EFFECT OF PEDESTRIAN CROSSING ON SATURATION FLOW AT SIGNALIZED INTERSECTIONS IN MIXED TRAFFIC CONDITIONS

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Abstract

Saturation flow rate is a key design parameter in the analysis of Level of Service and capacity of signalized intersections. In developing countries like India, pedestrians are observed to cross and interfere with the vehicular flow irrespective of signal provisions for their crossing. This results in unanticipated pedestrian-vehicle interactions at signalized intersections and effects the saturation flow estimation. In the present research work, pedestrian crossing effect on saturation flow is studied. Six signalized intersections are chosen from three cities to study the illegal pedestrian crossing on saturation flow. Width of approach, green time, percentage of two-wheeler and number of illegal pedestrian crossings are found to affect the saturation flow. A multiple linear regression model is developed for the estimation of saturation flow. In addition to the development of saturation flow model, this paper presents adjustment factors for pedestrians to incorporate the effect of unauthorized pedestrian crossing.

Keywords: **Pedestrian, saturation flow, adjustment factor, mixed traffic**

Introduction

Most of the traffic signals in India are of fixed time signals, only a few locations are operating with actuated signal control. Sometimes, police officials operate traffic signals based on traffic volume. Most of the traffic signals in India do not have a separate phase for pedestrians at signalized intersections. Even if a separate phase is provided for pedestrians, they do not follow it, especially near bus stops, unsignalized intersections and signalized intersections. As a result of this, the pedestrian-vehicular collisions are increasing

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every year. According to the road accident report of union transport ministry: 12,330 pedestrians were killed by road accidents in 2014 in India. According to the latest report 2019: 22,656 pedestrians were killed by road accidents and on an average 62 pedestrians die every day in India only by road accidents due to illegal crossings. These statistics represents the number of illegal pedestrian crossings in India at various road facilities. Therefore, the effect of pedestrians on design and analysis of various roadway facilities needs to be considered. This paper concentrates on pedestrian effect in the analysis of signalized intersections. The Highway Capacity Manual (2010) provides a saturation flow rate estimation model considering the effect of pedestrians, where there is a separate phase for pedestrians. But, the unauthorized crossing of pedestrians during vehicle green times, in the absence of pedestrian phase is not explained. It, in general applicable only for homogeneous and lane-based traffic. In the recent trends, the Indian Highway Capacity Manual (INDO-HCM, 2017) is developed where heterogeneous and non-lane-based traffic prevails. The INDO-HCM (2017) determines saturation flow model for mixed traffic scenario including adjustment factors for bus blockage due to curb side bus stop, bus blockage of through vehicles by standings right turning vehicles waiting for their turn and initial surge of vehicles due to approach flare and anticipation. But, INDO-HCM (2017) did not considered the effect of pedestrians in the analysis of signalized intersections. In developing countries like India where mixed and non-lane traffic behaviour exists, pedestrians often obstruct traffic movement especially at signalized intersections. Pedestrians are seen crossing roads during green time for an intersection leg in urban geography. This affects the saturation flow which in turn effects the capacity of signalized intersection. INDO HCM (2017) defined saturated flow model lags the effect of pedestrian illegal crossing during green times for intersection legs. So, there is a need to develop a model for estimating saturation flow in mixed traffic conditions considering the effect of illegal pedestrian crossings. This paper contributes to the existing literature where there is unauthorized pedestrian crossing during green signal under mixed traffic conditions. In addition to the development of a saturation flow model under such conditions, in this paper, adjustment factors for the pedestrians are also developed. These adjustment factors are developed to incorporate the effect of unauthorized pedestrian crossing. Milazzo *et al*. (1998) studied the effect of pedestrians on capacity of signalized intersections in Washington D.C. and pedestrian adjustment factors were found for homogeneous and lane disciplined traffic conditions. Alhajyaseen and Nakamura (2010) studied the required quality of pedestrian flow and cross walk width at signalized intersections in Japan. Roshani and Bargegol (2017) studied the effect of pedestrians on saturation flow at Rasht city. Thus, the effect of pedestrians on the performance measures of signalized intersections is a considerable element. The earlier research work presented pedestrian effect on saturation flow in the presence of a separate phase for pedestrians. The effect of unauthorized pedestrian crossing on saturation flow is not studied under mixed traffic conditions. This paper fills the above said gap considering the unauthorized pedestrian crossings. The objectives of the present study are to estimate the saturation flow at signalized intersections in mixed traffic conditions and develop pedestrian adjustment factors for saturation flow calculation.

