

STOPPED DELAYS FOR DIFFERENT VEHICLE TYPES AT SIGNALIZED INTERSECTIONS IN MIXED TRAFFIC CONDITIONS

Ramireddy Sushmitha^{1,*}, Jatoth Jithender², and Pathangi Eswanth²

Received: February 27, 2024; Revised: May 20, 2024; Accepted: July 31, 2024

Abstract

Vehicular delays are unavoidable while assessing the performance of signalized intersections, but measuring these vehicular delays in the field is a complex process in mixed traffic conditions. Different vehicle types have different dynamic and physical characteristics. Even when the specific vehicle category is taken there are many variations within that vehicle category. Therefore, the delay experienced by each vehicle category is different from other vehicle category. The aim of the present study is to evaluate the stopped delays for different vehicle category at signalized intersections and to develop vehicle category wise stopped delay model in mixed traffic scenario. For this purpose, data was collected from five locations. The study results showed that the stopped delay experienced by the two-wheelers and three-wheelers is less compare to LCVs and HCVs. Also, the obtained stopped delays were compared with the Indian Highway Capacity Manual (Indo HCM, 2017). The comparison results showed that the Indo HCM (2017) stopped delay model is either over estimating or underestimating the stopped delay values. The maximum and minimum Relative Percentage Error (RPE) between observed and Indo HCM (2017) estimated stopped delays are 27.67% and 7.40% respectively.

Keywords: Mixed Traffic Conditions; OSM tracker; Signalized Intersections; Stopped delay; Vehicle Types

¹ Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, 518007, India. E-mail: susmitharamireddy@gmail.com; eswanth.ce@gprec.ac.in

² Civil Engineering Department, Vignana Bharathi Institute of Technology, Aushapur, Ghatkesar, Hyderabad, Telangana, 501301, India. E-mail: jatoth.jithender@gmail.com

* Corresponding author

DOI: <https://doi.org/10.55766/sujst-2024-04-e03733>

Suranaree J. Sci. Technol. 31(4):010319(1-10)

Introduction

A prevalent issue in urban areas is traffic congestion at signalized junctions, especially in locations with mixed traffic conditions. When many vehicles types, such as cars, buses, motorbikes, bicycles, and pedestrians, are present at the same time and have diverse sizes, speeds, and operational characteristics, it is referred to as mixed traffic. The overall effectiveness of intersections can be greatly impacted by the complicated interactions and delays caused by traffic heterogeneity. The stopped delay that various vehicle types encounter at signalized intersections is a crucial component of traffic performance. The amount of time that a vehicle waits at a red light is known as the “stopped delay,” and it is a crucial indicator of intersection efficiency and traffic density. It is crucial to comprehend the differences in stopped delays for various vehicle types to optimize traffic signal timings, enhance road user satisfaction, and improve traffic flow. The variations in stopped delays under mixed traffic situations are influenced by a number of factors, including driver behavior, acceleration, vehicle size, and maneuverability. Smaller vehicles, like motorbikes, may be able to move through traffic more readily, potentially lowering their stopped delay, whereas larger vehicles, like buses and trucks, may incur lengthier delays due to their slower acceleration and wider turning radii. Traffic dynamics at intersections are further complicated by the interactions between various vehicle types and non-motorized road users, such as cyclists, and pedestrians. The purpose of this study is to examine stopped delays at signalized intersections under mixed traffic situations for various types of vehicles. The objective of the research is to offer insight into traffic management techniques that can reduce traffic and enhance the overall effectiveness of urban intersections by analyzing the variables affecting these delays and measuring the variations between different types of vehicles.

The study also evaluated the stopped delays for different vehicle categories and assessed the stopped delay evaluation performance of Indo HCM (2017) stopped delay model. For this purpose, five different signalized intersections were selected which consists of varying geometry, traffic, and control characteristics. In the past research work, Adebisi and Sama (1989) studied the effect of stopped delay on behavior of driver in gap acceptance. Othayoth and Krishnarao (2018) evaluated a conversion factor to convert stopped delay to control delay. Li *et al.* (2022) estimated vehicle emissions during their idling condition in the queue. Even with extensive

studies on traffic delays at signalized intersections, there are still several gaps, particularly where there is mixed traffic. Studies frequently overlook the effects of various parameters and fail to adequately distinguish between the delays encountered by different types of vehicles. Further investigation is required into the variability of driver behavior, the impact of intersection design, and the fluctuations in temporal traffic flow. Furthermore, not enough research has been done on how modern technologies and traffic control strategies affect stopped delays.

