



Bunching Effect of Motorised Two Wheelers on Delay at Signalized Intersections under Heterogeneous Traffic Conditions

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Abstract

The performance of signalized intersections is usually evaluated by measuring delay occurring to vehicles which are passing through the signalized intersections. The field delay under heterogeneous traffic condition will be influenced by many parameters such as cycle time, traffic volume, degree of saturation, percentage of different vehicle categories especially the bunching of motorized two wheelers. In the present research work, the delay is estimated from the field using Indian Highway Capacity Manual (Indo HCM) (2017) procedure and the bunching effect of motorised two wheelers is studied on delay at signalized intersections under heterogeneous traffic conditions. Also, a linear delay model is developed for control delay estimation considering heterogeneous traffic conditions. From the field data, it was observed that, the percentage of motorised two wheelers in a bunch is varying from 37% to 57% whereas the total average delay occurred to vehicles which are passing the approach is varying from 106 s to 163 s respectively.

Keywords: Delay; Bunching effect; Motorised two wheelers; Signalized intersections; Heterogeneous traffic.

1. Introduction

The delay is the most significant parameter which is to be accurately determined in order to evaluate the Level of Service of intersections accurately. When the delay experienced by the vehicles is more: the vehicle needs to be in the queue for longer time and the fuel consumption will be high which causes frustration and discomfort to the drivers. The delay experienced by the vehicles under heterogeneous traffic conditions depends on several factors among which driver behaviour is the one. In heterogeneous traffic conditions, the majority of traffic platoon consist of motorised two wheelers and

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cars. It is observed in heterogeneous traffic that, these motorised two wheelers try to occupy the front portion of the queue by passing through the empty gaps between other category of vehicles and they form a bunch in front of stop line. This formation of two-wheeler bunch in front of stop line imparts more delay to the following vehicles. The figure 1 shows the formation of motorised two wheeler bunch in the beginning of queue. The present study focusses on the bunching effect of motorised two wheelers on delay under heterogenous traffic conditions.



Figure 1: Figure showing the formation of motorised two wheeler bunch.

The present study focusses on the bunching effect of motorised two wheelers on delay under heterogenous traffic conditions. In the past research work, Arasan and Jagadeesh (1995) studied the impact of traffic heterogeneity on delay in mixed traffic conditions. Hellinga and Abdy (2008) studied the impact of day-to-day variation in volume of traffic on delay. Prasannakumar and Dhinakaran (2012) estimated delay using HCM (2010) model. Ravisekhar et al. (2013) studied the fuel loss to vehicles when they present in queue at signalized intersections. Dogan et al. (2016) studied the impact of cycle time and approach volume on delay. Saha et al. (2017) presented a modified HCM delay model considering signal timings, traffic volume and platoon ratio. In spite of these methods and parameters used, the present study considers the bunching effect of motorised two wheelers on delay using Indo HCM (2017) method. Also, the present research work proposed a non-linear model for delay.

2. Background

The Indian Highway Capacity manual (2017) defines delay as “the average delay experienced by a vehicle due to the presence of signal control”. The delay is expressed in sec/veh or sec/pcu. This delay was measured using various methods using several parameters by many researchers around the world.

Quiroga and Bullock (1999) measured delay at signal controlled intersections using GPS data by making 52 runs through the intersection. The speed-time, acceleration-time and distance-time relations were found. The study results found that the acceleration-deceleration delay value obtained was 20 seconds. Cheng et al. (2003) proposed a new minimum cycle length equation and suggested modification to Webster's delay equation using HCS software. The proposed equations showed impressive results for signal design and analysis. Kebab et al. (2007) measured approach delay using point detection method based on video recorded data. The study used HCM method to calculate delay and the

results indicated the accurate measurement of delay from the field. Hellinga and Abdy (2008) found that the day to day variation of traffic volume at signalized intersections follows normal distribution. The study found the average intersection control delay based on 1000 volume variations trails, based on degree of saturation and g/c ratio.

Yuelong et al. (2009) measured delay from the field by collecting data of 500 queues using charge coupled device cameras. The study results shown that the heavy vehicles and start up vehicle interfaces significantly affect the delay. Also, the study proposed a delay model based on heavy vehicle composition and start up interfaces. Wang and Tian (2010) proposed a pedestrian delay model to predict delay occurring to pedestrian at signalized intersections considering two stage pedestrian crossing. The pedestrian delay model was validated with wide traffic ranges and the R^2 value of the model was 99.9%. The study results showed that the developed pedestrian delay model accurately predicted pedestrian delay from field. Jameel (2011) measured delay at two intersections using HCM, in Baghdad city. A new delay model was developed incorporating random delay and uniform delay and was validated using another intersection data from Baghdad city. The validation results showed good accuracy in predicting delay at signalized intersections in Baghdad city.

