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Calibration of HCM equation to estimate the saturation flow at signalized junction under mixed traffic

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Abstract

The present paper deals with the modification of the highway capacity manual (HCM) equation to estimate the saturation flow under mixed traffic situations. The study precisely covers the queue release rate during the green time based on traffic data extracted through videography at signalized intersections in the cities of Gujarat, India. Passenger car units (PCU) have been estimated based on a concept of time occupancy for the different classes of vehicles. It was found that there is no significant variation in PCU values for different category of vehicles at different intersections. The derived PCU values are used in the analysis of saturation flow. Analysis of variance test is done to determine the saturation flow region and considering the various traffic attributes of mixed traffic, saturation flow models are developed using the multiple linear regression approach to estimate the base saturation flow. The stream equivalency and adjustment factors are derived to convert the traffic flow from mixed to passenger car equivalent. The derived base saturation flow and adjustment factors are adopted as a modifier in the HCM Equation. Result of validation found the less variation between the calculated saturation flow using modified HCM equation and observed saturation flow.

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Keywords: signalized intersections; mixed traffic; passenger car unit; saturation flow; India

1. Introduction

The operation efficiency of the roadway network in an urban area is greatly influenced by the signalized intersection. The traffic discharge flow is the basic characteristics used for modeling intersection operations during the green period. During the green phase of a cycle at the approaches, vehicles start discharging by accelerating to achieve their normal running speed until the green period ends. Hence, the queue discharging phenomena at a constant

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rate is known as the saturation flow. Saturation flow may vary as a function of items such as the layout of the intersection, the number of turning vehicles, and types of vehicles in the traffic stream. As per the present practice, the estimation of saturation flow is carried out by multiplying the adjustment factors of prevailing traffic and geometry conditions to the base saturation flow rate. The recently developed Indian Highway Capacity manual referred to Indo-HCM (2017) has suggested the equations to estimate the saturation flow considering the width only the criteria. It provides unit base saturation flow rate values in the unit of PCU/hour per meter width on the roadway. The values are 630 PCU/hour/m for width less than 7.0 m, 1140-60w PCU/hour/m for width between 7.0 to 10.5 m, and 500 PCU/hour/m for width greater than 10.5m. The unit base saturation flow for the width more than 10.5 m is found to be very less when the significant proportion of smaller size vehicles exist in the mixed traffic stream with a high arrival rate of vehicles during the peak times (Patel et al. (2015). The adjustment factors are limited to bus blockage, right turn and initial surge of vehicles only. The US highway capacity manual (HCM 2010) has proposed the equation to estimate the saturation flow homogeneous conditions with limited ability to address heterogeneity. The HCM (2010), includes a model to calculate saturation flow rate considering the effect of various factors like width (f_w), gradient (f_g), parking activity (f_e), heavy vehicles (f_{hv}), area type (f_a), lane utilization (f_{lu}), bus blockage (f_{bb}), turning movements for left and right (f_{lt} and f_{rt}), and pedestrian blockage for left and right turn (f_{Lpb} and f_{Rpb}). The adjustment factor for each of these parameters is calculated using the empirical equations suggested in HCM. The calculated factors of adjustment are then multiplied with the base saturation flow of 1,900 passenger cars per hour of green time per lane for a signalized intersection, to obtain the saturation flow rate of the intersection approach. But, the traffic in many parts of the world is highly heterogeneous and hence, defining a unified saturation flow concept is a challenging task. Due to the difference in roadway conditions, traffic conditions, the driver's behavior, cultures, etc., the base saturation flow rate provided by HCM may not be applicable in India to estimate the saturation flow rate. The empirical equation suggested in the Indian road congress (IRC) (1994) to estimate saturation flow does not account the factors like types of vehicle, gradient, and area types. Several attempts have been made to model the effect of homogenous as well as heterogeneous traffic on saturation flow. Arasan and Jagadeesh (1995) suggested that the probabilistic method be more suitable for the Indian condition to estimate saturation flow. Hossain (2001) developed a regression-based saturation flow model by using the simulation results. The various parameters of roadway and traffic were considered. Anusha et al. (2013) have studied the effects of two-wheelers on saturation flow at signalized intersections in Bangalore, India. Mathew and Radhakrishnan (2011) developed a saturation flow model by developing passenger car unit (PCU) using the optimization technique. The model was developed by considering the percentage compositions of different vehicles like cycle rickshaw, two-wheelers, auto-rickshaw, and car. Patel and Dhamaniya (2019) have set the methodology to develop stream equivalency factor at the signalized intersection to convert the mixed traffic flow into equivalent passenger car flow.

