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DELAY AT SIGNALISED INTERSECTION IN HETROGENEOUS TRAFFIC CONDITION

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Abstract—*Delay is additional travel time while crossing a signalized intersection which is due to de-acceleration, stop and acceleration of vehicle. Delay caused to an individual vehicle at a signalized intersection is a performance measure to assess the level of service. Estimation of delay is mostly done by Webster's delay model or Highway Capacity Manual (HCM) which is developed for homogeneous lane-based traffic condition. In India traffic is heterogeneous and lane behaviour is frequently violated. Thus, both these conventional delay estimation models give error in delay estimation. Therefore, a delay model is proposed as per Indian traffic conditions. The proposed model has been developed by modifying the existing HCM model based on platoon ratio under the two third of the field traffic data at two signalized intersection in Patna, India. Measured queue length was plotted with cycle time and Simpson's one third rule was used to estimate the total field delay in an individual cycle time and average delay of an individual cycle per vehicle was obtained by dividing the total number of vehicle cross the stop line in a green signal of that cycle length at signalized intersection. The proposed model was validated by using one third of the field traffic data of both the intersection. This paper presents the results of the research work done on delay estimation, model formation, and comparison with existing delay model at signalized intersection under the heterogeneous traffic condition. The difference between fields estimated delay and delay due to proposed model was observed less than 8.8%.*

Keywords: *Signalized intersection; Heterogeneous traffic condition; Delay; Queue length; Simpson's one- third rule; Platoon ratio.*

1. INTRODUCTION

Traffic management is a challenging task for traffic engineers at intersection particularly when the traffic volume is high. High traffic growth, lack of proper traffic management and poor lane discipline leads to delay of vehicle at intersections. At intersections traffic and pedestrian control are provided by signalization. In signalized traffic intersections, movement of traffic on different approach is controlled by traffic signals comprised of green, red and amber phases. Pre-timed signalization defines signal cycle lengths which repeat turn-wise for all the approach after a fixed time interval and fully actuated signals can change phase with variation in traffic volume. Properly designed traffic signal reduces vehicular delay. Delay at intersection implies extra time consumed by vehicle while negotiating the intersections. Delay at intersection include, delay during de-acceleration, stop, acceleration, and queue interference of vehicle. The efficiency and quality of traffic operation on signalized intersections are assessed in terms of total delay caused to an individual vehicle at the intersection. Highway Capacity Manual (HCM) and Webster's delay model are popular for measurement of delay under controlled signalized intersection. Equations developed in these models consider homogeneous traffic movements with good lane discipline that prevails in United State and United Kingdom. But traffic in developing countries like India is highly heterogeneous with poor lane discipline. There are many research works done on mixed traffic condition but still there is no standard method for delay calculation in mixed traffic. Thus, to represent heterogeneous traffic condition effectively, a number of researchers have developed delay models.

2. DATA COLLECTION

Video graphic technique was used for traffic data collection. Traffic data was collected in two signalized intersection in Patna City of Bihar in India namely Dakbanglow Chowk and Hadtali Chowk. Data is collected at both the signalized intersection in morning from 9 am to 11 am and in evening from 2 pm to 5 pm, when traffic flow is maximum. Both the intersections are four legged with fully actuated signals. In actuated signal, cycle time varies with traffic flow. All the intersections are free from intervention of road side parking, bus stops or any other side friction as shown in Fig.1. The camera was set-up in such a manner that can capture the vehicles queue formation and vehicle's arrival and departure rate in queue, at signalized intersections. The queue length was taken by visual observation of the selected approach without any mark on road, to keep vehicles in normal driving condition. The queue length is the distance between, the approaching vehicles at signalized intersection from which vehicles start retardation and stop line of the traffic signal. The details and average value of cycle time at signalized intersection chosen for data collection is shown in Table 1.

