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REVIEW OF EARLIER STUDIES ON SATURATION FLOW RATE AT SIGNALISED INTERSECTIONS

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Abstract

The three important parameters of signalised intersection are arrivals, stop and departure. By proper management of the above said parameters, the function of signalised intersection can be maximised by minimising delay, increasing the safety of pedestrians and road users. By proper management of signalised intersections, congestion can be reduced in turn reducing pollution. The uninterrupted flow facilities have more lacunae in terms of merging conflicts, safety of pedestrians compared to the interrupted flow, especially in urban areas. Intersections provided with signals are one of the important ways of interrupting traffic flow for proper movement of vehicles. Intersections with signal system are evaluated based on length of queue and clearance of queue during green period. In one of the study, using motorists survey, multiple factors were considered for defining Level of Service (LOS) at intersection was based on user's perception such as (i) efficiency, (ii) safety and (iii) convenience. In understanding the signalised intersections, study of SATURATION FLOW RATE (SFR) rate plays a major role. In this paper a review of various works on SFR (*S*) for heterogenous and homogeneous traffic have been presented.

Keywords:

Signalised intersection, Saturation flow rate, Level of Service, Volume to capacity, Highway Capacity manuals

1 Introduction

In the current situation, the country's economy is heavily reliant on its mobility system and network, particularly its urban transport system. If the urban transport planning is not done properly, it will have a negative impact on every aspect of life directly or indirectly. The rapid urbanization, ill planning of urban transport network, poor public transport systems, have caused and made a negative impact on most of the metropolitan cities causing hours of traffic jams, which needs to be addressed by traffic engineering professionals.

Intersections are the key elements to be considered in the design of road networks as they connect different approaches and allow the vehicle movement in different directions systematically. Intersections will have conflict points due to flows in opposite directions associated with the connected links. Intersections are the places where traffic flow changes to smooth flow from bottle necks and hence they are found to be critical compared to all other components, especially in case of mixed traffic conditions. With the use of traffic signals, signalised crossings allow for the controlled flow of vehicles. When it comes to the safety of road users and the efficient functioning of vehicles, signalised intersections are critical and must be studied for improved traffic efficiency.

2 Review of Earlier Studies

2.1 Review of Earlier Studies on Saturation Flow Rate and its Influencing Factors Under 'Homogenous' Traffic Conditions at Signalised Intersections

Studies on SFR and capacity analysis in developed countries have started long back due to the development of motorization. In developed countries, their traffic is dominated by either one or two types of vehicles, and hence, they are called as 'homogenous traffic'. The research pertaining to studies on SFR etc., under homogenous traffic have been reviewed and presented in the following section.

Analysis of saturation flow at signalized intersections in Lexington, Kentucky, USA, was carried out and presented in a research report during July 1982 [1]. The study has identified several factors that are found to significantly influence saturation flow. It has been recommended that appropriate adjustment factors can be used to a 'base saturation flow' value of 1650 vphg (vehicles per hour of green time/lane) to generate an effective saturation flow number for a specific intersection, approach, and lane. Furthermore, to estimate a suitable saturation flow value for a certain lane approaching an intersection, the following formula (provided by [eq:1]) has been recommended.

$$S = Sb * flp * fc * fvt * fg * fw * frt * ft * fs * fd(vphg) \quad (1)$$

where, S= saturation flow for specific intersection approach lane (vehicles per hour green (vphg)); S_b= base saturation flow (1,650 vphg); flp= adjustment factor for location in city level of pedestrian activity; fc =adjustment factor for city population; fvt= adjustment factor for vehicle type and turning maneuver; f_g= adjustment factor for gradient; fw= adjustment factor for width of lane; frt= adjustment factor for turning radius; ft =adjustment factor for type of lane; fs= adjustment factor for speed limit and fd = adjustment factor for light conditions.

The SFRs with respect to turning action (through or right); gradient (up or down); number of through lanes (1 & 2), and speed limit of 60 & 80 kmph were studied at a number of crossroads in the region of Stellenbosch, South Africa [2]. The effects of speed limit, gradient, and number of through lanes on SFR are substantially stronger locally than in the United States, according to the findings. Additionally, a detailed analysis covering the entirety of South Africa has been proposed in order to generate an equation for predicting SFRs in South Africa.