Literature Review

Indian Highway Capacity Manual (Indo HCM, (2017), defines the stopped delay as ‘The time a vehicle is stopped in the queue while waiting to pass through the intersection’. This stopped delay can be expressed in sec/vehicle or sec/pcu. The stopped delay was estimated using several methods using various parameters by many scientists around the globe. Adebisi and Sama 1989, investigated the impact of stopped delays on behavior of drivers in their gap acceptance for left turn maneuvers on minor roads. The critical gaps are found to be higher for stopped delays less than 25 sec and the critical gaps are found to be lower for stopped delays greater than 30 sec. Olszewski (1993) studied the number of stops, stopped delays, and overall delays at signals. The study investigated the ratio between overall delay and stopped delay. It was found that this ratio was nearly equal to 1.3 when the red time was greater than 60 sec. It was also found that, for overflow conditions, this ratio also depends on the degree of saturation and cycle time. Saito *et al.* (2001) evaluated stopped delays based on field observations, simulation methods, and analytical models. The motion method and gap method of measuring delays were proposed and were compared with field delay values. The time intervals between 1 to 20 sec were utilized for the analysis of stopped delays. The result showed that the gap method of measuring stopped delays gave good results for 15 sec time intervals, and the motion method of measuring stopped delays gave good results for 1 to 2 sec time intervals and the manual method of measuring stopped delays gave good results for 10 sec count interval and for less than 10 sec. Mousa (2002) evaluated the error in measuring delay by HCM (1994) procedure, for several ranges of count intervals. The study derived a mathematical model to estimate this error. The study results

showed an error of ± 100 percent of deterministic delay. Optimum offsets were found for 20 sec time intervals.

Hereth *et al.* (2006) estimated stopped delays using animated images created by CORSIM simulation software. These simulation images cannot differentiate pavement color, vehicle size, and vehicle color. The study proposed three methods: motion, gap-hybrid, and gap method. These methods overcome the problems associated with the image method. The three proposed methods in this study estimated stopped delays with superior accuracy. Qiwu and Jianguo (2011) proposed an instantaneous stopped delay index based on a feedback circuit using an image processing method. The instantaneous stopped delay index was developed based on algorithms and was tested for different climatic conditions. In all the climatic conditions the stopped delays from the image processing method were the same as the observed field stopped delays. Puangprakhon and Narupiti (2013) Proposed a stopped delay method and running speed method to evaluate travel time. These methods utilize trajectories of vehicles obtained by sensors. The performance of the proposed method was verified with the average speed method. The study results showed that the proposed method in this study accurately estimated the real travel time. Akgungor and Korkmaz (2016) proposed several models to define the relation between control delays and stopped delays. These models were established for several cycle lengths, green ratios, and traffic volumes. The data required for model calibration and validation was obtained from the CORSIM simulation. It was found that the conversion factor 0.76, given by HCM (2010) was not constant and it varies based on traffic conditions. Shaik and Rawoof (2016) assessed the accuracy of HCM (2010). The stopped delay values estimated using HCM (2010) were compared with field measured delays obtained from six intersections during the morning peak, afternoon peak, off peak, and evening peak. The study results found that the HCM (2010) overestimated for minor street delays and under estimated for major street delays. Othayoth and Krishna Rao (2018) evaluated the conversion factor to convert stopped delays into control delays. Global Positioning System (GPS) was used for recording vehicle trajectories. The study found a conversion factor of 1.19 for mixed traffic scenarios. Shin *et al.* (2019) used a Convolutional Neural Network to estimate vehicle delays from video recordings. The proposed method superiorly estimated vehicle delays. The proposed delay model based on the reinforcement learning algorithm was validated with real-time data, which showed good prediction of vehicle delays.

Bagdatil (2020) estimated delays at signalized intersections using Gene expression programming, which is an Artificial Intelligence Technique, which can estimate vehicle delays quickly and rapidly with more accuracy compared to analytical methods. The results of the study showed that the gene expression programming technique was highly accurate in estimating vehicle delays. Stankovic *et al.* (2020) modelled the relation between stopped and control delays using 1200 vehicle trajectories from 28 signalized intersection approaches. These vehicle trajectories were analyzed using a macroscopic approach and a microscopic approach. At the microscopic approach level, a linear relation was observed between stopped delays and control delays. At the macroscopic approach level, the ratio of stopped delay to control delay varied between 0.49 to 0.86. The study results found that the ratio between stopped delay and control delay given by HCM (2010) is not appropriate all the time to measure accurate delay and the study proposed a modified HCM delay model. Li *et al.* (2022) estimated various characteristics of stopped vehicles at toll gates using video data in Beijing. The study results showed that the average stopped delay was 6 sec and only 26 percent of total vehicles experienced a stopped delay. The average daily cost of fuel, fuel consumption, and exhaust emissions were evaluated using empirical models. The study results evaluated several stopped delay characteristics of vehicles which were very useful in evaluating fuel loss during idling conditions.

