systems. The saturation flow required to calculate the capacity of a signalized intersection can be obtained in two ways. First approach involves conducting field studies to measure saturation flows at the intersection(s) of interest. In this approach, capacity influencing factors are empirically included, and the measured saturation flows represents the capacity of the intersection(s) under the existing conditions. The second approach to the problem involves the use of "base saturation flow values," such as theoretical maximum values. These base values can be adjusted to account for the physical and operating conditions of the intersections, approaches being analyzed and used in intersection capacity studies. The assumption implicit in the use of base flow rates in capacity studies is that quantifiable relationships exist between saturation flows and the physical and operating characteristics of signalized intersections.

Signalized intersections use a common form of traffic control to address roadway operations. Signalized intersections allow road users to access new streets and change in the direction of travel. Intersections should be able to serve their varying traffic demands, provide minimum delay in passage, and maximum safety to all types of users especially pedestrians. One generally evaluates the functioning of a typical signalized intersection in terms of two parameters: 1) capacity, *i.e.*, volume to capacity (v/c) ratio, and 2) the level of service (LOS), with its delay and queue ranges. These parameters are functions of traffic volume characteristics, signal characteristics, and geometry of the intersection. One evaluates the capacity on the concept of saturation flow, whereas, LOS is measured based on the delay that a user experiences, while crossing an intersection.

2. Literature Review

Several studies have been carried out on HCM [1] signalized intersection model, its applicability, and on its modifications. This section addresses some of the important aspects of traffic models proposed so far, for modelling heterogeneous traffic movement at signalized intersections. Researchers have developed various models to evaluate the effectiveness of signalized intersections, in terms of their capacity and LoS. Some research works related to saturation flow rate for signalized intersections have been presented in this section.

2.1. Highway Capacity Manuals

The Highway Capacity Manual (HCM) is published by the Transportation Research Board (TRB) of the National Academies of Science in the United States. It offers standards, tips, and computational tactics for calculating the capacity and fine of carrier of various motorway centres, such as freeways, highways, arterial roads, roundabout, signalized and un-signalized intersections, rural highways, the effects of mass transit, pedestrians, and bicycles at the overall performance of these systems. There have been 5 versions with progressed and up to date strategies from 1950 to 2010, and primary updates to the HCM 1985 version, in 1994 and 1997. The HCM has been a worldwide reference for transportation and traffic engineering pupils and practitioners, and it has also serving as a base for numerous Nations, specific capacity manuals.

HCM are necessary for proper planning, design and operation of road traffic facilities. The fundamental traffic characteristics knowledge contained in such manuals are also an essential input in models for cost-efficient management of road systems, traffic forecasting and assignment with capacity restraint. Highway administrations in many developed countries therefore devote considerable resources to the production of such manuals and guidelines appropriate to their own, conditions.

The main hypothesis behind the project of developing Indonesia Highway capacity manual (IHCM), is Indonesian traffic characteristics are basically different from those of developed countries. Existing capacity manuals from such countries therefore cannot be successfully implemented in Indonesia. The aim of the research behind the production of IHCM manual has been to explore and model Indonesian driver behaviour and fundamental road traffic characteristics by means of extensive field data collection and analysis.

The Central Road Research Institute (CRRI), India is one of the research institute under the umbrella organisation Council of Scientific and Industrial Research (CSIR), has undertaken a national study to develop the Indian Highway Capacity Manual (Indo-HCM) [2].