Based on the review of past literature, it is interpreted that the model proposed by HCM can be used to mixed traffic condition after necessary adjustments. Considering this, an objective of the current study is to modify the base flow rate and adjustment factors of the HCM equation to suit for mixed traffic conditions.

Nomenclature

3W	three-wheelers
2W	two-wheelers
CB	big car
CS	standard car
HCV	heavy commercial vehicles
AR	arrival rate
LCV	light commercial vehicles
PCU	passenger car unit
PCE	passenger car equivalent
IRC	Indian road congress
HCM	highway capacity manual
MLR	multiple linear regression

2. Methodology

To fulfill the objective of the study, traffic flow data was collected using a videography technique during the peak hours at an approach of signalized intersection fulfilling the base conditions. Queue discharged vehicles of different category and their intersection clearance time are extracted from the video during a green phase of the cycles. During the saturated green time, the PCUs are derived for the different category of vehicles. The comparisons have been made between the field saturation flow and HCM 2010 model calculated saturation flow. Then, necessary adjustments are carried out in the HCM 2010 model to suit for the mixed traffic conditions. Following are the steps for data collections and processing.

2.1. Base conditions of signalized intersections

The signalized intersections ware selected considering the base criteria to estimate the ideal saturation flow rate and the adjustment factors under prevailing traffic conditions. The base criteria are a flat gradient, no parking, and stopping of transit services at the approaches, 3.5 m of lane width, location of intersections in the non-central business district, negligible right turning proportion, no effect of pedestrian and bicycles. The saturation flow model in HCM is based on the homogeneous traffic condition, but the dominating vehicle type is two-wheelers in the urban roads of India. So, the base saturation flow is estimated counting the effect of 2W. In the present study, the base conditions should be considered as mentioned above.

2.2. Discharge rate measurements

The classified volume at a stop line count during every 6 seconds interval of the green phase was suggested by the Road Note 34 (1963). The analysis interval of 5 seconds was suggested by Webster’s method. The recently developed Indian Highway Capacity Manual (2017) has suggested the interval of analysis as 5 seconds for the mixed traffic flow conditions. For every cycle, the vehicle discharge data for the 5 seconds interval have been extracted from the video for each direction of movement crossing the stop line of a green phase. The video is replayed for the number of times to extract the data of different category of vehicles.

2.3. Field data

The study was conducted at the 9 signalized intersections leading to the major corridor of Surat and Ahmedabad, India. The selected signalized intersections are four-legged and fulfilling the base conditions. The approach width is varying from intermediate lane to four lanes. The separate left turning lane, footpath and marking at the approaches were present. The vantage points were fixed to collect the mixed traffic flow data for every direction of movement. The analysis was carried out for the 130 cycles extracted from 13 heavily traffic approaches using the manual technique. Table 1 summaries the statistics of data collected the signalized intersections. In Table 1, IC indicates the intersections are considered for the estimation of various traffic flow parameters and, IV indicates the intersections are considered for the validation of traffic studies.

Table 1. Field traffic composition at approaches of signalized intersections

Intersection	Study Approaches	Composition, Percent					
		2W	3W	CS	CB	LCV	HCV
IC-01	A- 01	63.24	18.62	5.20	9.42	1.23	1.21
	A- 02	79.40	10.10	5.30	4.10	1.10	0.00
IC-02	A- 03	58.76	30.03	3.56	4.31	2.30	1.04
	A- 04	72.92	14.98	4.10	3.80	1.10	0.49
IC-03	A- 05	59.92	12.22	13.17	12.39	1.40	0.81

Intersection	Study Approaches	Composition, Percent					
		2W	3W	CS	CB	LCV	HCV
IC-04	A- 06	54.37	20.75	9.40	8.78	2.60	4.10
IC-05	A- 07	63.78	16.36	9.12	9.28	1.06	0.41
IC-06	A- 08	60.38	8.77	16.25	14.88	1.44	0.93
	A- 09	42.47	11.43	19.90	21.41	3.45	1.34
IC-07	A-10	77.34	4.45	9.47	7.24	1.32	0.39
IV-08	B-01	69.62	10.55	4.57	14.00	0.42	0.84
	B-02	65.69	10.43	11.50	12.20	0.61	0.93
IV-09	B-03	63.65	15.50	10.4	11.20	0.50	0.35