The effect of variations in saturation flow on the efficiency of traffic lanes at signalised junctions in three Polish cities (Krakow, Warsaw, and Rzeszow) was studied from 2007 to 2009 and reported. Saturation flow in traffic signal cycles at specific crossings has been demonstrated to be a random number with a gamma or normal distribution. Different weather conditions had an impact on saturation flow, as measured by the measurements.[3]

A ground saturation headway model was established for Huntsville, Birmingham, and Montgomery, Alabama, and compared to the US-HCM-recommended base saturation headway of 1.9s and the saturation headways observed in these cities. It was discovered that there is a statistically important gap between the actual saturation headways and the HCM recommended value of 1.9s, removing the premise of homogeneity in the application of HCM base flow rates and emphasizing the necessity for alternative saturation flow estimations. [4].

Using the macroscopic method, researchers in Rasht, Iran, estimated the SFR at far-side and near-side legs of signalised intersections and found a linear association between lane width and SFR at far-side legs [5]. When the microscopic approach was utilized, however, it was discovered that an exponential non-linear relationship exists between lane width and SFR at far-side legs while a logarithmic non-linear relationship exists at near-side legs.

Data obtained by videography at three crossings in Vienna, Austria was used to investigate the impact of severe weather circumstances on SFR. The findings revealed that snow on the road surface had a significant impact on SFRs. The SFR is reduced by 30% when the road surface is completely covered with snow, and by 20% when the road surface is covered in snow slush [6].

At 35 signalised intersection approaches in 14 Florida communities, the effect of area population, number of lanes, and speed limit on the SFR of the through lane group was investigated Based on the results of the previous experiments, a basic SFR of 1950 PCU/hr/ln was calculated, as well as additional adjustment parameters [7].

In an urban region of the District of Columbia, USA, the typical SFR for lane groups was evaluated at 81 signalised intersections with through (T), shared through and right (TR), shared through and left (TL), and exclusive left turn (L).[8]. The local base SFR was calculated using the results of this investigation as shown in equation (2).

$$So, local = \left[\frac{\left(1900 \sum_{i=1}^{m} S_{(Prevailing,i)}\right)}{\sum_{i=1}^{m} S_{(i)}} \right] \tag{2}$$

where, $S_{o,local}$– local base SFR (PCU/hr/ln);$S_{(Prevailing,\ i)}$ -Prevailing SFR for lane group i (PCU/hr/ln); S_i – adjusted SFR for lane group I (veh /hr/ln); and m- number of lane groups.

SIDRA Junction, Australia software, US-HCM, and TRANSYT applications were used to compare lane-based, and lane-group based models of signalised intersection networks for a T intersection in Melbourne, Australia. According to the experiments above, the SFR decreases due to the short lane impact and downstream queue congestion. [9].

The investigation covered a total of 25 intersection approaches from nine cities and five states in the United States [10]. The impact of lane width on SFR could be isolated because all of the study sites had similar baseline conditions. As per the findings, SFR varies with lane width, with mean SFRs varying from 1,736 to 1,752 passenger cars (pc)/h/ln for 2.9-m (9.5-ft) lanes; 1,815 to 1,830 pc/h/ln for 3.3- to 3.6-m (11to 12-ft) lanes; and 1,898 to 1,913 pc/h/ln for lane widths of. The SFRs that were measured were generally lower than those that are now used in the United States - HCM. Moreover, the difference in SFR across sites with 2.9-m (9.5-ft) lanes and locations with 3.6-m (9.5-ft) lanes was about half of the value utilised in the HCM above.

Data was obtained using a high-resolution approach from three crossings on the Indianapolis route in the United States. The study examined the model to estimate SFR and provided improved computation methods for grouping estimates of SFR by queue length. SFR estimations can be grouped by queue length to create a simple framework for evaluating SFR dependability. Characterizing the stochastic variation of SFR provides a basic input for assessing how reliably one can estimate important performance measures such as volume to-capacity ratios and other performance measures that build upon volume-to-capacity ratios, as SFR is a fundamental input to volume-to-capacity performance measures [11].