2.2. Study of Saturation Flow Rate of Signalized Intersections

While IRC: 106-1990 [3] gives an insight into the capacity of urban roads in plain areas, it does not mention about saturation flow rate and LoS for signalized intersections. IRC: SP41-1994 [4], Guidelines for the design of at grade intersections for rural and urban area, has defined saturation flow as $S = 525 \times W$, PCU/hg (S-saturation flow in PCU/hr, W-Width of road in m) for roads having a width above 5.5 m, and gives saturation flow rate based on radius of right turning vehicles. However, it does not specify anything about defining LoS for signalized intersections. In one of the study [5] it has been shown that HCM techniques have limited application for heterogeneous traffic situation prevailing in the developing countries. Another study [6] has affirmed that the adoption (through developing adjustment factors) of the roadway capacities determined for developed countries would not yield realistic results. Study conducted at China [7], confirm that the methodology for saturation flow rates, put forward by Highway Capacity Manual (HCM) can also be used in China. However, parameters should be systematically calibrated, based upon widespread study, before they can be used effectively in the practice of traffic control in China. Another study at China [8], base saturation flow was found to be 1800 PCU/hg and factor of width, turning radius affects are studied and a model is developed based on that, which yields better realistic field conditions. Studies carried out at Makkah, Saudi Arabia, [9] has shown that saturation flow rate and capacity adjustment factors for signalized intersections will vary from HCM recommendations. However, the outputs can form the basis formulating a HCM for the country and therefore estimated parameters is also useful for signal design and traffic system performance in Saudi Arabia. A study conducted in India [10] has confirmed that the methodology for saturation flow rates, put forward by HCM can also be used in India. However, parameters should be systematically calibrated, based upon widespread study, before they can be used effectively in the practice of traffic control in India. One more study [11], observed that regression model developed to estimate saturation flow showed good correlation with field value. Study [12], conducted at Beijing revealed that for different signalized intersections, the queue discharge headway distribution are often not identical. Based on the results that have been obtained using simulation in another study [13], it has been shown that the passenger car equivalent (PCE) values changes per the speed flow relationships along the road. Results from another study carried out in India, [14] has shown that the capacity of 2 lane roads given by HCM 2000 can be achieved with some adjustment factors.

Given the above background and importance, the present study gives an insight in to the traffic flow parameters influencing the capacity at signalized intersections of Bangalore urban area. Further the focus will be on assessing the impact of influencing factors, such as composition of heavy vehicles on the capacity of signalized intersections under heterogeneous traffic conditions.

3. Objectives

The main objectives are: 1) applicability of the HCM 2000 and IHCM 1997, IRC: SP 41-1994 models to prevailing Indian conditions, 2) development of geometric adjustment factors based on the field value. 3) comparison of field value with proposed model, HCM: 2000, IHCM: 1997, IRC: SP 41-1994 models.

4. Details of the Study Area.

15 signalized intersections from the Central Business District (CBD) of Bangalore area were selected for the study. **Figure 1** indicates the Bangalore map, showing study area.

5. Data Collection

During primary survey, data relating to land use, traffic, topographical and environmental features of the study area were collected. The data collection was divided into three parts as geometric data, traffic data and signal data. The traffic data was collected by the videography method. The Traffic Management Centre

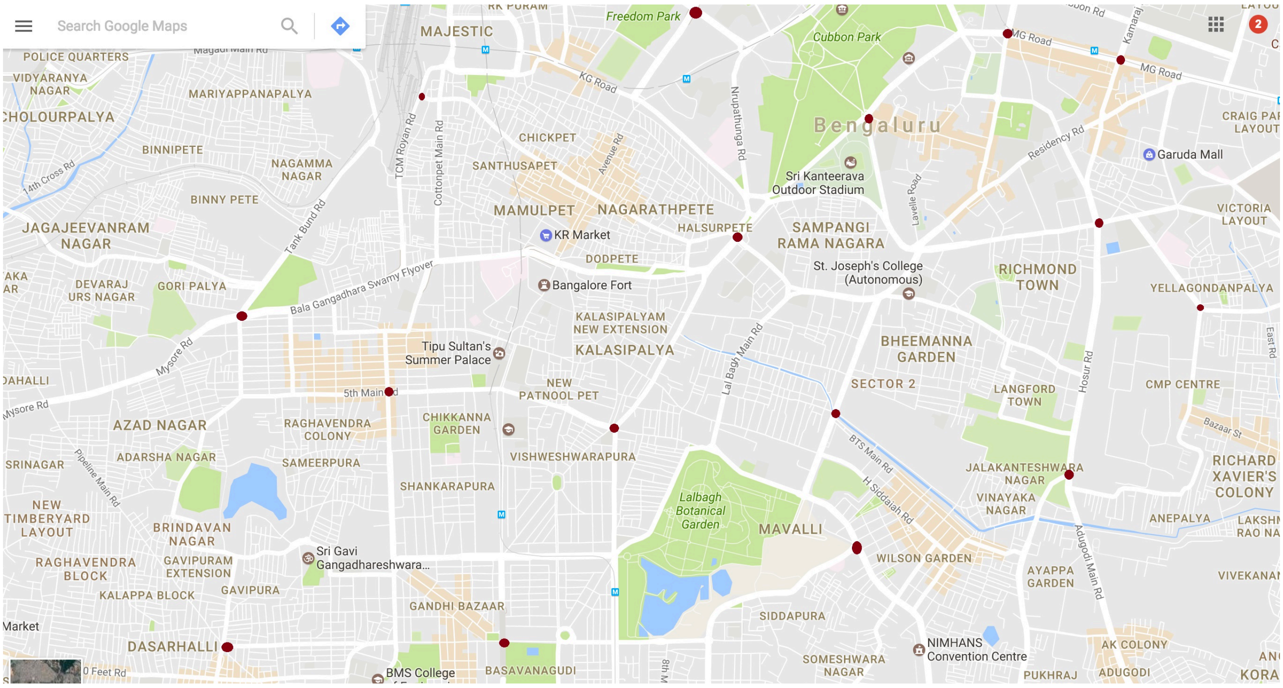

Figure 1. Bangalore area map highlighting study area.