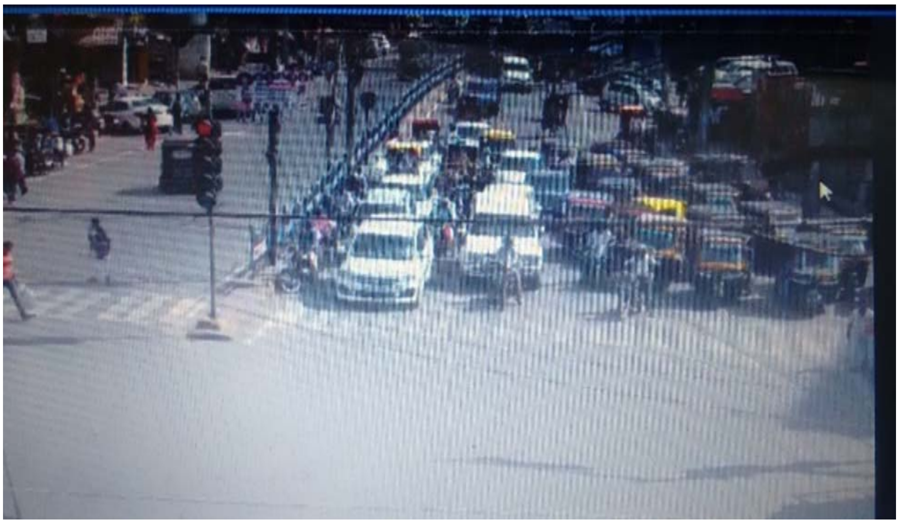

Fig. 1: Heterogeneous traffic at signalized intersection in Patna.

Table 1: Details of Signalized Intersection Chosen for Data collection

Name of intersection	Clock Time	Approach width (m)	Average Cycle length(sec)	Number of observed cycles	Average Green time(sec)
Dakbanglow Chowk	9 am to 11 pm	10.5	226.59	10	43.50
	2 pm to 5 pm		234.59	44	41.47
Hadtali Chowk	9 am to 11 am	12.5	210.67	9	88.33
	2 pm to 5 pm		187.58	39	63.46

3. DATA EXTRACTION

Video footages were collected in field and played in laboratory to obtain desirable information such as saturation flow, capacity, flow rate, platoon ratio, green cycle ratio, cycle time and degree of saturation at signalized intersection for every particular cycle time. Green time signal is chosen for data extraction and to find out different vehicle composition such as Auto, Car, Bus, Bicycle-rickshaw and Bicycle in queue length as shown in Table 2. The movement of vehicle's entry in queue is considered as entry time and movement of Vehicle's crossing the stop line of traffic signal is considered as exit time. The vehicle arrival and departure from queue is extracted in 5 second intervals for a particular approach. All types of vehicle arrival and departure from queue are measured in terms of passenger car unit as per IRC-106-1990, which is known as number of vehicles. The total number of vehicles in a queue is taken as number of vehicles enter in queue length plus number of vehicles already present in queue length minus number of vehicles cross the stop line of traffic signal in green time for a particular approach in a cycle time.

Table 2.Vehicle composition at intersection in percentage

Intersection	Bike	Auto	Car	Bus	Bicycle-rickshaw	Bicycle
Dakbanglow Chowk	38.07	37.04	12.08	5.69	4.98	2.14
Hadtali chowk	54.26	15.07	24.41	1.54	1.5	3.22

4. MEASUREMENT OF SATURATION FLOW

In this study, all parameters like traffic flow, capacity, and saturation flow of an intersection are measured in number of vehicles per hour. Saturation flow at signalized intersection is measured by area of graph plotted between numbers of vehicle departure at stop line of traffic signal in five second interval and green time of traffic signal of an individual cycle length as shown in Fig.2. At least three different types of vehicle departure from queue are taken for fulfilment of mixed traffic condition. The saturation flow is calculated by formula shown in equation (1).

$$S = \frac{N*3600}{g_e} \quad (1)$$

Where, S=Saturation flow (veh/hr); N=Number of vehicles crossing the stop line during green signal; g_e= effective green time in second.