2.2 Critical Observations on the Above Review

From the above reported research on SFR etc., under homogeneous traffic conditions the following critical observations are made:

1. The US-HCM with its universal appeal for countries with homogeneous traffic conditions, cannot be applied directly for all the developed countries, in the world.

2. The US-HCM can only form as a basis and must be modified according to the local conditions of any other developed country.

3. The number of assumptions made in the US-HCM, and other developed countries capacity manuals needs to be calibrated according to the local traffic conditions and driver's behavior, based on extensive field data collected, analyzed and validated over several towns/cities across a country.

4. HCM of many other developed countries have been developed based on US-HCM and according to their prevailing local conditions of traffic and driver behavior.

5. The base saturation flow (S_0), considered as 1900 PCU/ hr /ln, the validity of which has been studied by different investigators from various developed countries. Based on such studies, different values for So, have been recommended taking into consideration the prevailing local conditions.

6. The relevance / validity of various adjustment factors for SFR given by US-HCM were also studied by different investigators, especially, from developing countries. Based on such studies, modifications and factors have also been recommended considering local conditions.

2.3 Review of Earlier Studies on Saturation Flow Rate and its Influencing Factors Under 'Heterogeneous' Traffic Conditions at Signalized Intersections

The term 'homogeneous' refers to traffic that is composed of identical vehicles that observe a strict lane discipline. Heterogeneous traffic is defined as a mix of motorised and non-motorized two-wheelers (TWs) and three-wheelers, as well as a variety of other vehicles with no lane discipline. This heterogeneous traffic is distinct from that which occurs in the presence of trucks, which is also referred to as 'heterogeneous traffic.' In the absence of lane discipline, vehicular travel is impacted by the presence of vehicles both in front and on the sides. This results in complex traffic behaviour that can't be evaluated using traditional traffic factors like microscopic and macroscopic traffic variables. The following part reviews and presents research that has already been done and reported under diverse traffic.

SFR and LoS at signalised intersections are not included in IRC 106-1990, which provides information on the capacity of urban highways in plain regions. For roads with widths more than 5.5 m, the IRC SP41-Guidelines for the construction of at-grade intersections for rural and urban areas defines SFR as $S = 525 * W$(PCU/hg) (W-Width of road in m) and yields SFR depending on radius of right turning vehicles. It does not, however, determine the level of service at signalised intersections. Several research on the SFR and its influencing elements have been conducted in India, considering the varied traffic circumstances. However, when compared to other emerging and industrialised countries, research on SFR is quite restricted in India, due to the local/ specific characteristics that exist, yet it is urgently needed. This section reviews and presents some of the research conducted and reported after the year 2000.

Some Asian countries with diverse traffic patterns have established or are building their own capacity manuals based on the US-HCM to meet their specific needs. Malaysia, Japan, and Indonesia have already developed capacity guides, while China and India are in the process of doing so. This section reviews and presents some of the studies conducted in these nations with heterogeneous traffic.

According to research conducted in Indonesia, the formula for calculating the basic SFR (S=600*We) is only relevant for road widths up to 9 m, and considerable discrepancies in calculated saturation flows are detected when the road width is large (9 – 12 m) [12]. For wider road widths, a modified formula has been presented based on the above as shown in equation (3).

$$S = (500We+400)\ (PCu/hr) \tag{3}$$

where S, saturation flow in PCU/hg and We - the effective width of road.

Another study from China found that the approach for SFRs proposed by the Highway Capacity Manual (HCM) may be utilised in China as well [13]. However, before they can be used effectively in traffic control in China, parameters must be rigorously calibrated based on extensive research. Based on the percent of heavy trucks, the study calculated a SFR as given by equation (4)

$$S = \frac{2121}{(1+1.2p)} \tag{4}$$

The traffic capacity and SFR at 10 intersections of Bejing, were compared with the 3 intersections of UK using video graph data [14]. The comparison revealed that signalised intersection utilisation was less than in UK. The traffic flow distribution of intersection is not balanced in China when compared to UK. Study also revealed that capacity of lane in China is also less than in UK. But SFR at T intersections are more than in UK, thus proving the point that heterogeneous traffic, does not have an orderly movement when compared to homogeneous traffic, and also the effect of non-power driven vehicles and orderly movement of pedestrians is missing in China, when compared to UK.