2.4. Estimation of PCUs

There are several methods for the estimation of PCUs which can be used on the basis of suitability to particular traffic conditions. The suggested important methods for the estimation of PCUs are headway ratio method (Werner and Morall (1976), delay (Craus et al. (1980), simulation (Elefteriadou et al. (1997)), area occupancy (Preethi and Ashalatha (2016)), multiple linear regression (Branston and Zuylen (1978), Patel et al. (2015)), queue clearance rate (Mohan and Chandra (2016) and speed to area ratio (Chandra and Kumar (2003)). Each of the methods has its own limitations under the different traffic circumstances. Chandra and Kumar (2003) developed a method based on the relationship between speed and area of individual vehicle category with respect to a standard passenger car. This method indirectly incorporates the effect of travel time, delay, area occupancy and inter-vehicular interactions on PCU of a vehicle type. The Eq. (1) is suggested by Chandra and Kumar (2003) to determine PCU for a vehicle type.

$$PCU_m = (V_c/V_m) \ / \ (A_c/A_m) \quad (1)$$

Where V_c and V_m are mean speeds for passenger cars and vehicle type, and A_c and A_m are their respective projected rectangular areas on the road. It is the most widely used method under mixed traffic conditions for the estimation of individual vehicle's PCU.

In Eq. (1), in place of speed ratio, the ratio of clearing time (time occupancy) of the subject vehicle to the standard car is considered. Eq. (1) is modified as Eq. (2) for PCU estimation.

$$PCU_m = \ (T_m/T_c)/(A_c/A_m) \quad (2)$$

Where PCU_m = passenger car unit for the mode 'm' in the traffic for which PCU is to be estimated; T_m/T_c = clearing time ratio of mode 'm' to the standard car. The physical dimensions for a CS, CB, HCV, LCV, 3W, and 2W were measured in the field and found as 5.36, 8.11, 24.54, 9.50, 4.48 and 1.20 m^2 respectively. As per the Eq. (2), PCU of a vehicle type is directly proportional to the time occupancy ratio of the subject vehicle to passenger car and inversely proportional to area occupancy ratio of a passenger car to subject vehicle. The higher or lower value of PCU is directly affected by the higher or lower value of occupancy time of the subject vehicle to passenger car during the clearing of an intersection area between the stop line. Fig. 1 shows the extraction of time occupancy data with the help of Avidemux-2.6 software.

Table 2 shows the results of PCU estimation for the different vehicle category. Analysis of Variance (ANOVA) test was done at a 5% significance level to find dissimilarity in the variance of calculated PCU values of the different vehicle types for the seven signalized intersections.

As per the test results from Table 2, F-value found to be less than F-critical at a 95% confidence interval. Therefore, variation in PCU values is not significantly different for the 2W, 3W, CB, LCV and HCV at the different intersections. So, average PCU value has been taken for all vehicle category as a common PCU. The less variation is observed in the PCU of a vehicle size smaller than passenger car due to their small physical dimensions with high maneuvering ability makes less variation in occupancy time as compared to vehicle size larger than a passenger car.