Literature Review

A comprehension of earlier studies is been done and the various factors affecting saturation flow are identified. Milazzo *et al*. (1998) proposed an adjustment factor for the effect of pedestrians and bicycles on right turns in the lane group and proposed another adjustment factor for the effect of pedestrians on left turns in the lane group. An empirical relationship has been developed between pedestrian volume and occupancy of the conflict zone during pedestrian green phase.

The current HCM procedure does not consider the effect of pedestrians on left turn traffic. The proposed method indicates that capacity reduction decreases as the number of receiving lanes increases and as the pedestrian volume doubles, the capacity decreases. Hossain (2001) developed a model for estimating saturation flow using micro simulation approach. A regression Equation has been developed, which relates saturation flow with approach width, turning proportion, percentage of non-motorised and heavy vehicles. The model showed a good predictability of saturation flow. Potts *et al*. (2007) conducted a study on saturation flow rate on urban and suburban approaches of signalized intersections, considering the effect of width of lane. The study results indicated that with the variation in lane width, the saturation flow varies. If the lane width is between 3.3 m to 3.6 m, there is no significant difference in saturation flow rates, which varies from 1,815 to 1,830 pc/h/ln. For a lane width of 2.9 m, the saturation flow rate ranges from 1,736 to 1,752 pc/h/ln. For a lane width of 4m and above, the saturation flow ranges from 1,898 to 1,913 pc/h/ln. The saturation flow estimated for lane width ranging between 2.9 m to 3.6 m is observed to be 50% of that estimated using HCM. Hadiuzzaman *et al*. (2008) conducted a study on saturation flow at signalized intersection for non-lane based traffic. PCU values were determined using a synchronous regression analysis and were used the ROAD NOTE 34 method for the estimation of saturation flow. Two different types of models have developed one considering approach width and for the second model another one considering both turning movements and approach width. R^2 values shows that the model 2 gives a much higher measure of fit than model 1.

King *et al*. (2009) conducted a survey on pedestrian crossing against the lights or crossing close to the lights. The relative risk ratios were calculated for illegal crossings using crash data collected from signalized intersections. Crossing against the signal resulted into a crash risk per crossing event which was 8 times that of legal crossing at signal-controlled intersections. The results of the study indicated that the illegal crossing behaviours increase the level of crash risk. Susilo and Solihin (2011) conducted a study on saturation flow rate in Bandung city for a widely varying approaches 9 m to 12 m in their width. A linear regression model was developed for estimating saturation flow considering approach width as a significant parameter. A comparison study has been done on saturation flow rate between regression model developed in the present study $S = 500 W_e+400$, where W_e is approach width in meters and using a common saturation flow formula $S = 600 W_e$ used for Indonesian studies. It was observed that the Indonesian saturation flow formula gives better results of saturation flow when approach width is varying between 3 to 8 m and the developed model in the study $S = 500 W_e+400$ is suitable for approach width varying between 9 m to 12 m. Anusha and Verma (2013) observed the relationship between saturation flow and proportion of two wheelers. The correlation between saturation flow and type of vehicle was found and it was observed that the two wheelers have significant correlation with saturation flow and the correlation coefficient varies from 0.42 to 0.94. It was concluded from the study that the intersection capacity varies directly with volume of two wheelers, whereas it was inversely proportional to volume of all other vehicle categories. Fornalchyk *et al*. (2013) studied the effect of speed of vehicles passing through the intersection on saturation flow. The microsimulation of vehicle movement was studied using VISSIM software. It was observed that, when speed of passing vehicles in traffic volume is constant, the length of speed restriction segment has no impact on saturation flow rate. The study results show that, the speed impact and saturation flow are exponentially related, while the saturation flow and length of speed restriction area are linearly related.