(TMC) [15] at Bangalore city, is the hub of a transportation management system, providing information about the transportation network, are gathered and combined with other operational and control data to manage the transportation network and to produce traveler information. Videos were obtained from TMC, Infantry road, Bangalore and supplemented by site visits. From the videography following data were obtained: 1) through flows, right-turn flows, and left turn of traffic entities and 2) geometrical characteristics of the intersections and 3) signal timings of each phase and cycles. Representation of the geometric data, traffic data and signal data for a typical junction is shown in Figure 2, Figure 3 & Table 1 respectively.

6. Basic Model

The amount of traffic that may pass through a signal controlled intersection from a given approach depends on the available green time to the traffic and on the maximum flow of vehicles pass/cross the stop line during the green time. Once the signal changes to green, vehicles take some second to start, accelerate and attain the normal speed. After a few seconds, the queue discharges at constant rate called the saturation flow (S). Thus, saturation flow is the flow, which would be obtained if there was a continuous queue of vehicles and they were passed at green time, or the saturation flow is the maximum departure rate, which can be achieved when there is a queue. The saturation flow is generally expressed in vehicles per hour green time. Figure 4, the average rate of flow is lower during initial minutes, because vehicles are accelerating to normal running speed.

Wide variation within the determined saturation flow has resulted within the

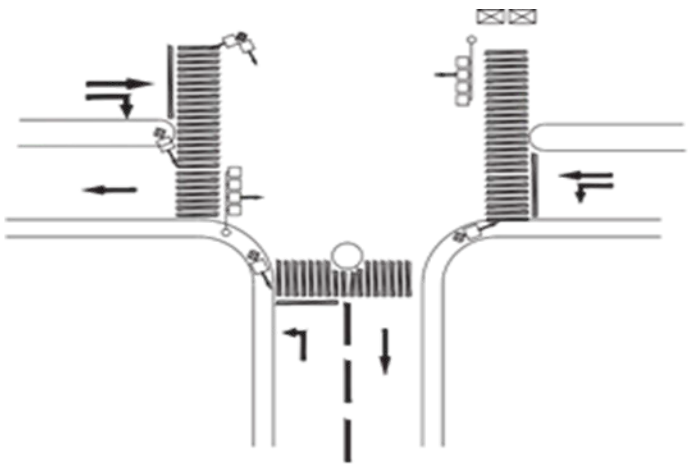

Figure 2. Geometric data collection for a typical junction.