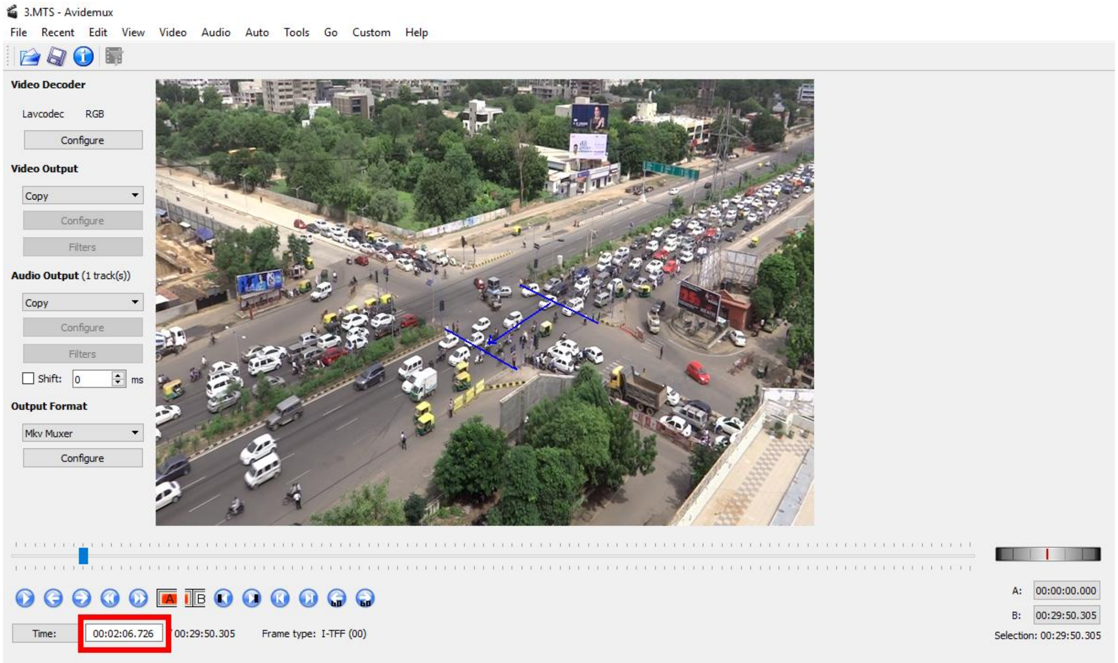

Fig. 1. Snapshot of time occupancy data extracted for each movement

Table 2. Average pcu values estimated for different vehicle categories

Type of Vehicle	IC-01	IC-02	IC-03	IC-04	IC-05	IC-06	IC-07	P value	F	F critical	$F<F_{critical}$	Average PCU
2W	0.19	0.20	0.19	0.20	0.19	0.21	0.21	0.7726	0.3730	2.6373	Yes	0.20
3W	0.64	0.69	0.7	0.68	0.69	0.79	0.77	0.1479	1.8379	2.7318	Yes	0.71
Small Car	1	1	1	1	1	1	1	-	-	-	-	1.00
Big car	1.51	1.51	1.56	1.47	1.45	1.55	1.54	0.9708	0.0800	2.6407	Yes	1.51
LCV	1.97	1.93	2.03	2.15	2.14	2.05	2.08	0.1751	1.7171	2.7862	Yes	2.05
HCV	5.93	5.09	5.4	5.83	5.81	5.93	5.57	0.9285	0.1497	3.1273	Yes	5.65

3. Estimation of Saturation Flow

3.1. Estimation of saturation green time

For measuring the saturation flow, the discharge pattern of several cycles is used together in the analysis. Fig. 2 shows the typical discharge pattern observed at a signalized intersection. Here flow values are expressed in vehicle/5-second. The flow observed at the start of green time is lower than the saturation due to initial lost time.