Shrestha and Marsini (2014) conducted a study on saturation flow and delay at signalized intersections in Kathmandu. Multiple regression models were developed for estimating PCU values of different vehicle categories. Also, a multiple regression model was developed for estimating saturation flow considering approach width, green time, percentage of two wheelers, heavy vehicles, right turning vehicles and parking. Saturated green time was divided by number of vehicle categories to get time headway. The inverse of the time headways was taken as saturation flow rate in pcu/h. Onelcin and Alver (2015) Studied the illegal pedestrian crossing behaviour at signalized intersections in Turkey. The results showed that, pedestrians take their decisions based on distance rather than the time gap before crossing. Mavani *et al*. (2016) determined the maximum discharge flow rate and saturation flow rate in the context of non-lane based heterogeneous traffic conditions. Volume conversion was carried out by adopting Justo and Tuladhar (1984) and IRC (1994) recommended PCU values. The analysis showed that maximum saturation flow rate observed using IRC suggested PCU values varies between 933 W

Table 1. Summary of earlier research

Author and year	Type of the model developed/method used for saturation flow	Variables considered for modelling
Milazzo *et al*. (1998)	Presented adjustment factors for pedestrians in the presence of pedestrian phase based on occupancy ratio method.	Pedestrian volume
Hossain (2001)	MIXNETSIM simulation model and Multiple linear regression model	Approach width, percentage of non-motorized vehicles, percentage of heavy vehicles, percentage of left turn and right turning vehicles
Potts *et al*. (2007)	Multiple linear regression model	Approach width
Hadiuzzaman *et al*. (2008)	Estimated saturation flow using ROAD NOTE 34 method and a Multiple linear regression model is developed	Approach width, turning movements
King *et al*. (2009)	Estimated percentage risk ratios when pedestrian is crossing against lights and crossing close to the lights	Pedestrian crossing data
Susilo and Solihin (2011)	Linear model	Approach width
Anusha and Verma (2013)	Modified HCM 2010 formula by modifying two-wheeler and heavy vehicle adjustment factors	Approach width, percentage of two wheelers and percentage of heavy vehicles
Fornalchyk *et al*. (2013)	VISSIM microsimulation model	Speed of vehicles passing through intersection
Shresta and Anil (2014)	Estimated saturation flow using headway method and a regression model was developed	Approach width, green time, percentage of right turning vehicles, percentage of heavy vehicles, percentage of two wheelers and parking.
Onelcin and Alver (2015)	Analyzed pedestrian crossing behaviour	Pedestrian characteristics
Kiran and Reddy (2016)	Estimated saturation flow using Indian Road Congress Special publication 41 (IRC SP 41) formula	Approach width
Mavani *et al*. (2016)	Regression model	Approach width
Rajgor *et al*. (2016)	Estimated saturation flow using TRR (Transport Research Record) method and a regression model was developed	Approach width, percentage of cars and percentage of two wheelers
Roshani and Bargegol (2017)	Estimated saturation flow using headway method and a multiple linear model is developed	Approach width and traffic composition
Preethi and Ashalatha (2018)	Developed a multiple linear regression model based on data created using VISSIM simulation	Approach width and traffic composition