Abbas et al. (2013) measured delay from the field using Bluetooth media and GPS. The study presented two different delay models: one model with considering Bluetooth media data and another one considering GPS data. The study results showed that some errors had occurred in delay with data taken using Bluetooth devices. Chen et al. (2013) proposed analytical methods to find delay at fixed time isolated intersections at Texas. The study results showed that the delay variant is very small over time but for oversaturated and saturated conditions there is no variation and the delay becomes same.

Buck et al. (2017) calibrated VISSIM simulation model to analyse the delay at signal-controlled intersections. The time taken by the vehicles to pass the intersection, headways and arrival distribution of vehicles were collected from four signalized intersections and was given as input to calibrate VISSIM model. Stankovic et al. (2020) measured stopped delays D_s and control delays D_c from 1200 observations collected from 28 approaches of signalized intersections. The study found the D_s/D_c ratio which varied from 0.49 to 0.86, which was different from that given by HCM model. The results of the study showed that the D_s/D_c ratio suggested by HCM model is not appropriate always in order to determine delay. Sushmitha and Ravishankar (2021) measured control delay under mixed traffic conditions, using OSM tracker mobile application. The data was collected by making runs through the intersection with different category of vehicles. Also, the study proposed a non-linear delay model to calculate delay which was very close to the field delay. Lei et al. (2022) proposed an integrated algorithm to minimise the waiting time for passengers on urban rail transit line, which guides passengers to divert from a heavy traffic platform to light traffic platform. The results showed that, after the implementation of the algorithm the passenger waiting time was reduced by 5.62% on urban rail network. Poliziani et al. (2022) measured waiting time for cyclists at intersections using Global Positioning System (GPS) trace results. The study found that, the longer waiting times were required for women, for those who are 25 years below age, especially at complex intersections. In peak hour, the cyclists experienced a waiting time of 6% more than the average daily waiting time. From the literature review of previous studies, it is concluded that, the most of the delay studies were reported considering homogeneous traffic behaviour. The delay studies reported under heterogeneous traffic conditions are very less. Also, the studies reported under heterogeneous traffic conditions did not consider the bunching effect of

motorised two wheelers on delay. The present study evaluated the average approach delay for each study approach considering bunching effect of motorised two wheelers in heterogeneous traffic conditions.

3. Study area

For the present research work, ten signalized intersections are selected. All the study intersections are four legged intersections and are chosen from four different cities: Thiruvananthapuram, Calicut, Hanmakonda and Hyderabad. Vazhuthakkad intersection is located in Thiruvananthapuram; Malaparamba, Eranhipalam and Palayam intersections are located in Calicut; Bachupally, Suchitra, Gandimaisamma and Patny circle intersections are located in Hyderabad; KU intersection and Adalath intersections are located in Hanmakonda. The satellite images of the intersections located in Tiruvananthapuram, Calicut, Hyderabad and Hanmakonda are shown in figures from 2 to 5 respectively.

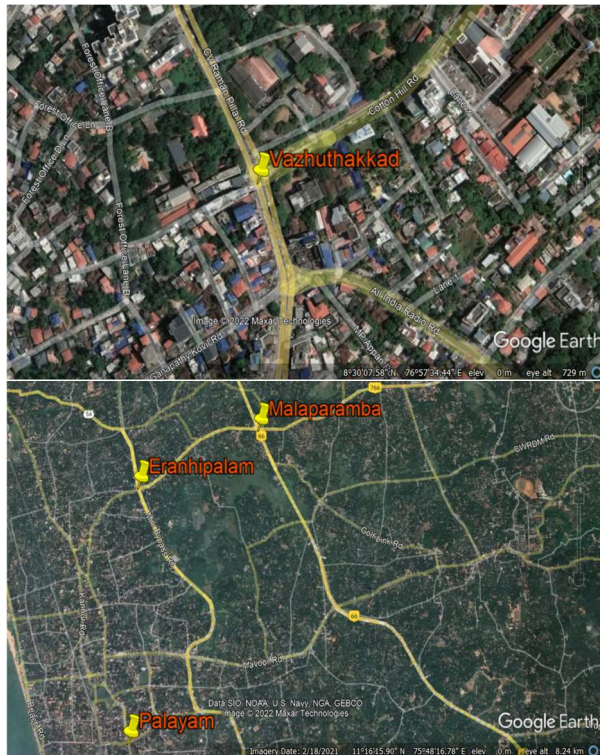


Figure 2: Study intersection in Tiruvananthapuram Figure 3: Study intersections in Calicut



Figure 4: Study intersections in Hyderabad



Figure 4: Study intersections in Hyderabad

All the study intersections shown through satellite images from 2 to 5 have permitted through, right and left movements.