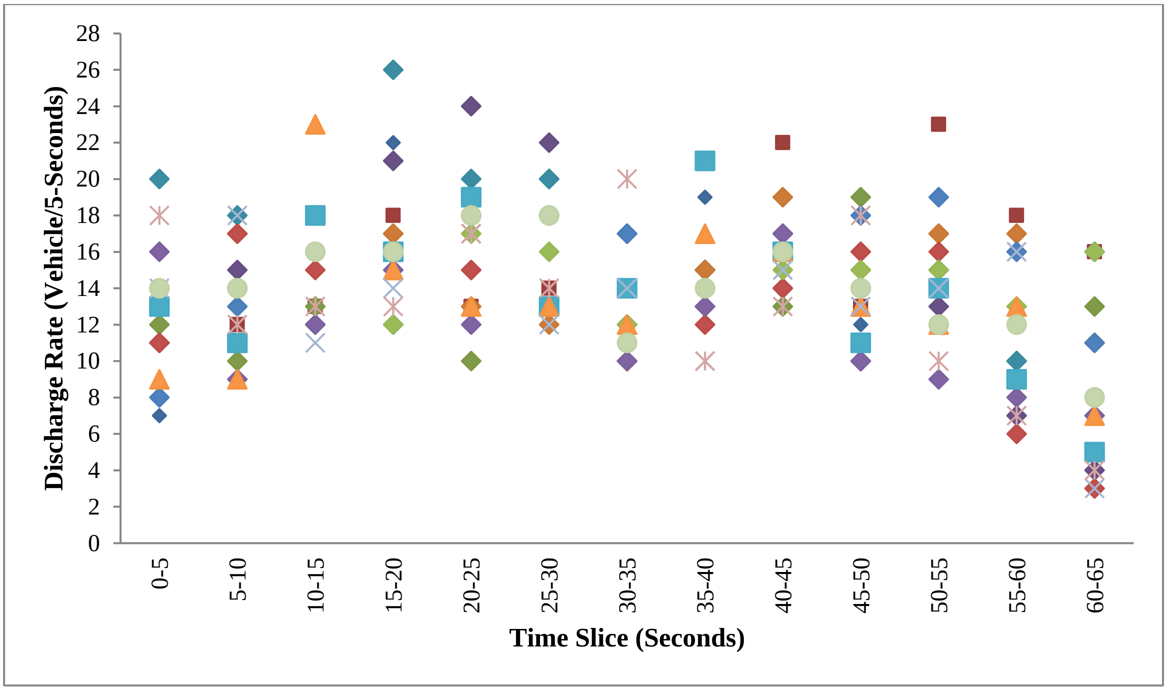

Fig. 2. Discharge pattern observed at intersections

The saturation period is found using the ANOVA test at 5% level of significance. Fig. 2 shows a sample pair of flow values, which are tested for equivalency of the samples. From the test, if the samples are found to be statistically equivalent, it means that saturation flow is continuing. The test is carried over for all the pairs and saturated green time is found. In Fig. 2 saturation flow is continuing up to 50-55 seconds interval and then the flow has reduced due to unavailability of vehicles, and saturation flow could not be continued. The obtained saturated green time may vary depending on the lost time, composition and flow at the approaches. Now onwards, the flow values observed in the saturated green time are used for the analysis.

The detailed description and statistical significance of saturated green time for the different intersections are shown in Table 3.

Table 3. Statistical Analysis of Saturated Green Time

Sr. No	Intersection	Study Approaches	Total Green Time in seconds	Saturated Green Time in seconds	P value	F	F critical	$F<F_{critical}$
1	IC-01	A- 01	0-45	5-35	0.7094	0.5874	2.3860	Yes
		A- 02	0-15	5-15	0.3151	1.0677	4.4138	Yes
2	IC-02	A- 03	0-35	10-25	0.1214	2.2821	3.3541	Yes
		A- 04	0-41	5-35	0.6169	0.7121	2.3860	Yes
3	IC-03	A- 05	0-50	5-30	0.1140	1.9785	2.5787	Yes
4	IC-04	A- 06	0-65	5-40	0.7818	0.5321	2.2464	Yes
5	IC-05	A- 07	0-40	10-25	0.1601	1.9791	3.4028	Yes
6	IC-06	A- 08	0-55	5-50	0.1351	1.6167	2.0698	Yes
		A- 09	0-70	10-60	0.4085	1.0502	1.9991	Yes
7	IC-07	A- 10	0-75	15-50	0.1352	1.7022	2.2464	Yes

Table 4 shows geometric details, field saturation flows and volume for the intersections under study. The comparison has been made between the field saturation flow and calculated saturation flow by using HCM model as shown in Table 5. A high percentage error has been observed in the saturation flows due to heterogeneous traffic characteristics as shown in Table 5. Hence, this clearly shows that the influence of heterogeneous traffic should be considered in order to get the saturation flow closer to field saturation flow.

Table 4. Geometric Details, Volume and Saturation Flow for Selected Junctions

Intersection	Study Approaches	Width (m)	Gradient (%)	Green Time in seconds	Cycle Time in seconds	Right Turn (%)	Saturation Flow in vehicle/hour
IC-01	A- 01	14	- 0.94	44	110	0	15588
	A- 02	7.2	-1.13	17	146	0	9000
IC- 02	A- 03	10.5	-0.40	35	110	5	13212
	A- 04	10.5	-0.48	41	115	20	15804
IC-03	A- 05	9.50	1.20	45	140	13.48	10440
IC-04	A- 06	10.5	-0.70	60	220	42	9060
IC-05	A- 07	10.5	1.90	35	125	31.78	10770
IC-06	A- 08	14	1.56	55	195	13.89	16330
	A- 09	14	-0.78	65	195	19.80	11182
IC-07	A-10	12	1.20	60	220	10.78	19325

Table 5 shows that for the same width of the road the saturation flows are different, and it is due to the arrival rate and composition of the vehicles. The residual variation in measured field saturation flow and theoretical saturation flow is supposed to be explained by the vehicular arrival rate and the considerable presence of two-wheelers and their effect are considered by finding a new base saturation flow rate in the HCM model. The next step is to observe the discharge rate and develop the model to estimate the base saturation flow rate for mixed traffic conditions.