The influence of area type characteristics on SFR was analysed from 11 signalized intersections, (all of which are managed by pre-timed signals), were chosen for the study in Ghana’s Kumasi Metropolis. [15]. Further, adjustment factor for area was developed and given by equation (5). Furthermore, the average fa values generated for the area-type adjustment factors for the different friction environments were 0.99 for low/no friction areas, 0.98 for medium friction areas, and 0.94 for high friction areas. The HCM’s recommendation to utilise fa=0.9 for CBD intersections and fa=1.00 for all other intersections implies, inadvertently but incorrectly, that the nature of non-CBD intersection regions has no bearing on the intersection discharge. The above proposal could lead to an overestimation of flow where there is severe intersection area interference.

$$fa = [0.9945-6.9*10^{-5}N_{pc}-0.00039Nph];\ (R^2 = 0.93) \quad (5)$$

where, fa - area-type adjustment factor; N_{pc} - number of crossing pedestrians; N_{ph} - number of pedestrian hawkers.

For the purpose of analysing the SFR for shared left-turn lanes, real-time traffic data was collected from 6 signalised intersections in Aichi Prefecture, Japan [16]. The results were analysed using the methodologies described in the US-HCM 2000 and Japan Society of Traffic Engineering (JSTE) recommendations. The results of both methods have been demonstrated to overstate the performed SFR in shared left turn lanes. Furthermore, when compared to HCM, the JSTE standard appears to overestimate the shared left turn SFR in Japan. [16].

From the data collected for through traffic with level gradient, no parking and no bus blockage was collected through out Malaysia to compare and determine the ideal base saturation flow [17]. The regression model obtained for calculating the base saturation flow based on width of the road [w(m)] is given by equation (6). The base saturation flow estimated as 1930 PCU / hr / ln, this is marginally higher than the value indicated in US-HCM, resulting in a 1.7-second headway.

$$S = (527.16w)\ PCU/hr \quad (6)$$

Saturation flow and delay models were developed for 3 signalised intersections of Kathmandu, Nepal [18]. Based on the independent variables used and the regression method some of the models for estimating the SFRs is given by equation (7).

$$S = (525.88w)\ PCU/hr \quad (7)$$

The effect of right turning vehicles, influencing the straight-ahead vehicles were studied and adjustment factor for right turning movement was developed from the data on shared and exclusive lanes at signalised intersections of several cities of Malaysia [19] . By considering the turning radius (r) along with the proportion of right turning vehicles (prt), the adjustment factor for right turn (frt), was developed using regression analysis, which is given by equation (8). Further, results also show that the right-turn adjustment factor decreases with higher proportions of turning vehicles and lower turning radius.

$$f_{rt} = \left[\frac{1}{(1+\sqrt{((P_{rt})/r)})}\right] \quad (8)$$

In Kampala, Uganda, a study was performed to assess the SFR for through traffic at two operational signalised crossings. The computed SFR was compared to the suggested value of 1900 vphgpl [vehgpl] and adjusted values based on the US -HCM 2000 model. The results of the study demonstrated that designing with an ideal SFR resulted in capacity overestimation but adopting the US-HCM 2000 model with 13 right adjustment factors results in capacity depicting the operational conditions [20].

To determine the causes of their occurrence, a thorough analysis of saturation flow and its variability was conducted by investigating the flow patterns at 10 intersections in Aichi Prefecture, Japan. It has been revealed that as the wait length grows, headways tend to compress, and that headways tend to compress at minor intersections and on the kerb sides of through lanes. [21]

A investigation was carried for three approaches at the Suemoridori-2 crossroads in Nagoya, Japan [22] based on influencing factors such as lane utilisation, turning proportion, turning radius, pedestrian and bicycle traffic, and queue discharge rate of shared left-turn lane. It has been discovered that efficient use of a shared lane by through traffic can boost the SFR dramatically. Because more turning vehicles may be stored within turning bays, the SFR of the shared lane with a bigger turning radius shows a stable trend, implying a lower likelihood of lane blockage. A comparison of observed SFRs with US-HCM and Japanese guideline estimates shows that both overestimate SFRs in shared left-turn lanes in Japan [22].