Jithender and Mehar (2023) estimated delay and passenger car unit values at signalized intersections, using queued vehicles at approaches. The control delay values obtained from the study were compared with HCM and delay values. The comparison results showed that the HCM delay values were overestimated with field values. Kumar and Aggarwal (2023) estimated fuel consumption due to delays at signalized intersections for a duration of 12 h. The study results found that, during this 12-hour period, an extra amount of petrol of 103.78 liters, which costs 13018 INR was consumed due to delay. The study also suggested remedial measures to minimize this extra petrol consumption. Radhareddy *et al.* (2023) proposed an analytical model for evaluating waiting time delays. These analytical models were compared with SUMO simulation output. The validation results showed better results compared to SUMO output.

Almutairi *et al.* (2024) estimated control delay occurring at intersections at the Network level. The study proposed a total travel delay estimation technique which computes delay data. The results obtained from the total travel delay estimation

technique were compared with VISSIM output, then the total travel delay estimation technique showed better results in calculating control delay. Cakici and Aksoy (2024) examined whether the performance outcomes of ‘Minimization of Average vehicle delay’ and the ‘the minimization of an average number of stops’ are the same or not? This question was analyzed in three different phases: in the first phase, two different signal optimization models were created; in the second phase optimum signal timings were identified using MATLAB; and in the third phase 30 different traffic scenarios were created. The study results showed that the utilization of ‘minimization of an average number of stops’, may increase vehicular delays up to 113.44% and ‘minimization of average vehicle delay may increase an average number of stops up to 16.28%.

From the previous studies, it can be concluded that most of the stopped delay studies were reported for lane disciplined traffic behavior. The stopped delay studies reported for non-lane based mixed

traffic conditions are very less and these studies did not consider the effect of vehicle type on stopped delays. The present research work evaluated the average stopped delay for different vehicle types in mixed traffic behavior.

Study Area

For the present work data was collected from five signalized intersections: KU (I-1), Kazipet (I-2), Suchitra (I-3), Bachupally (I-4), and Gandimaisamma (I-5). The intersections I-1 and I-2 are in Warangal city and the intersections I-3, I-4 and I-5 are in Hyderabad. All the study intersections are four legged intersections with permitted right, straight and left turn movements. The Figure 1 shows satellite image of the study intersections in Warangal city and Figure 2 shows satellite image of the study intersections in Hyderabad city.



Figure 1. Satellite image of intersections I-1 and I-2



Figure 2. Satellite image of intersections I-3, I-4 and I-5

Table 1. Signal details and geometric details of study approaches

Intersection	Approach	Approach width (m)	Cycle time (sec)	Green time (sec)	Red time (sec)
I-1	NB-1	7	138	32	95
	SB-1	7		32	90
	EB-1	5.7		27	106
	WB-1	5.5		27	110
I-2	NB-2	8.6	136	35	97
	SB-2	8.2		35	97
	EB-2	6.2		30	102
	WB-2	6		20	112
I-3	NB-3	9.5	180	30	131
	SB-3	10.5		20	134
	EB-3	10		50	93
	WB-3	10		60	85
I-4	NB-4	7.5	162	45	80
	SB-4	5.3		30	119
	EB-4	6.4		45	114
	WB-4	7.3		30	75
I-5	NB-5	7.5	147	45	85
	SB-5	5.5		30	108
	EB-5	5.5		35	98
	WB-5	5.8		25	90

Data Collection and Extraction

The geometric data, signal details, and traffic data are collected. Tape was used to collect geometric details of the intersections, stop watch was used to collect signal detail, and video recording was done to collect traffic data. Classified vehicle volume count was taken from video recorded data. The signal details and geometric details of the study approaches are given in Table 1.

The approach widths of the study locations varied from 5.3 m to 10.5 m and Cycle time varied from 136 sec to 180 sec. The traffic volume, degree

of saturation, and percentage of different vehicle types at study approaches are given in Table 2.

The percentage of two-wheelers was observed to be high and varied from 37% to 56.6%. The heavy vehicle percentage of low and it varied from 1.61% to 10.30%.