Table 5. Adjustment Factor and Calculated Saturation Flow

Study Approaches	*fw*	*frt*	*fhv*	*fg*	Number of Lanes	Saturation Flow by HCM in vehicles/hour	Field Saturation Flow in vehicles/hour
A- 01	0.9889	1.0000	0.9538	1.0047	4	7202 (54.00)	15588
A- 02	1.0000	1.0000	1.0000	1.0057	2	3821(58.00)	9000
A- 03	0.9889	0.8000	0.9600	1.0020	3	4338(67.00)	13212
A- 04	0.9889	0.5000	0.9807	1.0024	3	2771(82.00)	15804
A-05	1.1278	0.5974	0.9686	0.9940	2	2465(76.00)	10440
A-06	0.9889	0.3226	0.8591	1.0035	3	1568(83.00)	9060
A-07	0.9889	0.3862	0.9838	0.9905	3	2122(80.00)	10770
A-08	0.9889	0.5901	0.9641	0.9922	4	4243(74.00)	16330
A-09	0.9889	0.5025	0.9491	1.0039	4	3599(68.00)	11182
A-10	1.0444	0.6498	0.9846	0.9940	3	3786(80.00)	19325

4. Modification of HCM Model

4.1. Discharge rate model

Based on the data collected, the discharge rate model is developed considering the effect of various characteristics of the mixed traffic through regression approach. The statistical importance of the model is then to be tested, from the R^2 values, t-test, and p-values. Several combinations are selected on the basis of statistical test results.

The parameters have been considered for the development of discharge rate model are discharge rate with independent variables like width, percentage share of two-wheelers and the ratio of percentage arrival rate to width. The model is shown in Eq. (3).

$$Y_A = -2.448 + 0.141 \times X_1 + 0.039 \times X_2 + 0.169 \times X_3 \, , R^2 = 0.92 \quad (3)$$

Where, Y_A is Average discharge rate (vehicle/second), X_1 is the width of the approach in meter, X_2 is a share of two-wheelers (2W) in mixed traffic (%), and X_3 is ratio of percentage arrival rate to the width of approach (%AR/W). The 't' values of the coefficients are more than the critical value at a 95 percent level of confidence and hence all the coefficients are significant. The R-square values also indicate good strength of the models in forecasting the discharge rate. The Eq. (3) indicates that the discharge rate has a positive effect with an increase in the width of the road, the percentage of two-wheelers in the composition and the arrival rate. The arrival rate is an equally important parameter for the mixed traffic.

To understand the impact of mixed traffic on saturation flow, Table 6 provides saturation flow values based on Eq. (3) in which the width and composition of 2W are varied. In this model average arrival rate of 0.10 vehicle/second per meter, width has been considered as fixed input with variation in width from intermediate lane to 4-lane and two-wheelers composition from 50 to 80%.

Table 6. Saturation Flow Values in Vehicles per Hour

% 2W	Width (m)			
	6.6	7.5	10.5	14
50	7641	8098	9621	11398
60	9045	9502	11025	12802
70	10449	10906	12429	14206
80	11853	12310	13833	15610

4.2. Simplified width base saturation flow model

The range of saturation flow values is obtained using the Eq. (3) by considering 60% of 2W and average arrival rate of 0.1 vehicle/second for lane width from 6.6 m to 14 m which are given in Table 6 and, based on that flow values a simple regression model has been developed to provide the saturation flow in vehicle/hour quickly for the approach having any width from 6.6 m to 14m. The model is given in Eq. (4).

$$S = 1115W,\ 6.6m \leq W \leq 14m,\ (R^2 = 0.97) \quad (4)$$

Where, S is saturation flow in vehicle/hour, and W is the width of the road in the meter. The't' and 'p' values of the coefficients are statistically significant at a 95 percent level of confidence. The R-square values also indicate good strength of the models in predicting the flow rate. The Eq. (4) can be modified with the variation in the composition of two-wheelers from 50% to 90% for each percentage change.

$$SM = S\ (1 \pm 0.014\ p) \quad (5)$$

Where SM is modified saturation flow in vehicle/hour, S is saturation flow computed from the width-based model as per Eq. (4), and p is the percentage increase or decrees 2W in a range of 50% to 90%.
The Eq. (5) is used to estimate the base saturation flow in a modified HCM model.

4.3. Stream equivalency factor

Dhamaniya and Chndara (2013) developed the concept of stream equivalency (k) to convert mixed traffic flow into equivalent passenger car flow without making the use of PCUs. Stream equivalency (k) is defined as the ratio of discharge rate in PCU per seconds to discharge rate in the vehicle per seconds. The estimated average PCU values are used in the derivation of stream equivalency factor.