4. Data

Data such as geometric details, traffic details and signal timings were collected from the field. Video recording is done at the study locations from 7AM to 11 AM and 4 PM to 8 PM which covered both peak and off peak hours. The geometric details include number of lanes and width of approach; traffic details include classified vehicle count and number of vehicles joining the queue during red time; signal timings include green time, red time, amber time and cycle time. The classified vehicles are counted for every 15 minutes count interval for the recorded video data. Based on the 15 minutes classified vehicle count, the peak hours and off-peak hours are identified. Then the number of vehicles joining the queue for every 10 seconds count interval during the red period is counted during peak hours and off peak hours. Also, in the present study, the number of motorised two wheelers forming the bunch in the beginning of queue are counted during each cycle. The number of lanes and signal timings of the study approaches are presented in table 1.

Table 1: Number of lanes and signal timings.

<i>Intersection</i>	<i>Approach</i>	<i>Number of lanes</i>	<i>Green time (s)</i>	<i>Amber time (s)</i>	<i>Red time (s)</i>	<i>Cycle time (s)</i>
Vazhuthakkad	NB1	2	50	2	126	178
	SB1	2	50		126	178
	EB1	2	40		136	178
	WB1	2	30		146	178
Malaparamba	NB2	2	32	2	142	176
	SB2	2	33		141	176
	EB2	Intermediate	43		131	176
	WB2	Intermediate	60		114	176
Eranhipalam	NB3	2	38	2	136	176
	SB3	2	44		130	176
	EB3	2	46		128	176
	WB3	Intermediate	40		134	176
Palayam	NB4	2	30	2	86	118
	SB4	2	30		86	118
	EB4	2	25		91	118
	WB4	2	25		91	118
Bachupally	NB5	2	45	2	111	158
	SB5	Intermediate	30		126	158
	EB5	2	45		111	158
	WB5	2	30		126	158
Suchitra	NB6	3	60	3	119	182
	SB6	3	50		129	182
	EB6	3	30		149	182
	WB6	3	30		149	182
Gandimaisamma	NB7	2	45	3	99	147
	SB7	Intermediate	35		109	147
	EB7	Intermediate	30		114	147
	WB7	Intermediate	25		119	147
Patny circle	NB8	2	25	2	73	100
	SB8	2	25		73	100
	EB8	2	25		73	100
	WB8	2	25		73	100
KU	NB9	2	31	5	104	140
	SB9	2	31		104	140
	EB9	Intermediate	29		106	140
	WB9	Intermediate	29		106	140
Adalath	NB10	2	40	2	103	145
	SB10	2	41		102	145
	EB10	2	27		116	145
	WB10	2	26		117	145

The study intersections have approaches with number of lanes varying from intermediate lane to two lanes and the cycle time is varying from 100 seconds to 182 seconds. The traffic volume during, degree of saturation and percentage of different categories of vehicles: motorised two wheelers (%TW), Three Wheelers (%3W), Car (%Car), Light Commercial Vehicles (%LCV), Heavy Vehicles (%HV) and the percentage of motorised two wheelers in the bunch are presented in table 2.

Table 2: Degree of saturation, traffic volume, percentages of vehicle categories and percentage of motorised two wheelers in bunch