to 1,283 W, whereas for the Justo and Tuladhar suggested PCU values the maximum saturation flow rate varies between 636 W and 821 W, where W is width of approach in meter. Rajgor *et al*. (2016) conducted a study on saturation flow in various intersections of Ahmedabad city. The saturation flow is obtained by extracting the video data in each 3 sec interval during the green period. The main factor considered for the development of multiple linear regression models for saturation flow is approach width. Kiran and Reddy (2016) estimated the saturation flow rate from the field data using the relation, saturation flow is equal to total number of vehicles (PCU) divided by saturated green time in sec multiplied by 3,600 and also estimated the saturation flow using IRC formula. It was found that, with the increase in the proportion of two wheelers, saturation flow per meter width increases due to the filling of empty space by two wheelers and heterogeneity in the traffic flow, and with the increase in proportion of cars, the saturation flow decreases because of its homogeneity in the traffic flow. Roshani and Bargegol (2017) studied the effect of pedestrians on right turn movements, to estimate saturation flow rate at signalized intersections in Rasht city. For the estimation of saturation flow from the field, headway method was used. A linear relation was found between vehicular volume and pedestrian volume. A pedestrian adjustment factor was found by comparing the developed linear Equation with ideal conditions. Preethi and Ashalatha (2018) calculated saturation flow using the concept of area occupancy. A multiple linear regression model was developed for estimating saturation flow based on composition of traffic and approach width. VISSIM simulation tool was used to generate saturation flow values for varying traffic compositions and approach widths. The results show that as percentage heavy vehicles increases saturation flow decreases.

The summary of the earlier research presented in this paper, is provided in Table 1. It can be concluded from the earlier studies that, there are several variables which affects saturation flow at signalized intersections: approach width, green time, percentage of two wheelers, percentage of three wheelers, percentage of cars, percentage of Light Commercial Vehicles, percentage of heavy vehicles, turning vehicle percentages, percentage of non-motorized vehicles, parking and pedestrian crossing behaviour when a separate pedestrian phase is given. But, the effect of unauthorized pedestrian crossing in the absence of a pedestrian phase, on saturation flow is not reported. Researchers around the globe who worked in this area developed various adjustment factors for different elements. The HCM (2010) adjustments factors may not be suitable for mixed traffic conditions. INDO-HCM (2017) is not considering pedestrian adjustment factor and traffic volume composition. So, there is a need to develop a saturation flow model considering traffic volume composition and unauthorized pedestrian effect. The adjustment factors were found for incorporating pedestrian effect on saturation flow in mixed traffic conditions.

Method

Figure 1 shows the flowchart of proposed methodology to develop a saturation flow model considering unauthorized pedestrian effect. The flow chart clearly describes the conceptual framework of the present study. The various variables such as approach width, green time, percentage of two wheelers, percentage of three wheelers, percentage of cars, percentage of LCV, percentage of heavy vehicles, percentage of turning movements and pedestrians are taken as input.

Study Area and Data Collection

For the present study, the data was collected from six signalized intersections, which are in three different cities: Raipur, Hanmakonda and Hyderabad. All the intersections from 1 to 6 have four legs with all through, right and left turn movements permitted. The layouts of the intersections 1 to 6 along with their geometric details are given from Figures 1 to 5.