Measuring Stopped Delays from Field

The field stopped delay was collected using the OSM tracker mobile application. The mobile application was operated from 'the point exactly

Table 2. Traffic volume, degree of saturation and percentage of vehicle types

Intersection	Approach	Volume (veh/h)	Degree of saturation	Percentage of two-wheelers	Percentage of three-wheelers	Percentage of Cars	Percentage of LCV	Percentage of HV
I-1	NB-1	1,050	0.63	40.70	12.30	33.87	7.12	6.01
	SB-1	1,250	0.74	44.80	14.40	27.08	7.40	6.32
	EB-1	673	0.81	37.80	11.60	31.16	12.10	7.34
	WB-1	893	0.47	39.80	13.40	25.96	12.70	8.14
I-2	NB-2	2,450	0.80	40.00	16.30	33.07	5.32	5.31
	SB-2	1,898	0.64	37.60	12.10	34.77	9.36	6.17
	EB-2	467	0.41	37.00	8.60	31.94	13.10	9.36
	WB-2	540	0.45	46.00	6.30	30.69	15.40	1.61
I-3	NB-3	1,400	0.84	42.60	20.10	33.50	0.8	3.00
	SB-3	750	0.81	44.70	21.80	29.43	0.87	3.20
	EB-3	3,206	0.95	54.30	20.70	19.91	0.93	4.16
	WB-3	3,556	0.97	56.60	20.90	17.70	0.90	3.90
I-4	NB-4	1,326	0.84	52.10	17.40	20.50	05.10	4.90
	SB-4	669	0.65	44.40	09.90	25.91	12.40	7.39
	EB-4	950	0.76	49.00	13.70	26.71	08.90	1.69
	WB-4	1,454	0.71	48.00	15.30	25.03	06.14	5.53
I-5	NB-5	1,860	0.71	44.00	17.30	31.58	03.91	3.21
	SB-5	850	0.54	42.00	08.00	25.10	14.60	10.30
	EB-5	1,350	0.61	41.00	11.00	26.12	12.90	8.98
	WB-5	1,960	0.83	47.50	17.50	18.59	11.10	5.31

Table 3. Field stopped delays

Intersection	Approach	Average approach Stopped delay (veh/s)	Average stopped delay for two-wheelers (veh/s)	Average stopped delay for three-wheelers (veh/s)	Average stopped delay for LCV (veh/s)	Average stopped delay for HV (veh/s)
I-1	NB-1	112	89	106	121	132
	SB-1	122	98	112	128	150
	EB-1	108	86	92	108	146
	WB-1	109	84	96	117	139
I-2	NB-2	117	92	114	126	136
	SB-2	106	83	104	115	130
	EB-2	102	82	98	109	119
	WB-2	112	87	93	125	143
I-3	NB-3	140	104	123	153	180
	SB-3	134	91	118	152	175
	EB-3	149	112	128	163	193
	WB-3	159	109	135	168	224
I-4	NB-4	149	110	126	164	196
	SB-4	118	93	104	123	152
	EB-4	125	97	116	135	152
	WB-4	133	92	118	150	172
I-5	NB-5	122	102	115	126	137
	SB-5	142	112	128	149	179
	EB-5	112	98	106	118	126
	WB-5	110	97	104	115	124

before the deceleration starts' to the point on the downstream side where the reacceleration is obtained. Parallely, a video recording was done for each run. As this mobile application gives the speed of the vehicle and the corresponding time interval; the stopped, acceleration, and deceleration delays were determined accurately. A total of 50 runs were made for each study intersection with different types of vehicles: two-wheelers, three-wheelers, Light Commercial Vehicles, and Heavy vehicles. The average stopped delay experienced by each type of vehicle was computed. Also, the average stopped delay of all the vehicle types passing through the study approaches was considered as the final average stopped delay for that study approach. Table 3 shows the field stopped delays measured using the Open Street Map tracker.

From Table 3, the observed field stopped delays for two-wheelers and three-wheelers are less compared to LCVs and HVs.

Modelling Stopped Delays

This section provides stopped delay models for different vehicle types which are applicable for Indian traffic conditions. For this purpose, the data of four study intersections (I-1, I-2, I-3, and I-4) is used, and the remaining one intersection (I-5) is used for validation of the developed models.

The parameters such as G/C ratio (λ), cycle time, degree of saturation (X), traffic volume (q), and percentage of light vehicles such as two-wheelers and three-wheelers were considered for modelling stopped delays. Table 4 shows the correlation matrix of the significant variables affecting two-wheeler, three-wheelers, LCV, and HV-stopped delays.

Modelling Two-Wheeler Stopped Delay

The parameters such as G/C ratio (λ), cycle time, degree of saturation (X), traffic volume (q), and percentage of light vehicles such as two-wheelers and three-wheelers were considered for modelling Two-Wheeler stopped delays. When Correlation analysis (Table 4) was performed among these variables, a significant correlation of two-wheeler stopped delay was found with the traffic volume, cycle time, degree of saturation, and percentage of light vehicles. The two-wheeler stopped delay is varying linearly with cycle time and traffic volume, exponentially with degree of saturation, and logarithmically with the percentage of light vehicles.