<i>Approach</i>	<i>Traffic volume veh/hr</i>	<i>Degree of saturation</i>	<i>%TW</i>	<i>%3W</i>	<i>%Car</i>	<i>%LCV</i>	<i>%HV</i>	<i>%TW in bunch</i>
NB1	1541	0.65	49	14	16	12	9	43
SB1	1736	0.78	51	18	21	5	5	48
EB1	1786	0.81	54	16	12	13	5	50
WB1	1956	0.89	58	17	12	7	6	53
NB2	1903	0.84	59	15	9	11	6	55
SB2	1658	0.79	50	18	6	18	8	44
EB2	1647	0.76	51	21	14	12	2	47
WB2	1231	0.51	35	22	19	16	8	30
NB3	1435	0.63	49	18	25	6	2	42
SB3	1389	0.61	41	15	26	10	8	37
EB3	1178	0.53	38	18	23	14	7	35
WB3	1578	0.74	49	27	16	6	2	45
NB4	564	0.50	27	37	25	8	3	22
SB4	509	0.50	29	42	16	6	7	23
EB4	685	0.55	31	38	27	3	1	27
WB4	763	0.48	32	22	27	12	7	28
NB5	1376	0.59	42	32	21	4	1	37
SB5	1568	0.68	47	24	15	12	2	41
EB5	1098	0.48	32	27	18	19	4	29
WB5	1756	0.72	54	24	13	6	3	49
NB6	1896	0.82	56	12	22	8	2	55
SB6	1874	0.87	53	17	22	5	3	49
EB6	2051	0.93	60	18	10	11	1	57
WB6	2321	0.98	67	21	8	2	2	62
NB7	1104	0.46	35	24	12	18	11	31
SB7	1521	0.64	45	16	28	9	2	40
EB7	1639	0.69	49	19	22	7	3	43
WB7	1543	0.69	48	12	27	11	2	42
NB8	494	0.49	27	22	32	14	5	22
SB8	754	0.49	31	23	26	12	8	28
EB8	469	0.50	25	29	22	16	8	22
WB8	856	0.51	32	22	26	18	2	29
NB9	1089	0.51	39	27	26	7	1	34
SB9	1453	0.58	42	22	31	4	1	38
EB9	1063	0.48	34	27	28	9	2	31
WB9	1109	0.54	40	25	22	9	4	34
NB10	1648	0.71	47	22	13	11	7	42
SB10	1087	0.52	37	32	16	11	4	34
EB10	1063	0.53	38	26	24	8	4	33
WB10	1564	0.64	41	25	22	7	5	38

It is observed from table 2 that, the percentage of motorised two wheelers and cars are high compare to other vehicle categories. Also, it is observed that among total percentage of motorised two wheeler present in the queue, 80 to 95% of motorised two wheelers are forming a bunch in the starting of queue.

6. Observed delay

The delay is measured from the field using video recorded data for the study approaches. The number of vehicles standing in the queue for every 10 seconds interval during red interval is counted and also a separate classified vehicle volume count of total number of vehicles arriving during the survey period is done (Indo HCM (2017)). The survey duration covered 40 consecutive signal cycles. The stopped delay of an approach can be calculated in veh/s using equation 1.

$$d_s = I \times \frac{\sum V_i}{V_a} \times 0.9 \quad (1)$$

Where, d_s =average stopped delay in s/veh, I = Time interval in seconds, V_i =number of stopped vehicles that can be seen in each count interval, V_a =total number of vehicles during the survey period, 0.9 is the correction factor. The average delay can be estimated using equation 2. Equation 2 gives average approach delay using acceleration and deceleration correction factor.

$$d = 1.19 \times d_s \quad (2)$$

Where, d = control delay in s/veh, d_s = stopped delay in s/veh. The field average approach delay values of the study intersections are presented in table 3.

Table 3: Observed average approach Delay.

<i>Approach</i>	<i>Average delay (s/veh)</i>	<i>Approach</i>	<i>Average delay (s/veh)</i>
NB1	128	NB6	147
SB1	136	SB6	141
EB1	139	EB6	158
WB1	152	WB6	176
NB2	148	NB7	115
SB2	134	SB7	125
EB2	131	EB7	131
WB2	118	WB7	129
NB3	125	NB8	89
SB3	121	SB8	105
EB3	118	EB8	87
WB3	130	WB8	108
NB4	94	NB9	116
SB4	97	SB9	127
EB4	101	EB9	114
WB4	103	WB9	117
NB5	121	NB10	134
SB5	128	SB10	116
EB5	114	EB10	112
WB5	136	WB10	125

For the study approaches, the minimum value of the delay is observed as 87 s/veh at 25% of motorised two wheelers and the maximum value of the delay is observed as 176 s/veh at 67% of motorised two wheelers. As the percentage of motorised two wheelers increases the delay also observed to be increased. Therefore, the percentage of motorised two wheelers in the bunch significantly affects the filed average delay of an approach.