Fig. 3 shows the staggering data points of discharge rate in PCU per seconds to the vehicle per seconds. As an increase in the proportion of heavy vehicles in a traffic stream, k- value found to be increased.

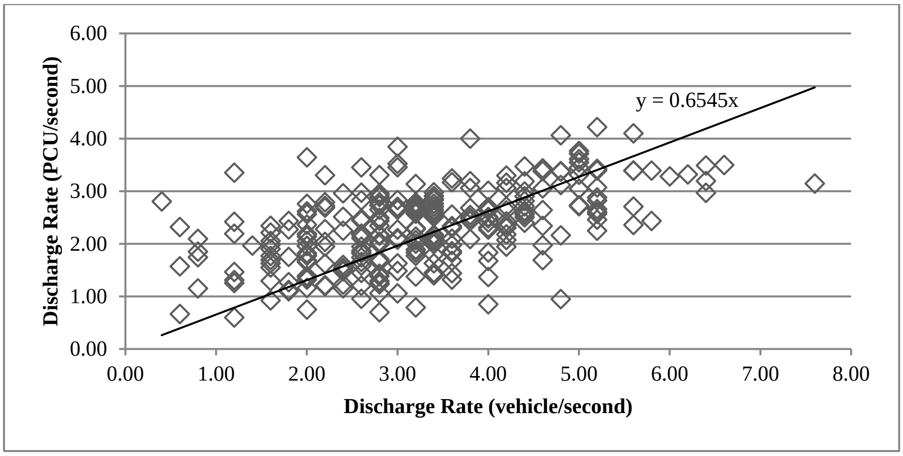

Fig. 3. Development of stream equivalency factor

The effect of mixed traffic compositions and saturation flow rate is considered for the derivation of k-value. A generalized Eq. (6) for k-value is developed using the multiple linear regression method. The base saturation flow from Eq. (5) is converted from vehicles to the passenger car units using the stream equivalency factor given in Eq. (6).

$$k = 1 + 0.3793 \times \frac{1}{N} + 0.005 \times P_{CB} - 0.0032 \times P_{3W} - 0.0078 \times P_{2W} + 0.0479 \times P_{HCV} + 0.0081 \times P_{LCV}\ , R^2 = 0.97 \quad (6)$$

Where, P_{2W}, P_{CB}, P_{HCV}, P_{3W}, and P_{LCV} are the average proportion 2W, CB, HCV, 3W and LCV respectively for every 5 seconds of saturated green time and N is an average number of vehicles discharged during every 5 seconds of saturated green time. The t values are significant at the 95% level of confidence. Signs of coefficients show that the k value will increases with vehicles size larger than a small car and it decreases with vehicles size smaller than a car. The R^2 indicates good strength in predicting the value of k.

Further, the model is validated using data from a different set of intersections. From the Eq. (5), the base flow rates have been calculated for the approaches of intersections under validation. The same are tabulated in Tables 7 and 8.

4.4. Adjustment factors

The capacity drop due to heavy vehicles in traffic stream is given in the HCM (2010) by multiplying this base flow rate with an adjustment factor of the heavy vehicle as per the following Eq. (7).

$$f_{hv} = \frac{1}{1+P_{HCV}\,(PCE_{HCV}-1)} \quad (7)$$

Where f_{hv} is heavy-vehicle adjustment factor, and PCE_{HCV} is HCV's passenger car equivalent. The capacity drops due to light-duty trucks have been observed by Kockelman and Shabih (2000) and added the adjustment factor for heavy vehicles as follow.

$$f_{hv} = \frac{1}{1+P_{HCV}\,(PCE_{HCV}-1)+P_{LDT}\,(PCE_{LDT}-1)} \quad (8)$$

Where, P_{LDT} is the proportion of LDT, and PCE_{LDT} is LDT's PCE. The similar kind of variations is observed for 3W and CB, which are mostly found on Indian roads, results in a capacity drop with the rise in their respective percentage (Anusha et al., 2013). The equation is modified in the same way as Kockelman and Shabih (2000) to incorporate the effect of 3W and CB as follows.

$$f_{hvm} = \frac{1}{1+P_{HCV}\,(PCE_{HCV}-1)+P_{LCV}\,(PCE_{LCV}-1)+P_{3W}(PCE_{3W}-1)+P_{CB}(PCE_{CB}-1)} \quad (9)$$

Where, f_{hvm} is modified heavy-vehicle adjustment factor, PCE_{LCV} is LCV's PCE, PCE_{3W} is 3W's PCE, and PCE_{CB} is CB's PCE. Adopting the Eq. (9) and derived PCUs based on the concept of time occupancy for each category of vehicles given in Table 2, the modified factor f_{hvm} is incorporated to modified HCM model to account for the effect of vehicular types on saturation flow.