Regression Analysis was performed to find the coefficients of significant variables. The results of the Regression Analysis for two-wheeler stopped delay model are given in Table 5.

The R^2 value of the model is 0.867. The t stat values of the significant variables are more than

Table 4. Correlation matrix of the significant variables affecting stopped delay for different vehicle types

Two-Wheelers Stopped Delay					
	SD	C	Q	e^x	$\ln(P)$
SD	1				
C	0.59	1			
Q	0.61	0.28	1		
e^x	0.72	0.27	0.11	1	
$\ln(P)$	0.80	0.19	0.16	0.23	1
Three-Wheelers Stopped Delay					
	SD	C	Q	e^x	$\ln(P)$
SD	1				
C	0.73	1			
Q	0.72	0.28	1		
e^x	0.82	0.17	0.01	1	
$\ln(P)$	0.91	0.29	0.16	0.23	1
LCV Stopped Delay					
	SD	C	q	e^x	$\ln(P)$
SD	1				
C	0.826	1			
q	0.581	0.289	1		
e^x	0.777	0.179	0.112	1	
$\ln(P)$	0.952	0.191	0.161	0.034	1
HV Stopped Delay					
	SD	C	q	e^x	$\ln(P)$
SD	1				
C	0.797	1			
q	0.576	0.389	1		
e^x	0.821	0.679	0.712	1	
$\ln(P)$	0.909	0.791	0.661	0.834	1

Where, SD= Stopped delay (sec/veh), C= Cycle time (sec), q= Vehicle volume (veh/hr), X= degree of saturation and P= Percentage of light vehicles.

± 1.96 and the P values are less than 0.05. The VIF values of the variables obtained are less than 5.

Modelling Three-Wheelers Stopped Delay

The parameters such as G/C ratio (λ), cycle time, degree of saturation (X), traffic volume (q), and the percentage of light vehicles such as two-wheelers and three-wheelers were considered for modelling three-wheelers stopped delays. When Correlation analysis (Table 4) was performed among these variables, a significant correlation of three-wheelers stopped delay was found with the traffic volume, cycle time, degree of saturation, and percentage of light vehicles. The stopped delay is varying linearly with cycle time and traffic volume, exponentially with the degree of saturation, and logarithmically with the percentage of light vehicles.

Regression Analysis was performed to find the coefficients of significant variables. The results of the Regression Analysis for three-wheelers stopped delay model are given in Table 6.

The R^2 value of the model is 0.871. The t stat values of the significant variables are more than ± 1.96 and the P values are less than 0.05. The VIF values of the variables obtained is less than 5.

Modelling LCV Stopped Delay

The parameters such as G/C ratio (λ), cycle time, degree of saturation (X), traffic volume (q), and percentage of light vehicles such as two-wheelers and three-wheelers were considered for modelling LCV stopped delays. When Correlation analysis (Table 4) was performed among these

variables, a significant correlation of LCV stopped delay was found with the traffic volume, cycle time, degree of saturation, and percentage of light vehicles. The stopped delay is varying linearly with cycle time and traffic volume, exponentially with the degree of saturation, and logarithmically with the percentage of light vehicles.

Regression Analysis was performed to find the coefficients of significant variables. The results of the Regression Analysis for the LCV-stopped delay model are given in Table 7.

The R^2 value of the model is 0.922. The t stat values of the significant variables are more than ± 1.96 and the P values are less than 0.05. The VIF values of the variables obtained are less than 5.

Modelling HV Stopped Delay

The parameters such as G/C ratio (λ), cycle time, degree of saturation (X), traffic volume (q), and percentage of light vehicles such as two-wheelers and three-wheelers were considered for modelling HV stopped delays. When Correlation analysis (Table 4) was performed among these variables, a significant correlation of HV stopped delay was found with the traffic volume, cycle time, degree of saturation, and percentage of light vehicles. The stopped delay varies linearly with cycle time and traffic volume, exponentially with the degree of saturation, and logarithmically with the percentage of light vehicles.