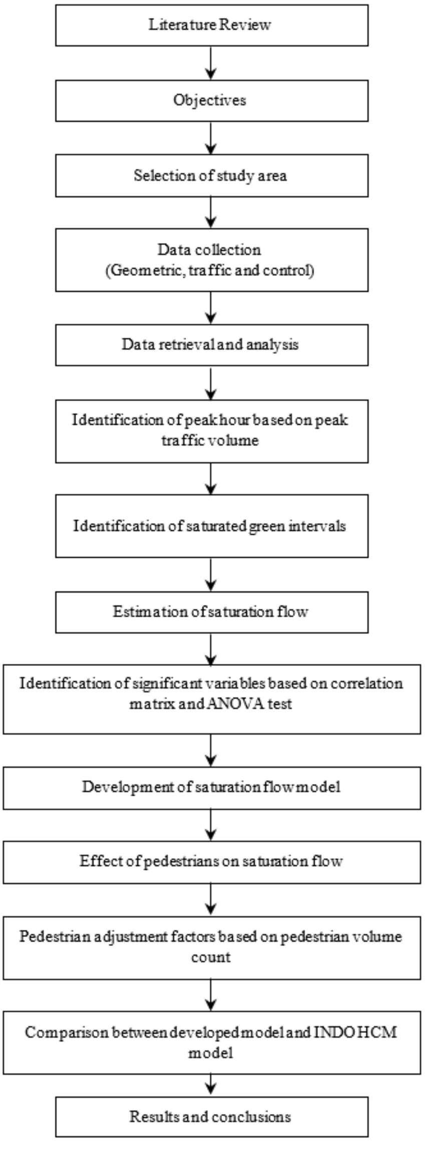

Figure 1. Methodology

Figure 2. Satellite map of study intersections located in Hyderabad

Figure 3. Satellite map of study intersections located in Hanmakonda

Figure 4. Satellite map of study intersection located in Raipur

Intersections 1 (Bachupally intersection), 2 (Gandimaisamma intersection), 4 (Suchitra intersection) are in Hyderabad city, Intersections 3 (Kazipet intersection) and 5 (KU cross roads) are in Hanmakonda and Intersection 6 (Gurunanakdwar intersection) is located Raipur. The study intersections are selected based on pedestrian vehicle collisions at signalized intersections reported by police officials. Traffic data and pedestrian data were collected from the field using video graphic method. Traffic data was collected both during morning and evening from 7:30 AM to 10:30 AM and 4:30 PM to 7:30 PM. The width of the approach was measured using odometer. The green time, red time, amber time and cycle times were measured using stopwatch. The Geometric and control details of the intersections from 1 to 6 is presented in Table 2. The satellite images of the intersections located in Hyderabad, Hanmakonda and Raipur are shown in Figures 2 to 4 respectively.

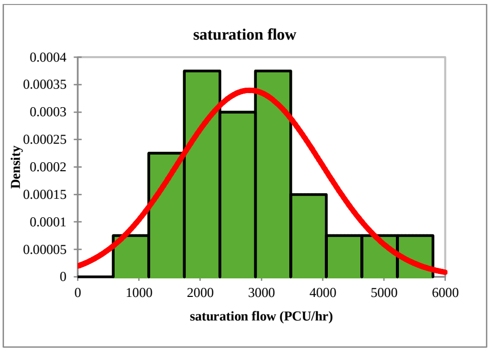

Figure 5. Normal distribution chart for saturation flow

Data Extraction

From the playback videos, classified volume count is done for every fifteen-minute count interval for six hours volume data, in order to identify the peak volume and peak hour. Saturated green intervals are identified based on peak hour volume. Pedestrian crossing illegally during the green phase for vehicles are counted manually. Observed percentage of vehicle categories and number of illegal pedestrian crossings are presented in Table 3.

Field Measurement of Saturation Flow

In the present study, the classified vehicle volume count as well as turning proportions are extracted for every 5 sec count interval during saturated green intervals. The flow corresponding to each count interval in each cycle is determined for 30 cycles in saturated

Table 2. Geometric and control details of selected intersections

Location	Intersection	Approach	Approach width (m)	Green time (s)	Amber time (s)	Cycle time (s)
Hyderabad	Intersection1	NB1	9	40	4	180
		SB1	7	35	4	180
		EB1	12	40	4	180
		WB1	9.5	50	4	180
Hyderabad	Intersection2	NB2	8	35	3	170
		SB2	8	45	3	170
		EB2	10.6	34	3	170
		WB2	5	43	3	170
Hanmakonda	Intersection 3	NB3	8.8	35	5	130
		SB3	10.2	35	5	130
		EB3	6	15	5	130
		WB3	7.7	25	5	130
Hyderabad	Intersection 4	NB4	10.4	30	2	230
		SB4	7.5	40	2	230
		EB4	9.9	80	2	230
		WB4	10	70	2	230
Hanmakonda	Intersection 5	NB5	7	27	3	150
		SB5	7.2	27	3	150
		EB5	7.5	42	3	150
		WB5	7	42	3	150
Raipur	Intersection 6	NB6	5.8	35	4	110
		SB6	3.7	35	4	110
		EB6	10.4	10	4	110
		WB6	13.5	10	4	110