5. Validation

The modified HCM 2010 model to estimate the saturation flow has been validated using the data from another set of intersections. The details of geometry and traffic compositions at the approaches are shown in Table 1 and 7 (IV-08 and IV-09). Saturation flow is then computed using the modified (by incorporating the base flow rate and modified adjustment factors) and the original HCM model, and this flow is compared with field saturation flow. The validation results are shown in Table 8. The result of estimated against observed flow values indicates much closeness. Percentage error earlier and later adjustment of the HCM equation is given in Table 8, which indicates a significant reduction in the percentage error.

Table 7. Geometric and Flow Data of the Intersections Considered For Validation

Intersections	Study Approaches	Width (m)	Gradient (%)	Green Time in seconds	Cycle Time in seconds	Arrival Rate in veh/sec	Right Turn (%)	Number of Lanes
IV-08	B-01	9.5	-2.8	36	160	0.74	14.76	2
	B-02	9.5	2.3	45	140	0.93	9.23	2
IV-09	B-03	8.5	-1.3	19	70	0.93	7.15	2

Table 8. Results of Validation

Study approaches	Base rate PCU/hr	*fw*	*frt*	*fhvm*	*fhv*	*fg*	Saturation Flow in PCU/hr by Original HCM	Saturation Flow in PCU/hr by Modified HCM	Field Saturation Flow in PCU/hr
B-01	8308	1.1000	0.9927	0.9199	0.9999	1.0140	4313 (45.26)	7694 (2.36)	7880
B-02	7401	1.1000	0.9954	0.9141	0.9999	0.9885	4216 (44.96)	7208 (5.90)	7660
B-03	6825	1.0722	0.9964	0.9724	0.9999	1.0065	4086 (48.23)	7140 (9.50)	7894

6. Conclusions

The mixed traffic is composed of different vehicle category of different physical size, variation in their acceleration, deceleration and speed characteristics, and aggressive driving behavior creates extremely complex operations on the urban road network as well as at the intersections. The variation in traffic characteristics like composition, volume, speed, and physical size are able to explain in PCU for a vehicle category. Time occupancy method has been used for the derivation of passenger car units at different intersections. Results of the Analysis of variance (ANOVA) test confirmed that the variation in PCU values at the seven signalized intersections for the different vehicle category are not significantly different at 5% level of significance. Therefore, an average PCU value for the different vehicle category has been taken as a common PCU. The increase or decrease in the PCU value of a particular vehicle category is directly affected by clearing time (occupancy time) taken by the subject vehicle for clearing the intersection area. The large size vehicles with lower maneuvering ability under mixed flow interaction observed more variation in occupancy time clearing the intersection area. So, more variation is observed in the PCU value of LCV and HCV. The estimated average PCU values have been used for the development of stream equivalency factor. So, the mixed traffic flow is converted from vehicles to equivalent PCUs without making the use of individual vehicle's PCU.

The saturation flow values have been derived by finding the saturation period using the ANOVA test at 5% level of significance. The obtained saturated green time may vary depending on the lost time, composition and flow at the approaches. The study on saturation flow indicates that saturation flow varies for the mixed traffic plying on Indian roads. Saturation flow mainly depends on the composition of traffic stream and magnitude. Therefore, with the presence of smaller size vehicles like 2W, when they increase in the stream, flow rises. The study shows that the effect of the arrival rate of vehicles is significant on the saturation flow rate. The arrival rate is an equally important parameter for mixed traffic conditions. The HCM equation is modified to suit for mixed traffic conditions by deriving the base saturation flow and adjustment factors. The base saturation flow values are derived considering the effect of two-wheelers in the mixed traffic situations. The adjustment factors are modified and a stream equivalency factor is developed to change mixed traffic flow into corresponding passenger car flow. The saturation flow estimated using adjusted HCM model is nearer to field values. The results confirm that the methodology of saturation flow rates given by HCM can also be used in India.

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