The change in the parameters characterising the linear connection between the entry time and average probe travel time for varied turning rates of signalised crossings in Japan [23] was observed for different turning rates. It is predicted that the study, which will be based on turning rates, average travel times, and delay, will be able to estimate and control traffic signals [23].

A study on different methods of calculating the saturation flow volume were examined in Ukraine, and it was found that none of them considers the speed of vehicles passing through the intersection (intersection passing speed). Hence, simulation of signalised intersections was carried out to examine the effect of including intersection passing speed on the accuracy of assessing traffic conditions at intersections using VISSIM software [24]. Tests showed that accurately assessing the saturation flow volume depends on including intersection passing speed and the size of the intersection.

The researchers selected eight signalised crossroads (with two-lane and three-lane approaches) along eight main Riyadh streets with the goal of analysing the entering headway on selected signalised crossings. The SFRs for two-lane and three-lane sites, respectively, were 2,293 and 2,195 vehicles/hour of green per lane, according to the study. In comparison to prior studies from other countries, these junction approaches appear to have higher SFRs [25].

The distribution of departure headway data acquired using video cameras from four crossings in Beijing, China between 2006 and 2007 was investigated. The distributions of departure headways at each location in a queue (save the first one) are found to roughly follow a specific log-normal distribution, and the related mean values level out gradually. Furthermore, a driver-perspective car-following model has been presented to explain why departure headways have such a log-normal distribution. According to the authors, the new car-following model described above gives an appropriate representation of the unseen interactions between vehicles in a discharge queue and is thus suitable for simulation-based junction capacity assessments and traffic signal control [26].

Data on discharge headway was collected at 11 signalised junctions in Beijing using video cameras during morning and evening peak periods (7:00 to 9:00 and 17:00 to 18:00) on weekdays and manually analyzed. The average value of queue discharge headways is bigger than the median value, and the skewness of the headways is positive, according to the findings. Before and after a log transformation of the headways, normal distribution tests were performed, and the goodness-of-fit test revealed that the queue discharge headways for some of the surveyed sites can be fitted by the normal distribution, while the headways for others can be fitted by the lognormal distribution.[27]. Furthermore, the median value of queue discharge headways has been presented for determining the saturation headway, resulting in the development of a new approach for predicting SFRs.

For the analysis of estimation of turning adjustment factors at signalised intersections, eighteen intersections with shared and exclusive left-turn lanes, thirty intersections with shared and exclusive right-turn lanes, and thirteen intersections with shared (exclusive right-turn with U-turn) and exclusive U-turn lanes from Malaysian cities were chosen [28] . Regression analysis is used to calculate the left-turn, right-turn, and U-turn adjustment factors. The results show that as the proportion of turning vehicles grows and the turning radius falls, the left-turn and right-turn adjustment factors drop. The proposed method yields a higher value for the anticipated left-turn and right-turn adjustment factors than the MHCM 2006. The results of the U_{turn} adjustment factor show that as the proportion of U-turning cars increases, the U-turn adjustment factor drops. According to the findings, the U-turn adjustment factor reduces by 2.25 percent for every ten percent rise in the percentage of U-turns. The daily conflict of a U-turn with a conflicting left-turn from different lanes is likewise found to be 1.4 times higher than the daily conflict of a U-turn in the same direction.

Highly Maneuverable Vehicles (HMV) are vehicles with a significant level of transverse and vertical freedom. The effect of two independent variables, namely, width of road and the effect of HMV's on the SFR were studied for four, 4-legged intersections of CBD area of Hyderabad and Secundarabad [29] . The study resulted in the development of statistical models to explain the relationship between the SFR (in veh/hour) and the two independent variables, namely the width available for movement, and the proportion of HMV. It is observed that the SFR increases with the increase in any of the above 2 variables. The linear regression, non-linear regression models and Artificial Neural Networks (ANN) were developed for obtaining the SFR. SFR by linear and non-linear regression mare given by equation (9), equation (10).

$$Sf \;=\; [-9656 + 1327PHMV \;+ 821w]\; PCU/hr \tag{9}$$

$$S_f = [2719(P_{HMV})^{1.24} w^{0.954}]\; PCU/hr \tag{10}$$

where, Sf = SFR, vph; P_{HMV} = Proportion of Highly Maneuverable vehicles; and W =Width available for the combined straight and right movement from an approach, m; The above study has established that the prediction capability of SFR by ANN model is 29.67 percent is higher than that of multiple linear regression model, and 31.11 percent higher than multiple non-linear regression model.