Table 3. Percentage of vehicles and number of pedestrians

Intersection	TW%	3W%	Car%	LCV%	HCV%	P (ped/h)
Intersection1	59	7.65	22.7	3.39	6.67	1594
Intersection2	38.2	6.16	37.75	9.2	8.675	2077
Intersection3	39.9	7.02	41.8	4.625	6.8	2173
Intersection4	60	4.54	24.25	6.98	4.05	2406
Intersection5	39	14.6	40.7	1.52	4.06	1421
Intersection6	74	4.3	14	1.52	7.68	1473

green interval. If in any count interval, in any cycle is having less than two vehicles passed through the intersection, then that count interval is been ignored for analysis. The average flow of all count intervals in all saturated green cycles is taken as final saturation flow value for that approach. For example, if an approach is having 40 sec saturated green time in one cycle: for 30 cycles the sample size would be 30×8 for a single approach. The Passenger Car Unit (PCU) values suggested by INDO HCM (2017) are used to convert the saturation flow from vehicle/hr to pcu/h. Equation 1 shows the saturation flow estimation in pcu/h given by the INDO HCM 2017 (Chand *et al*., 2017).

$$S = \sum Xn \times \frac{3600}{T} \tag{1}$$

where, S = saturation flow in pcu/h, X = pcu value, n = number of vehicles crossing the stop line during count interval, T = saturated green count interval in seconds.

Estimation of Saturation Flow Using INDO HCM

In INDO HCM (2017), the base saturation flow is calculated based on approach width in meters using Equation 2.

$$USF_0 = \begin{pmatrix} 630 & \text{for} & w < 7.0m \\ 1140 - 60w & \text{for} & 7.0 \le w \le 10.5m \\ 500 & \text{for} & w > 10.5m \end{pmatrix} \tag{2}$$

where, USF_0 = unit base saturation flow rate (PCU/h/m),
w = width of approach (m)

The prevailing saturation flow rate of the intersection approach for the movement group under consideration is then obtained as presented in Equation 3 (INDO HCM (2017)).

$$SF = W \times USF_0 \times f_{bb} \times f_{br} \times f_{is} \tag{3}$$

where, SF = Prevailing saturation flow rate in PCU/h,
W = effective width of the approach in m,
USF_0 = Unit base saturation flow rate,
f_{bb} = adjustment factor for bus blockage due to curb side bus stop,
f_{br} = adjustment factor for blockage of through vehicles by standing right turning vehicles waiting for their turn,
f_{is} = adjustment factor for the initial surge of vehicles due to approach flare and anticipation effect.

Saturation Flow Model

Green time, cycle time, approach width, proportion of two wheelers, proportion of three wheelers, proportion of cars, proportion of LCV, Proportion of HCV, percentage of turning vehicles and pedestrian crossing are the various important factors affecting saturation flow in mixed traffic conditions. The IRC SP 41 (1994) was developed for Indian traffic conditions. Which considers only approach width in calculating saturation flow. Also, recently INDO HCM (2017) is been developed for Indian traffic conditions. Which considers various adjustment factors such as: adjustment factor for bus blockage due to curb side bus stop, adjustment factor for bus blockage of through vehicles by standing right turning vehicles waiting for their turn and adjustment factor for the initial surge of vehicles due to approach flare and anticipation effect. But, both IRC SP 41 as well as INDO HCM (2017) are not considering pedestrian effect on saturation flow, which is one of the most important factors affecting saturation flow especially in mixed traffic conditions. In the present study, Green time, approach width, proportion of two wheelers, proportion of cars, proportion of heavy vehicles, number of pedestrians crossing against the green to vehicle traffic are considered. But a significant correlation is observed with green time, width of approach, percentage two wheelers, and number of pedestrians crossing illegally. As the data was collected from six signalized intersections in the present study, the number of data points used for modelling are 24 (6 intersections×4 approaches). The correlation matrix showing significant variables is presented in Table 4.