Regression Analysis was performed to find the coefficients of significant variables. The results of

Table 5. Regression analysis results for two-wheeler stopped delay

	Coefficients	Standard error	t stat	P-value	VIF
Intercept	115.7	7.91	3.05	0.008	-
C	0.04	0.14	2.28	0.007	2.203
Q	0.001	0.00	2.41	0.006	1.421
e^x	4.47	9.09	4.49	0.000	3.443
$\ln(P)$	44.81	2.80	1.96	0.006	3.212

Table 6. Regression analysis results for three-wheelers stopped delay

	Coefficients	Standard error	t stat	P-value	VIF
Intercept	122.26	10.24	4.042	0.001	-
C	0.050	0.118	3.479	0.006	2.121
Q	0.002	0.002	4.404	0.018	1.245
e^x	3.178	7.252	2.438	0.006	3.845
$\ln(P)$	55.479	8.191	3.049	0.008	1.332

Table 7. Regression analysis results for lcv stopped delay

	Coefficients	Standard error	t stat	P-value	VIF
Intercept	170.083	11.47492	4.663022	0.000	-
C	0.214	0.143516	2.492569	0.015	3.214
Q	0.006	0.002515	2.22465	0.008	2.456
e^x	3.359	8.74641	4.38405	0.007	1.231
$\ln(P)$	114.544	2.93997	5.220811	0.000	3.224

the Regression Analysis for the HV stopped delay model are given in Table 8.

The R^2 value of the model is 0.922. The t stat values of the significant variables are more than ± 1.96 and the P values are less than 0.05. The VIF values of the variables are obtained is less than 5.

Validation of Stopped Delay Models

Validation represents the applicability of the developed model to a real system. Out of the five signalized intersections studied, one (I-5) was used for validation. The validation of the developed stopped delay models is shown in Figure 2.

The observed vs predicted stopped delays of each vehicle category are shown in Figure 2. The validation chart shows a good prediction of developed stopped delay models.

Comparison of Field Stopped Delay with Indo HCM (2017) Stopped Delay Values

Indian Highway Capacity Manual (Indo HCM, (2017) was developed in the year 2017, based on Indian Traffic Conditions. In this section a brief

comparison was done between field average stopped delay and Indo HCM measured stopped delay and the results are presented in Table 9.

The comparison results showed that the Indo HCM (2017) stopped delay model is either overestimating or underestimating the stopped delay values. The maximum and minimum Relative Percentage Error (RPE) between observed and Indo HCM estimated stopped delays are 27.67% and 7.40% respectively.

Results and Discussion

The variables chosen for modelling are tested for correlation (Table 4). The results of the analysis showed that the cycle time, traffic volume, degree of saturation, and percentage of light vehicles showed a strong correlation with stopped delay. The statistical values such as t -stat, p -value, and VIF (Variance Inflation Factor) were obtained using Regression Analysis. In the present study, the analysis showed significant results in obtaining control delay for different vehicle types. Also, the field stopped delay values were compared with Indo HCM (2017) stopped delay values. The results indicated a higher or lower value of stopped delay

Table 8. Regression analysis results for HVs

	Coefficients	Standard error	t stat	P-value	VIF
Intercept	137.719	7.414	2.901	0.016	-
C	0.282	0.284	2.992	0.006	2.334
Q	0.002	0.004	4.470	0.004	3.456
e^x	20.788	1.364	2.197	0.049	1.223
$\ln(P)$	120.978	13.558	2.777	0.014	1.987

Table 9. Comparison between field and INDO HCM stopped delays

Approach	Observed average stopped delay (sec/veh)	Average Stopped Delay estimated by INDO HCM (2017)	RPE (%)
NB-1	112	131	16.96
SB-1	122	144	18.03
EB-1	108	116	7.40
WB-1	109	121	11.00
NB-2	117	134	14.52
SB-2	106	127	19.81
EB-2	102	92	9.80
WB-2	112	143	27.67
NB-3	140	159	13.57
SB-3	134	114	14.92
EB-3	149	165	10.73
WB-3	159	172	8.17
NB-4	149	163	9.39
SB-4	118	134	13.55
EB-4	125	142	13.60
WB-4	133	156	17.29
NB-5	122	142	16.39
SB-5	142	154	8.450
EB-5	112	133	18.75
WB-5	110	125	13.63