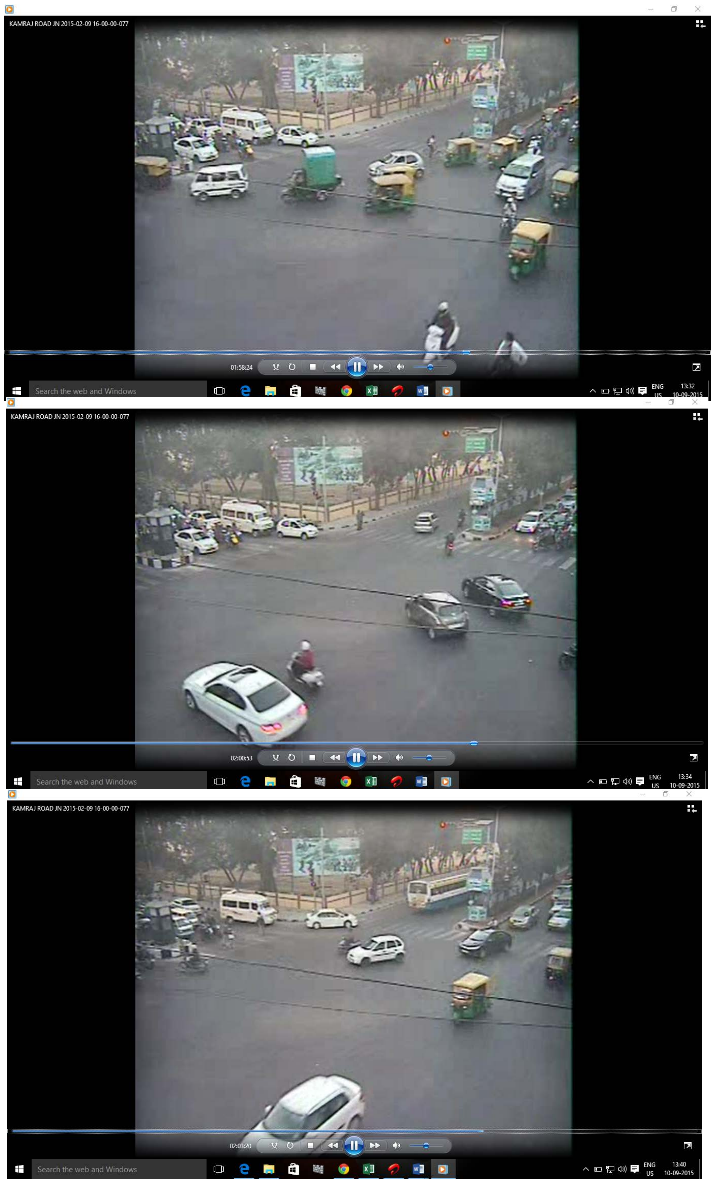

Figure 3. Traffic data collection for a typical junction by videography.

development of models for predicting saturation flow. Webster and Cobbe (1966) [16] outlined saturation flow as a perform of dimension of road as in Equation (1).

$$S = 180w,\ \text{PCU/hg/lane} \tag{1}$$

where, S is the saturation flow in PCU/hour/lane and w is the width of road approach in feet. But the scope of the above formula does not cover the full range of road widths.

The same formula has been adopted by the IRC: 106-1990, with w in meters and suitable adjustment factors are provided to account for the effect of left

Table 1. Summary of the signal data for a typical junction.

	Timings data						CYCLE TIME
	Phase						
	Road	**From**	**1**	**2**	**3**	**4**	
Data	A	Basappa Road	R L S	L			
	B	Shivashenkar Rd		L S	L	Pedestrian	
	C	Minto Rd			R L		
Timings	07:00	08:30	30	40	30	10	110
	08:30	11:00	60	80	35	10	185
	11:00	16:00	45	65	30	10	150
	16:00	20:00	55	75	35	10	170
	20:00	23:00	35	35	30	10	110
Sun day	07:00	23:00	35	35	30	10	110

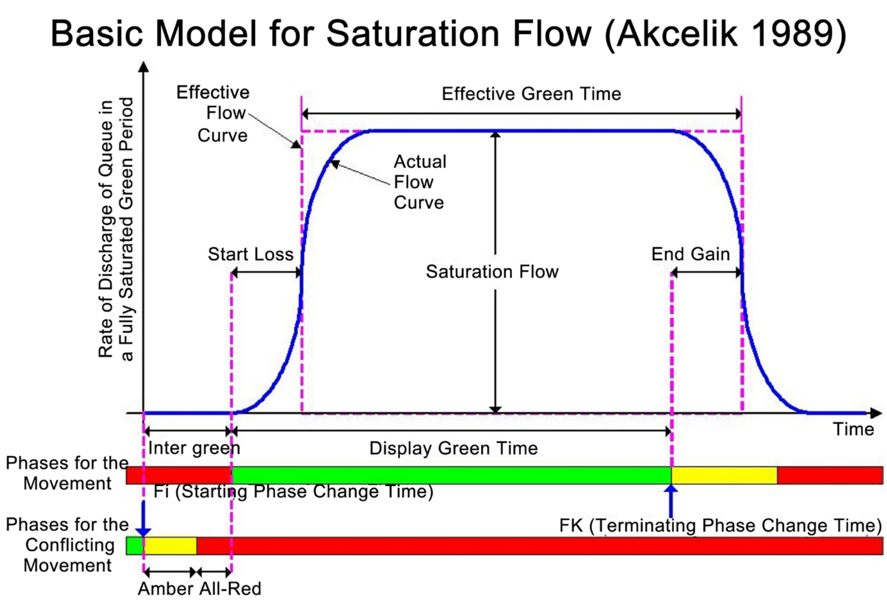

Figure 4. Basic model of saturation flow rate, (Source HCM 2000).

turns and right turns as in Equation (2)

$$S = 525w \text{ PCU/hg} \quad (2)$$

As per TRB, the saturation flow rate of an approach at a signalized intersection can be calculated using Equation (3).

$$S = S0xNxfwxfhvxfgxfpxfbbxfaxfLuxfrtxfltxfRpbxfLpbPCU/hg \quad (3)$$

where,

S = saturation flow rate under prevailing conditions, expressed in vehicle per hour of effective green time in lane group (PCU/hg).