Table 4. Correlation matrix showing significant variables

	S	W	G	Ptw	p
S	1				
W	0.73	1			
G	0.52	0.22	1		
Ptw	0.81	0.13	0.34	1	
P	-0.98	-0.26	-0.51	-0.13	1

Where, S = saturation flow in pcu/h,
W = approach width in meters,
G = green time seconds,
P_{tw} = percentage of two wheelers,
P_c = percentage cars,
P = number of pedestrians crossing vehicular traffic per hour.

In the present study, a multiple linear regression model is developed to estimate saturation flow, based on significant variables. Multiple linear regression model develops a linear relationship between response (dependent) variable and explanatory (independent) variables. A multiple linear regression model must follow four basic assumptions: 1. All independent variables must be independent of each other, 2. All variables are normally distributed, 3. All variables are continuous and 4. A linear relation should exist between independent and dependent variables. The multiple linear regression model developed for saturation flow in the present study is shown in Equation 4.

$$S = 39.3W + 29.6 \times G + 30.01 \times P_{tw} - 1.96P + 2745 \quad (4)$$

where S = saturation flow in pcu/h, W = width of approach in meters, G = green time in sec, P_{tw} = percentage two wheelers, P = number of illegal crossing pedestrians per hour. The R^2 value of the model is 0.86 and the standard error of the estimate is 176. The saturation flow rate is increasing with the increase in approach width, increase in green time and increase in percentage of two wheelers. Whereas, the saturation flow is decreasing with the increase in unauthorized pedestrian volume count. Two wheelers occupy small gaps between vehicles in queue, which obviously increases the saturation flow rate. Due to the pedestrian vehicle interactions at intersections, pedestrians cause delay to the vehicles. This slow movement of vehicles decreases saturation flow rate.

Pedestrian Adjustment Factor

In the present study, pedestrian adjustment factors were found for saturation flow by dividing Equation 4 with ideal conditions when P = 0. The pedestrian adjustment factor F_{ped} is given by Equation 5.

$$F_{ped} = \frac{39.3W + 29.6G + 30.01Ptw - 1.96P + 2745}{39.3W + 29.6G + 30.01Ptw + 2745} \quad (5)$$

The pedestrian adjustment factors were found using Equation 5 and are presented in Table 5.

Table 5. Pedestrian adjustment factors

Range of pedestrian number (pedestrians/h)	Adjustment factor
656-927	0.77-0.68
1257-1432	0.56-0.50
1552-1993	0.47-0.32
2160-2400	0.29-0.20
2502-2738	0.18-0.10

Comparison of Saturation Flow Rates

In this section a brief comparison of the saturation flow values is been done using the model developed in the present study and INDO HCM 2017 and the results are presented in Table 6.

From Table 6, the saturation flow values obtained using MLR developed in the present study, are very close to those obtained from the field when compare to INDO HCM 2017.

Results

The variables chosen for modelling are tested for normal distribution using Kolmogorov-Smirnov (K-S) test. The saturation flow, green time, approach width, percentage two wheelers and pedestrian volume are the variables following normal distribution and only those variables are considered for modelling saturation flow rate. The K-S test results for variables following normal distribution are presented in Table 7 and the normal distribution chart is presented for dependent variable (saturation flow) in Figure 5. The statistical values of the model (for variables following normal distribution) such as standard error, t-stat, p-stat, 95%CI and VIF are presented in Table 8. The various