7. Control delay model

Various parameters such as G/C (Green time to Cycle time) ratio, cycle time C, traffic volume (q), degree of saturation (X) and percentage of motorised two wheelers are considered to affect intersection delay. But, from the correlation analysis of statistical measure, it is observed that the traffic volume, degree of saturation and percentage of motorised two wheelers in the bunch, affect intersection delay significantly. In the present research work, an attempt is made to fit the relation between significant parameters in MATLAB. Out of ten intersections used in the present research work, seven intersections are used for model calibration. Equation 3 represents the delay model obtained from MATLAB.

$$d = (0.02 \times q) - (0.5 \times X) + (0.8 \times \% \text{ TW in bunch}) + 63 \quad (3)$$

Where, d= average delay in sec/veh, q= traffic volume in veh/h, X= degree of saturation and P=percentage of motorised two wheelers in bunch.

The R^2 value of the model is 0.961. From equation 3, the volume, degree of saturation and percentage of motorised two wheelers in the bunch are varying linearly with delay. For every 10% increase in hourly traffic volume and % TW in bunch, the marginal increase in the delay was observed to be 1.67% and 2.84% respectively. Whereas, for every 10% increase in the degree of saturation, the marginal decrease in the delay was observed to be 2.29%. The statistical values of the model variables are presented in table 4 and the results of the K-S test are shown in Table 5.

Table 4: The statistical values of the model variables.

Parameter	Std. error	p-value	t-stat	Lower 95% CI	Upper 95% CI	VIF
Q	0.050	0.032	2.24	57.32	69.95	3.15
X	12.32	0.012	4.55	0.010	0.031	2.56
% TW in bunch	0.310	0.002	2.36	-25.501	24.49	4.08
Intercept	3.150	0.023	4.02	0.185	1.446	-

Table 5: K-S test results.

Parameter	K-S test p-value
Delay (d)	0.779
traffic volume (q)	0.663
Degree of saturation (X)	0.854
% motorised two wheelers in bunch	0.708

From the results of the K-S test and statistical values of the model parameters, it is observed that the p- values of the variables: delay, traffic volume, degree of saturation and % motorised two wheelers in bunch are greater than 0.05. Therefore, it can be concluded that, the variables selected for the development of delay are satisfying the assumptions of MLR model.

8. Comparison of delay values

In this section the field delay values are compared with those calculated using the developed model, Webster's delay model and Indo-HCM empirical delay model. The comparison among different delay values is shown in Table 6.

Table 6: Comparison of delay values

<i>Approach</i>	<i>Average delay (s)</i>	<i>Model delay (s)</i>	<i>webster's delay(s)</i>	<i>Indo-HCM delay (s)</i>	<i>Approach</i>	<i>Average delay (s)</i>	<i>Model delay (s)</i>	<i>webster's delay (s)</i>	<i>Indo-HCM delay (s)</i>
NB1	128	130	186	28.91	NB6	147	152	199	21.09
SB1	136	134	187	19.12	SB6	141	148	203	32.62
EB1	139	138	189	23.74	EB6	158	162	231	21.52
WB1	152	151	205	22.37	WB6	176	183	228	26.14
NB2	148	155	198	25.00	NB7	115	117	169	23.48
SB2	134	136	189	23.13	SB7	125	129	205	47.20
EB2	131	128	179	25.19	EB7	131	135	188	18.32
WB2	118	120	169	21.19	WB7	129	136	195	19.38
NB3	125	128	187	21.60	NB8	89	98	148	28.09
SB3	121	125	176	39.67	SB8	105	110	159	20.95
EB3	118	123	169	14.41	EB8	87	92	139	20.69
WB3	130	145	194	18.46	WB8	108	114	177	18.52
NB4	94	101	154	29.79	NB9	116	123	187	23.28
SB4	97	100	148	28.87	SB9	127	136	179	21.26
EB4	101	98	155	13.86	EB9	114	121	169	20.18
WB4	103	97	159	17.48	WB9	117	118	186	18.80
NB5	121	126	164	18.18	NB10	134	135	178	15.67
SB5	128	132	166	28.91	SB10	116	119	187	27.59
EB5	114	118	159	33.33	EB10	112	116	176	16.96
WB5	136	139	168	22.06	WB10	125	121	173	24.80

The Index of Agreement (IA), Mean Absolute Percentage Error (MAPE) and relative percentage error (RPE) are calculated for delay values and are represented in equation 4,5 and 6 respectively.

$$RPE = \frac{(y_{\text{exp}} - y_{\text{pred}})}{y_{\text{exp}}} \times 100 \quad (4)$$

$$MAPE = \frac{1}{N} \left| \frac{y_{\text{exp}} - y_{\text{pred}}}{y_{\text{exp}}} \right| \quad (5)$$

$$IA = 1 - \left[\frac{\sum_{i=1}^n (y_{\text{pred}} - y_{\text{exp}})^2}{\sum_{i=1}^n \left(\left| y_{\text{exp}} - \overline{y_{\text{exp}}} \right| + \left| y_{\text{pred}} - \overline{y_{\text{pred}}} \right| \right)^2} \right] \quad (6)$$

The results of the comparison are shown in Table 7 using accuracy and error measurements.