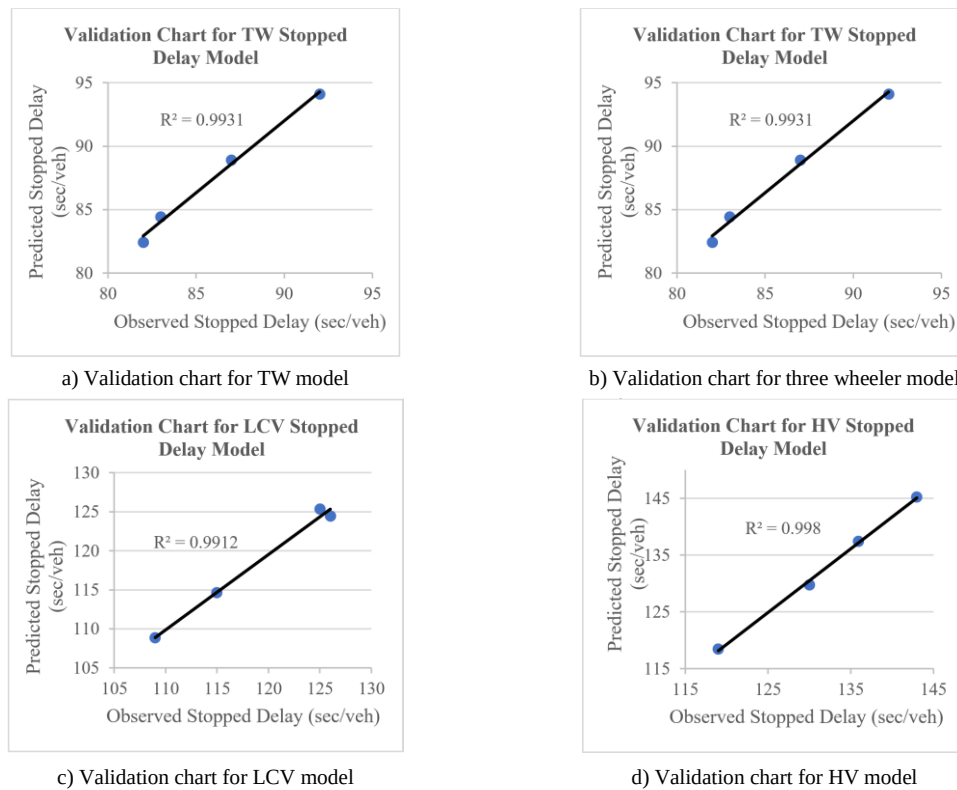


Figure 3. Validation charts

values compared to field delay values. The reason is that the Indo-HCM delay model not considered the effect of vehicle type. Most of the stopped delay 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 vehicle type. The present research work will be helpful in estimating realistic stopped delay values in urban intersections. The intersections selected for the present study are only four legged intersections. The study can be extended by also considering three legged intersections. Also, The other vehicle categories such as car and non motorized vehicles were not considered in the present study. The stopped delays for cars and non motorized vehicles can be further evaluated.

Conclusions

In the present research work, the average stopped delays at signalized intersections were measured using an OSM tracker mobile app. For this purpose, five intersections were considered from two different cities, i.e., Hanmakonda and Hyderabad.

The correlation analysis results showed a good correlation of stopped delays with the parameters cycle time, traffic volume, degree of saturation, and percentage of light vehicles. In the present study individual stopped delay models were developed for four vehicle types: two-wheeler, three-wheelers, Light Commercial Vehicle and Heavy Vehicle. Each model can be used to compute its own vehicle type stopped delay. The developed models were validated using Gandimaisamma intersection (I-5). The validation results indicated the good predictability of the developed stopped delay models. Also, in the present study, the Indo HCM (2017) model was used to compute the stopped delay values for comparison purpose. Indo HCM (2017) stopped delay values were either overestimating or underestimating the stopped delay values and the model was not adequate to give stopped delay values under heterogeneous traffic conditions. The reason is that, Indo HCM (2017) was developed only based on traffic volume and acceleration deceleration correction factor and did not consider the effect of vehicle type. So, the developed vehicle wise stopped delay models in the present study are useful to predict stopped delays accurately under mixed traffic conditions.

Acknowledgement

Authors are thankful to Principal of G. Pulla Reddy Engineering College (Autonomous), Kurnool: Dr. B. Srinivasa Reddy and Management, for their support and encouragement during this research work.