Based on the field data obtained from three Indian cities (Jaipur, Bangalore, and Trivandrum), PCU values were derived and then a new model for SFR was proposed using the regression method and using the data from measured percentage composition and saturation portion of flow [30]. The new saturation flow model thus developed is given by equation (11).

$$[S = 25.59P_{cr} + 60.11P_{tw} + 18.25P_{Auto} + 14.82P_{Car}]\ PCU/hr \quad (11)$$

where, S is the saturation flow in vehicles/3.6m/hour of green; Pcr, P_{tw}, P_{Auto} and P_{Car} are percentages of cycle rickshaws, two-wheelers, auto-rickshaws and cars, respectively. In the above study, for the SFR model was developed, based only on the Passenger Car Equivalence values and other influencing factors, such as: gradient, width, parking, percentage of heavy vehicles, percentage of right turn and left turn, were not considered.

The effect of diverse traffic on the SFR was investigated and analysed at a signalized intersection in Ahmedabad city, Gujarat State, based on data collected by videography method during the peak hour, and using the method of classified volume count [31]. It has been concluded that the observed saturation was very different from the one calculated using US-HCM 2000 and that the above difference is attributed to the higher percentage of two wheelers (i.e., 70%), which in turn has adversely affected the computed saturation flow. Further, it has been suggested that equation (12) be used to obtain the SFR, so that it is closer to the observed values.

$$[S = 714w]\ PCU/hr \quad (12)$$

where,w - width of road in m.

t has been confirmed that the approach for SFRs proposed by US-HCM may also be applied in India based on research conducted for Ahmedabad city, Gujarat state, using data from four junctions of the aforesaid city [32]. However, before they can be used effectively in traffic control in India, parameters must be rigorously calibrated based on extensive research. The suggested SFR as proposed in equation (13) is supplied by based on the above investigation.

$$[S = 986.57w]\ PCU/hr \quad (13)$$

where, S= saturation flow in PCU/hg and w-width of road in m.

The findings of a research on SFR analysis at four signalised intersections in Delhi, India, under mixed traffic conditions were used in the preparation of the Indian Highway Capacity Manual (Indo-HCM) [33].

Correlation relationships developed based on the above data collected between average saturation flow and width of approaches; between saturation flow and percentage of car developed for the approaches; between saturation flow and percentage of two wheelers developed for all approaches, are given in equation (14), equation (15) and equation (16). It has been observed that the saturation flow based on effective width of road is expected to provide a better understanding of relationship, in particularly in India, where heterogeneous traffic and no lane discipline is the general norm.

$$[S = -63w^2 + 2093w - 704] PCU/hr \tag{14}$$

$$[S = 9.61 * T_p + 575]\ PCU/hr \tag{15}$$

$$[S = 5.39 * C_p + 1097]\ PCU/hr \tag{16}$$

where, S -Saturation flow (PCU/h), w- Width of approach in meters, Tp = Average percent of two-wheeler, Cp = Average percent of Cars.

The effect of side frictions on traffic characteristics of urban arterials was investigated in Indian cities such as Mumbai, Bangalore, and Thiruvananthapuram. The research was limited to a few side friction variables, such as buses stopped at bus stops, pedestrians walking along the sides of carriageways, and vehicle parking on the street. To link the elements that contribute to the reduction in speed caused by side friction factors, multiple linear regression (MLR) analysis was utilised. The findings demonstrated that side friction has a considerable impact on vehicular speed on urban road arterials, necessitating the inclusion of side friction components in all traffic-related studies of urban roadways.[34].