Table 6. Comparison of saturation flow values

Approach	Field saturation flow pcu/h	Model saturation flow pcu/h (considering pedestrian effect)	%reduction in saturation flow when compared with MLR developed in the present study	Saturation flow in pcu/h using INDO HCM (2017)	%reduction in saturation flow when compared with INDO HCM
NB1	2,845	2,823	0.77	5,400	47.32
SB1	2,243	2,185	2.59	5,040	55.49
EB1	3,326	3,321	0.15	5,040	34.00
WB1	3,220	3,146	2.30	5,415	40.53
NB2	3,650	3,582	1.86	5,414	32.58
SB2	2,655	2,701	1.73	4,095	35.16
EB2	2,015	2,003	0.60	3,780	87.59
WB2	1,568	1,523	2.87	3,528	55.55
NB3	2,881	2,893	0.42	5,385	86.90
SB3	3,040	2,991	1.61	5,393	77.40
EB3	1,222	1,146	6.22	3,780	67.67
WB3	1,760	1,783	1.31	4,221	58.30
NB4	5,026	4,943	1.65	5,124	01.94
SB4	5,705	5,732	0.47	5,040	11.65
EB4	3,932	3,724	5.29	5,355	34.82
WB4	4,430	4,104	7.36	5,280	19.18
NB5	2,008	2,032	1.20	5,040	60.15
SB5	1,629	1,634	0.31	3,780	56.91
EB5	2,380	2,221	6.68	5,175	54.09
WB5	3,134	3,102	1.02	5,040	60.80
NB6	3,099	2,989	3.55	6,750	54.08
SB6	2,040	2,213	8.48	5,366	61.98
EB6	3,299	3,098	6.09	3,654	10.76
WB6	989	934	5.56	4,221	76.56

descriptive statistics (mean, standard deviation, skewness and kurtosis) of observed variables (following normal distribution) are presented in Table 9. From the correlation matrix, statistical values and K-S test results it is very clear that, the variables chosen for modelling are not violating the assumptions of multiple linear regression model.

Conclusions

This study draws the interest of researches to understand the effect of pedestrians on the saturation flow in urban area where considerable pedestrian movement prevails both in developed countries and developing countries. In the present study, a multiple linear regression model is developed to estimate saturation flow in the presence of illegal pedestrian crossings. The R^2 value of the developed model is 0.86 and the developed model showed better predictability of saturation flow when pedestrians are obstructing vehicular flow. The developed can be used to estimate saturation flow when there is considerable amount of pedestrian volume moving between vehicles. Also, a comparison of saturation flow values obtained from field, MLR and INDO HCM (2017) is made. The INDO HCM (2017) is predicting saturation flow values which are widely deviated from field values. Also, the INDO HCM (2017) defined a common saturation flow model irrespective of land use characteristics and city size and INDO HCM (2017) is not explaining the effect of unauthorized pedestrian crossing. But the intersections chosen in the present study are both from medium size and metropolitan cities. Also, the unauthorized pedestrian crossing is observed at study intersections.

Table 7. K-S test results for variables following normal distribution

Variable	P value from K-S test
Saturation flow (S)	0.857
Green time (G)	0.840
Approach width (W)	0.667
Percentage of two wheeler (P_{tw})	0.638
Pedestrians (P)	0.770

Discussion

Most of the saturation flow models developed in the previous research works were based on homogeneous traffic conditions. only, a few studies were based on mixed traffic conditions. Also, the research work done under mixed traffic condition did not considered the effect of unauthorized pedestrian crossing on saturation flow. The present research work will be helpful in estimating realistic saturation flow values in urban intersections where high

Table 8. Statistical values of the model

Variable	Standard error	t-stat	p-stat	Lower 95%CI	Upper 95%CI	VIF
Intercept	1023	2.34	0.013	-1726	3205	-
G	13.43	2.15	0.025	0.72	66.2	1.925
W	10.8	3.56	0.018	11.21	56.71	2.165
P_{tw}	39.43	-2.58	0.026	-10.61	59.91	3.076
P	0.645	5.61	0.007	0.126	2.037	3.952

Table 9. Descriptive statistics of observed variables

Variable	Mean	Standard deviation	Skewness	Kurtosis
G	36.6	16.01	0.049	0.93
W	8.45	2.32	0.118	0.84
P_{tw}	0.51	0.15	-0.008	0.69
P	1857	318	-0.03	-0.017

pedestrian flows are observed. The intersections selected for the present study are only four legged intersections. The study can be extended by also considering three legged intersections. The pedestrian vehicle interactions also cause increased delays at signalized intersections. The microscopic analysis of pedestrian vehicle interactions can be further analysed in the analysis of control delay.

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