References

- Adebisi, O. and Sama, G.N. (1989). Influence of stopped delay on driver gap acceptance behaviour. *Journal of Transportation Engineering*, 115(3):305-315. [https://doi.org/10.1061/\(ASCE\)0733-947X\(1989\)115:3\(305\)](https://doi.org/10.1061/(ASCE)0733-947X(1989)115:3(305))
- Akgungor, A.P. and Korkmaz, E. (2016). Analysis and modelling of relationship between stopped and control delays by differential evolution algorithm. *The Open Civil Engineering Journal*, 10:266-279. <https://doi.org/10.2174/1874149501610010266>
- Almutairi, A., Yi, P., and Owais, M. (2024). New approach for estimating intersection control delay from passive traffic sensors at network level. *IEEE Access*, 12:2882-2900. <https://doi.org/10.1109/ACCESS.2024.3349499>
- Bagdatil, M.E.C. (2020). Vehicle delay modelling at signalized intersections with gene-expression programming. *Journal of Transportation Engineering*, 146(9). [https://doi.org/10.1061/\(ASCE\)0733-947X\(2020\)146:9\(04020063\)](https://doi.org/10.1061/(ASCE)0733-947X(2020)146:9(04020063))
- Cakici, Z. and Aksoy, G. (2024). Does the minimization of the average vehicle delay and the minimization of the average number of stops mean the same at the signalized intersection? *International Journal of Transportation Science and Technology*, 13:213-228. <https://doi.org/10.1016/j.ijst.2024.01.003>
- Hereth, W.R., Zundel, A., and Saito, M. (2006). Automated estimation of average stopped delay at signalized intersections using digitized still image analysis of actual traffic flow. *Journal of Computing in Civil Engineering*, 20(2):132-140. [https://doi.org/10.1061/\(ASCE\)0887-3801\(2006\)20:2\(132\)](https://doi.org/10.1061/(ASCE)0887-3801(2006)20:2(132))
- Highway Capacity Manual (HCM). (1994). TRB, Washington, D.C., USA.
- Highway Capacity Manual (HCM). (2010). TRB, Washington, D.C., USA.
- Indo HCM. (2017). Indian Highway Capacity Manual. Council of Scientific and Industrial Research (CSIR), New Delhi.
- Jithender, J. and Mehar, A. (2023). Modelling passenger car unit and delay at signalized intersections in mixed traffic conditions. *U. Porto Journal of Engineering*, 9(3):28-40. https://doi.org/10.24840/2183-6493_009-002_001508
- Kumar, A. and Aggarwal, P. (2023). Fuel consumption at signalized intersection due to delay. *London Journal of Engineering Research*, 23(4):45-52.
- Li, J., Yang, X., Chen, Y., Li, R., and Zhang, C. (2022). Analysis of stopped delay and stopped idling emissions of car of expressway toll gate. In: 2021 6th International Conference on Intelligent Transportation Engineering, 901:833-851. https://doi.org/10.1007/978-981-19-2259-6_74
- Mousa, R.M. (2002). Accuracy of stopped delay measured by stopped vehicle counts method. *Journal of Transportation Engineering*, 128(5):439-447. [https://doi.org/10.1061/\(ASCE\)0733-947X\(2002\)128:5\(439\)](https://doi.org/10.1061/(ASCE)0733-947X(2002)128:5(439))
- Olszewski, P. (1993). Overall delay, stopped delay and stops at signalized intersections. *Journal of Transportation Engineering*, 119(6):835-845. [https://doi.org/10.1061/\(ASCE\)0733-947X\(1993\)119:6\(835\)](https://doi.org/10.1061/(ASCE)0733-947X(1993)119:6(835))
- Othayoth, D. and Krishna Rao, K.V. (2018). Estimation of stopped delay to control delay conversion factor and development of delay model for non-lane-based heterogeneous traffic. *European Transport*, 69(3):1-21.
- Puangprakhon, P. and Narupiti, S. (2013). Travel time estimation by running speed and stopped delay method on urban road using probe vehicle data. In: *Proceedings of Eastern Asia Society for Transportation Studies*, 9:1-17.
- Qiwu, R., and Jianguo, Y. (2011). Measurement of instantaneous stopped delay at intersections using image processing technology. *Energy Procedia*, 13:693-701. <https://doi.org/10.1016/j.egypro.2011.12.693>
- Radhareddy, Almeida, L., Santos, P., and Tovar, E. (2023). Waiting time analysis for a network of signalized intersections. *Procedia Computer Science*, 220:503-510. <https://doi.org/10.1016/j.procs.2023.03.064>
- Saito, M., Walker, J., and Zundel, A. (2001). Use of image analysis to estimate average stopped delays per vehicle at signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 1776(1):67-75. <https://doi.org/10.3141/1776-14>
- Shaik, and Rawoof, M.A. (2016). Comparison of stopped delay between field measurements and HCM 2010 estimations at actuated signalized intersections. *Graduate Dissertations and Theses at Illinois. University of Illinois at Urbana-Champaign*.
- Shin, J., Roh, S., and Sohn, K. (2019). Image-based learning to measure the stopped delay in an approach of a signalized intersection. *IEEE Access*, 7:176349-176357. <https://doi.org/10.1109/ACCESS.2019.2957661>
- Stankovic, S., Celar, N., Kajalic, J., and Bisevac, I.V. (2020). Micro and macro approach to modelling relationship between control and stopped delays at signalized intersections. *Journal of Transportation Engineering, Part A: Systems*, 146(1). <https://doi.org/10.1061/JTEPBS.0000288>