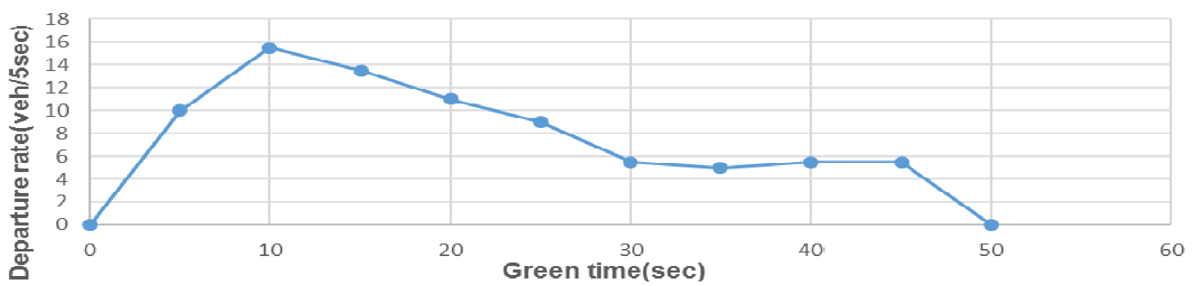

Fig. 2. Saturation flow measurement

5. FIELD DELAY MEASUREMENT

Field delay is measured by area between queue lengths with cycle time in a particular approach of signalized intersection. The area is estimated either by integration, Simpson's rule, trapezoidal rule or triangular rule which depends on accuracy of area estimation. Here area of queue length variation with cycle time was estimated by Simpson's one third rule for five second interval as shown in Fig.3. The queue length is the sum of vehicles enter in a particular approach plus number of vehicles already present in approach minus number of vehicles cross the stop line of approach in particular interval. The area of Simpson's one third rule gives the total delay of a particular cycle time. The average field delay is obtained by dividing the total delay with total number of vehicles cross the stop line of traffic signal in green time of an individual cycle length. Simpson's one third rule is given in equation 2.

$$\int_0^C f(Q_L)dq = \frac{h}{3} * \left((q_0 + q_n) + 4(q_1 + q_3 + q_5 + \cdots .. + q_{(n-1)}) + 2(q_2 + q_4 + \cdots + q_{(n-2)})\right) \text{.........(2)}$$

Where h=(c-o)/n; (c-o) = difference between the start time and end time of queue observation; Q_L = Queue length; c=cycle time (sec); n=number of five second intervals; and $q_{0,}\ q_{1,}\ q_{2,} q_3 \ldots \ldots \ldots q_n$=queue length at 0, 1st, 2nd, .nth interval.

HCM 2010, suggest that field delay curve plotted with cycle time is either triangular or trapezoidal means that vehicle's arrival and departure rate in queue is constant with cycle length but in mixed traffic condition it may vary with cycle which lead to error in delay estimation under saturated cycle. Hence Simpson's one third rule gives more accurate results as compared to triangular or trapezoidal-rule.