SFR (S_f) of right turn lanes were compared with that of through lanes at five 4-legged, right-angle intersections with protected right turn, in New Delhi, India [35] . The equivalency factors for right turning vehicles ($e_{turncar}$) were calculated using the equation (17). Further, in the above study reduction in the SFR by turning vehicles has been proposed, which is given by equation (18).

$$e_{turncar} = 1 + \frac{5729}{r^{\ 2.9}} \tag{17}$$

% Reduction factor,

$$\left[S_f = \frac{(S - S_{rt})}{S}\right] PCU/hr \tag{18}$$

The SFR was measured based on the videography data on a 4 legged signalized intersection of Ahmedabad city, India and based on the above data the SFR was given by equation (19). It is stated that the values suggested by IRC for saturation flow values observed is quite higher than the suggested values, indicating that there are other factors that influence the SFR, and that such factors need to be identified and considered [36].

$$[S = 874]\ PCU/hr/meter\ width\ of\ approach \quad (19)$$

For the signalised junction of Cenotaph Road, Anna Salai, in the southern portion of Chennai, a simulation model called 'HETEROSIM' was used to estimate SFR of heterogeneous traffic with the influence of road width on SFR measured in terms of passenger car unit (PCU) per unit width of road. According to the results of the preceding study, the software 'HETEROSIM' may be used to estimate the SFR of a typical heterogeneous traffic [37].

A study was conducted in India that focused on simulating traffic movements at signalised crossings by constructing a micro-simulation model using a high-level computer language. The proposed model, TRAFFICSIM, is said to be extremely user-friendly and capable of simulating any traffic movements with varying geometry and signal phasing features. Because it can update the acceleration, lateral and linear spacing, as well as deceleration characteristics, which are heavily influenced by traffic behaviour and signal phasing, the above model is a genuine replica of the actual traffic scenario. The validated model was used to calculate SFR models in both car-only and mixed traffic scenarios [38]. S = 525w, where S is the saturation flow in pc/hr and w is the carriageway width in m, is the SFR model produced under a 100 percent automobile only situation. The SFR obtained under 100 percent automobile alone in both homogeneous and mixed traffic conditions is 1911 pc/hr and 1908 pc/hr, respectively, demonstrating that the results are quite near to the US-HCM values.

The process for building a dynamic Passenger Car Unit (PCU) under diverse vehicular interactions in India's mixed traffic situations. Experiments were conducted using the TRAFFICSIM microsimulation model, which was designed by the authors for signalised junctions and described elsewhere. The dynamic PCU values were calculated using TRAFFICSIM results for different approach widths, traffic compositions, stream speeds, and traffic volumes. In a mixed traffic situation, Dynamic PCU values were developed using the modified area occupancy approach. The area occupancy of various vehicle types for various traffic compositions is compared to the area occupancy of passenger vehicles in a car-only traffic condition with the same stream speed in the modified area occupancy technique [39]. PCU values are very sensitive to traffic variables such as approach width, traffic composition, stream speed, and flow ratio, according to the study.

From data obtained in Thiruvananthapuram and Kochi, Kerala state, India, and Bangalore, Karnataka state, India, a study on the use of dynamic PCU based on the number of standard car space (Ncs) for different kinds of cars travelling through signalised junctions was used to estimate SFR [40]. According to the findings of the preceding study, traffic mix, geometric factors, and control circumstances all have a substantial impact on dynamic PCU values. With the exception of tiny autos, the PCU value increases with increasing approach width and decreases with increasing its own proportion. The impact is more pronounced in large vehicles. The adaptive PCU values for different vehicles categories were discovered by utilizing equation (20).

$$PCU_i = \left[\frac{N_{cs}}{ni}\right] \quad (20)$$

where, *PCUi* is Passenger Car Unit for the category of vehicle i; *Ncs*- Number of standard car spaces according to ith category of vehicle; ni-number of vehicles in the ith category.