S = Saturation flow in pcu/hg, So = 1900, base flow in veh/hr, N—Number of lanes, fw—factor of width.

fhv = adjustment factor for heavy vehicle, fg = adjustment factor for gradient, fp = adjustment factor for parking, fbb = Factor for bus blocking, fa = Factor for type of area, fLu = Factor of lane utilization, fLt = adjustment factor for left turn movement, fRt = adjustment factor for right turn movement, fLpb = adjustment factor for pedestrian and bike movement for left turns, fRpb = adjustment factor for pedestrian and bike movement for right turns.

Many countries have developed their own capacity manuals based on HCM, as per their physical and geographical conditions.

7. Analysis

In this study, to calculate the capacity, base saturation flow and adjustment factor for heavy vehicles, the following points are noted.

- The junctions have an approach width above 5.5 m as the saturation flow rate formula given by IRC: 106-1990 is valid for width above 5.5 m.
- All the right turning vehicles follow a double stream at 3 legged signalized intersections and single stream at 4-legged intersection as per IRC: SP41-1994.
- Majority of junctions have no free left turning movements, contributing for the saturation flow of signalized intersection.
- There are no bus stops near (within 50 m), of the signalized intersections, reducing the saturation flow at the intersection.
- There is no parking provided near the junctions, causing reduction in the saturation flow at intersection.
- The PCU values for different categories of vehicles are considered as given by IRC SP: 41-1994.

7.1. Field Measurement of Saturation Flow

The normal headway method based on time headway of passing vehicles cannot be used for non-lane based traffic condition, because, in non-lane based traffic flow, headways are hard to observe, as vehicles do not move in definite lanes. Traffic is analyzed based on total width of approach and hence, the option of vehicle counting is adopted. Saturation flow is considered autonomously for each observed saturation period and then averaged over observed cycles. All counted vehicles are added and the sum is divided by saturation period to get saturation flow in vehicles per hour.

7.2. Comparison of Saturation Flow Rate by HCM-2000, IHCM-1997 and IRC: SP41-1994

Before developing the adjustment factors for saturation flow rate, the existing specifications and guidelines by IRC: SP 41-1994, HCM 2000 & IHCM-1997 was compared with observed field data. The comparison of the saturation flow rate for these 15 signalised intersections are shown in Figure 5.

From the graph, the field observations show more realistic values with IHCM -1997, than with HCM 2000 & IRC SP: 41-1994. It can be seen from the graph, HCM 2000, IRC: SP41-1994 underestimates the saturation flow at signalized intersections. Hence in this study saturation flow rate has been developed based on IHCM-1997.

7.3. Saturation Rate Flow Model

A new saturation flow model has been developed, based on HCM 2000 and the field studies and by using the factor of gradient, factor of turning radius along with the base saturation flow as given in Equation (4).

$$S = S0 * fg * ftr \text{ PCU/hr} \tag{4}$$

where, S is Saturation flow in PCU/hg, S0 is base saturation flow in PCU/hg and given by Equation (5)

$$S0 = 600 * W \text{ PCU/hr}, \ W - \text{width of road } (m) \tag{5}$$

Factor of gradient (fg) is calculated by Equation (6)

$$fg = 1 - 0.013 * (\%g) \tag{6}$$

Proposed factor of turning radius (ftr) is calculated by Equation (7).