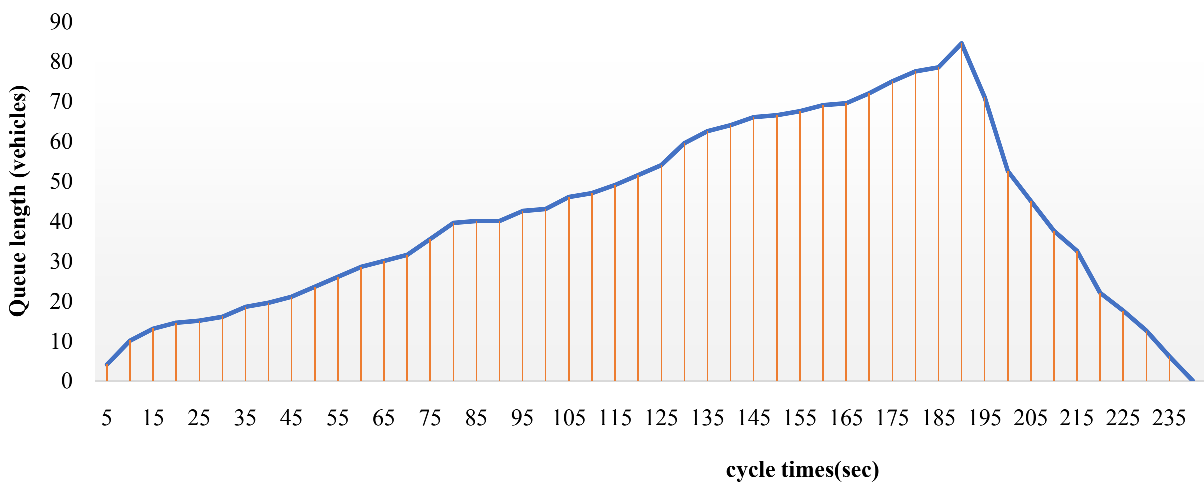

Fig. 3. Field delay estimation curve

6. DEVELOPMENT OF DELAY MODEL

In many studies it was found that delay at signalized intersection depends on parameters, like signal cycle time, green ratio (g/c), volume capacity ratio (v/c), green time, number of phases, number of lanes, platoon ratio. The present study is based on control delay and platoon ratio concept which depends on all type of delay parameters. Delay model is developed by two third of total traffic data of two signalized intersection and rest one third traffic data is used for model validation. Delay model comprises three terms such as uniform delay, random delay and overflow delay. Uniform delay (d_1) depends on cycle length, volume capacity ratio (v/c) and green ratio (g/c) which is calculated by HCM (2010) equation (4) and initial queue delay (d_3) is zero because of considered as under saturation means that no vehicle left in queue after completion of a cycle. The random delay or incremental delay (d_2) depend on arrival vehicle platoon in a queue of an individual cycle time and platoon ratio (R_p) is calculated by equation (5).

Total delay (d) = $d_1 + d_2 + d3$ ... (3)

$$d_1=0.5*c*\frac{\left(\left(1-\frac{g}{c}\right)^2\right)}{\left(1-\min[x,1]*\frac{g}{c}\right)} \text{ .... } \mathbf{(4)}$$

$$R_p=\frac{PVG}{PTG} \text{ .... (5)}$$

Where c= cycle time (sec), g=green time (sec), x=volume capacity ratio (v/c); green time ratio (g/c) PVG=percentage of vehicle arriving in green time; PTG=percentage of time green.

Model is formulated by incremental delay (d_2=d-d_1) with platoon ratio which best suited with linear as shown in Fig. 4. Because of total delay which is not shows more accurate linear relation with platoon ratio (Rp) as shown in Fig. 5.