PCUi stands for Passenger Car Unit in the category of vehicle I Ncs stands for Number of Standard Car Spaces in the ith vehicle category; and ni stands for Number of Vehicles in the ith category. The video graphic technique was used to collect data from 18 approaches located at various signalised intersections in Thiruvananthapuram and Kochi, Kerala, India, and Bengaluru, Karnataka, India, to propose a methodology based on the area occupancy concept for the realistic estimation of SFR in PCU/hr without using individual PCU values under heterogeneous traffic conditions . The results of the preceding analysis revealed that site-specific factors have an impact on SFR [41]. SFR data was generated using the microscopic simulation programme VISSIM for a wide variety of traffic composition and approach width, and the findings revealed that SFR is dependent on approach width and traffic composition. The study's findings also demonstrated that when the number of heavy vehicles in the traffic stream grows, the SFR in PCU/hr drops, and the rate of reduction in SFR lowers on broader approaches. A right-turn traffic adjustment factor was also designed to account for the influence of right-turn traffic on SFR. It can be observed that as the proportion of right turn traffic increased, the aforementioned factor declined. When right turn traffic rose by 10%, the adjustment factor decreased by 3% for a 25-meter turn radius and by 2.6 percent for a 40-meter turn radius. The above study's SFR(S) (veh/hr) and right turning adjustment factor are supplied by equation (21), equation (22).

$$S = [550 + 10l_{nw} + 3P_{2w} - 2.5P_b - 2P_{3w}], (R^2 = 0.93)\ veh/hr \quad (21)$$

$$frt = \frac{1}{(1 + \frac{0.02P_{rt}}{\sqrt{R}})} \quad (22)$$

where, S- SFR in (PCU/hr); w- width of road (m); P_{2w}- percentage of 2 wheelers; P_b- Percentage of bus; P_{3w}- Percentage of three wheelers; f_{rt}- Factor of right turn; P_{rt}- Percentage of right turn; R- turning radius (m)

Using video graphic techniques, data for this study were collected from nine signalised intersections located in urban areas of Thiruvananthapuram and Ernakulam, Kerala State and Bengaluru, Karnataka State, India for introducing a new methodology for the determination of saturation flow in PCU/h under heterogeneous traffic conditions based on the concept of area occupancy (AO) [42]. AO is defined as "the proportion of time a set of observed vehicles occupies an observation region on a chosen stretch of a roadway". Traffic data collected from signalised intersections were analysed to determine AO and the equivalent number of standard car spaces (Ncs). Saturation flow in PCU/h was then estimated based on the Ncs. The Ncs and AO are given by Equations (23) and (24)

$$Ncs = \left[\frac{A_{eq}}{a_{cs}}\right] \quad (23)$$

where, A_{eq}- Equivalent homogeneous traffic stream area; a_{cs}- area of standard car space

$$\frac{OCF = (Saturation flow in \left(P\frac{CU}{h}\right))}{(Saturation flow in \left(\frac{veh}{h}\right))} \quad (24)$$

occupancy conversion factors.

An attempt has been made by a few investigators from Parul University, Gujarat, India, to review some of the published literature on the SFR at signalised intersections under mixed traffic conditions in India [43] . From the above study, following observations have been made.

1. Because the SFR is not only determined by the width of the approaches (w), but the calculation also proposed in the Indian code may not be applicable.
2. SFR calculated with the calibrated US-HCM 2000 model (TRB-2000) is closer to field values, suggesting that the influence of two-wheelers and approach volume should be taken into account while modelling SFR in Indian settings.
3. For the time being, the above methodology can be used as an alternative to the way provided in Indian code, pending the availability of a changed method.

2.4 Critical Observations on the Above Review

Based on the above review, following critical observations are made:

1. Some of developing countries in the world, wherein, heterogeneous traffic is quite prevalent, have also developed their capacity manuals, based on US-HCM and other developed countries manuals.
2. The HCMs from developed countries having homogenous traffic, cannot be implemented directly in developing countries due to the unique nature of their heterogeneous traffic and other local conditions.

3. The HCMs of developing countries have developed, several adjustment factors such as factor of composition, factor of side friction, factor of U turns based on their prevailing local conditions and driver's behavior, which are different from the ones that are prescribed in the HCMs of some developed countries.

4. In some of the developing countries, the base saturation flow (So), has been developed only based on the width of the road. The Universal US-HCM, developed for countries with homogeneous traffic conditions, cannot be applied directly to the developing countries.

5. Developing countries, where in 'heterogeneous traffic' is the norm, should develop their own HCM based on their local conditions.

6. Based on proper data base and based on field and simulation studies considering local conditions, it is possible to develop highway capacity manual, applicable for each developing country.

7. SFR calculation needs to be redefined along with the suitable adjustment factors for Indian conditions.

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