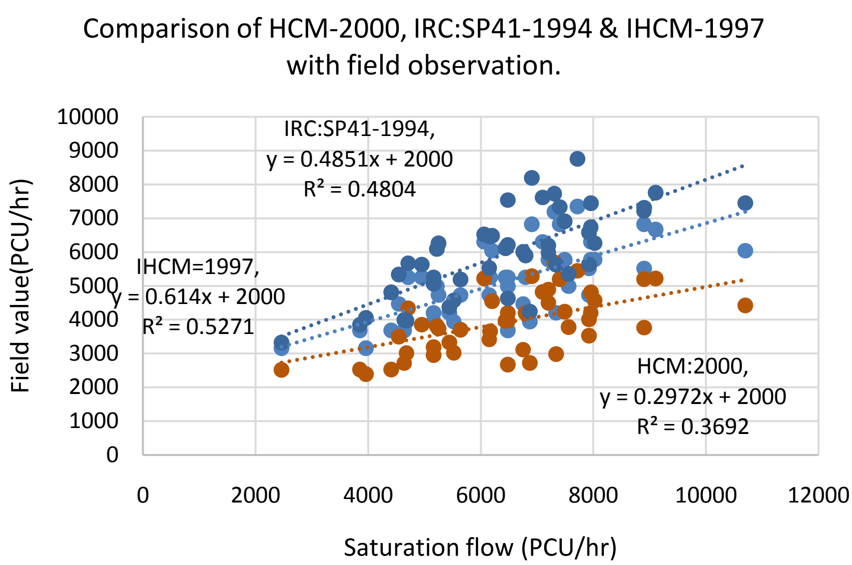

Figure 5. Comparison of field value with HCM-2000, IHCM-1997, IRC: SP41-1994.

$$ftr = 1 + 4 * (r/1000) \tag{7}$$

The field value has been compared with proposed model, IRC: SP 41-1994, IHCM-1997 and HCM-2000 as shown in Figure 6. From the Figure 6, the new proposed model yields better realistic values with the field conditions compared to the other fields.

By the introduction of the adjustment factors to the proposed model, it can give better realistic field values, which will be helpful in obtaining the capacity at signalized intersections, which in turn to will help to assess the Level of Service (LoS) at signalized intersection(s), especially under heterogeneous traffic conditions.

8. Conclusions

In this paper, 15 signalized junctions in Bangalore urban area with varying traffic parameters were studied. The results obtained are summarised as follow:

1) Saturation flow rates were calculated by HCM 2000, IHCM-1997, IRC SP: 41-1994 method and were compared with the field values.

2) HCM: 2000 and IRC: SP 41-1994, underestimates the saturation flow. IHCM-1997 provides a better realistic value.

3) Saturation flow rates were calculated by a proposed saturation model, which considers a base saturation flow with other geometric characteristics such as factor of gradient (fg) and factor of turning radius (ftr).

4) Base saturation (S0) model has been obtained from field conditions as: S0 = 600 × W PCU/hr, where, W is the width of road (m).

5) The adjustment factor, of gradient (fg), is given by, fg = 1 − 0.013 × (%g), where, %g is the percentage of gradient.

6) The adjustment factor, of turning radius (ftr), is given by, ftr = 1 + 4 × (r/1000), where, *r* is the turning radius (m) of right turning vehicles.

7) By the introduction of adjustment factors fg & ftr, along with the new base

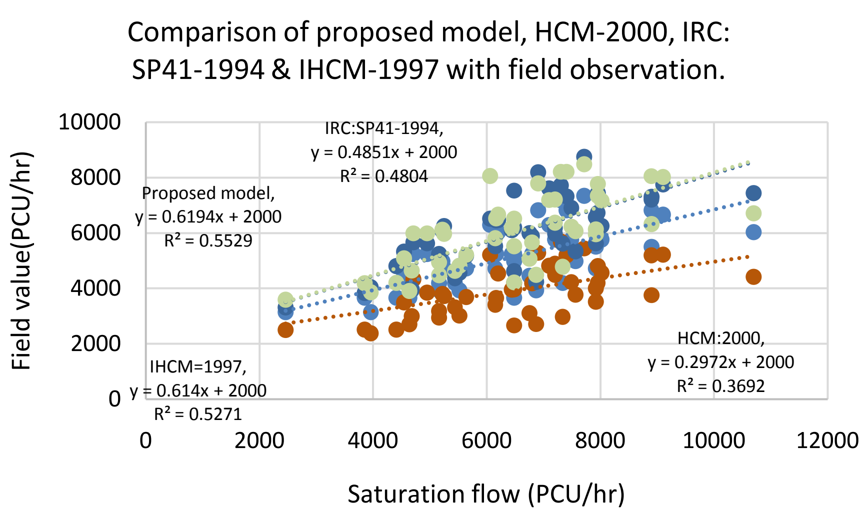

Figure 6. Comparison of saturation flow rate by IRC method & proposed model.

saturation flow model into the saturation flow model, there is an increase in R2 value when compared to the saturation flow by IHCM-1997 method.

8) Results prove that introduction of adjustment factors with base saturation flow can give better picture of field conditions at signalized intersections, especially, under heterogeneous traffic conditions of an urban area in the Indian context.

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