Table 7: Comparison of different delay models

<i>Accuracy/Error measurement</i>	<i>Linear model</i>	<i>Indo HCM model</i>	<i>webster's model</i>
IA	0.98	0.74	0.36
MAPE	5.6%	12.8%	33.6%
RPE	Minimum 0.45%	Minimum 16%	Minimum 39%
	Maximum 11%	Maximum 39%	Maximum 63%

The accuracy of the linear delay model presented in this paper is high and the error is low when compare to webster's model and Indo-HCM (2017) model.

9. Validation

Validation of the calibrated model is essential to represent the application of the calibrated model in the real scenario. In the present research work, out of ten study intersections, three are used for model validation. The validation chart for the developed model is shown in figure 6.

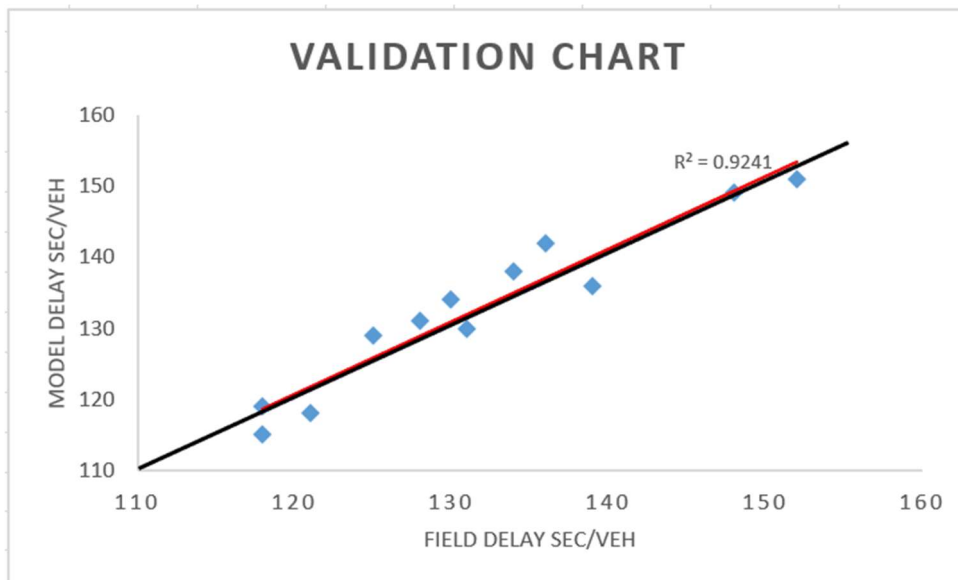


Figure 6: Validation chart.

The validation chart in figure 6 shows the good prediction of average delay model arrived in the present study.

10. Conclusions

In the present research work, the field delay is collected at signalized intersections using the procedure suggested by Indo-HCM (2017). For this purpose, data of ten signalized intersections is collected from four different locations. The correlation analysis results showed that the traffic volume, degree of saturation and percentage of motorised two wheelers in bunch are more influencing the delay at signalized intersections in heterogeneous traffic and a linear model is developed for average delay using MATLAB. It is observed from the raw delay data that, when the percentage of motorised two

wheelers in a bunch is varying from 37% to 57%, the average delay is varying from 106 S to 163 S respectively.

Also, a comparison study is done among linear delay model, Indo-HCM (2017) and webster's delay model. it is proved that; the linear delay model is proved to predict average delay accurately compared to webster's and Indo-HCM (2017) delay models. The reason is, the webster's model was arrived considering lane-disciplined homogeneous traffic conditions. Even though, the Indo-HCM (2017) model is developed for heterogeneous traffic condition, it is not considering the percentage motorised two wheelers in a bunch which affect delay under heterogenous traffic conditions. Therefore, the developed linear model can be used to predict average delay under heterogeneous traffic conditions, when motorised two wheelers form in to bunches.

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