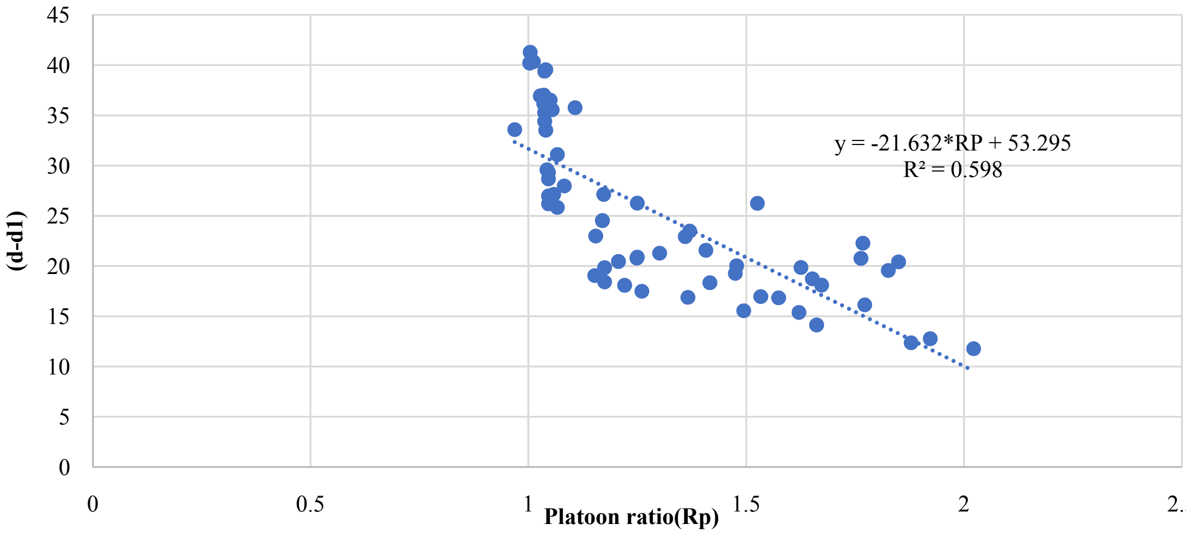

Fig.4. Incremental delay(d2) with platoon ratio

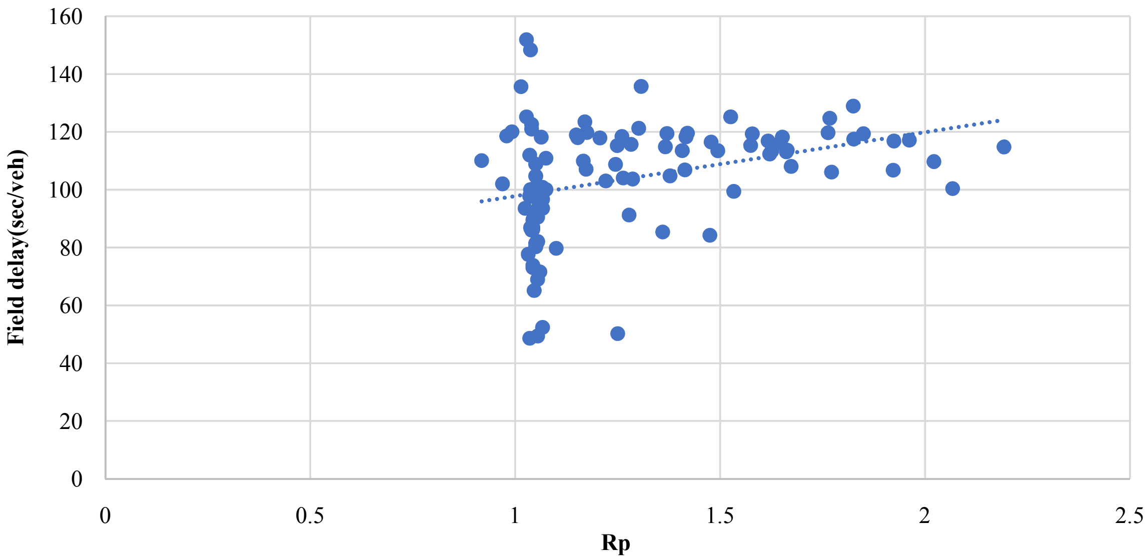

Fig. 5.Total field delay(d) with platoon ratio(Rp)

The regression analysis is used to get a line relationship between incremental delay (d_2) and platoon ratio (R_P) as shown in equation (6). The regression output statistics is shown in table (3).

d_2=-21.631*R_P+53.295(R^2=0.5979) …(6)

Where d_2= (d-d_1) =incremental delay (sec/veh); R_P= platoon ratio.

The modified delay model was given in equation (7).

$$d = 53.295 + \frac{0.5*C*(1-g/c)^2}{\left(1-X*\frac{g}{c}\right)} - 21.631*Rp \quad .....(7)$$

7. MODEL VALIDATION

Model validation is done by one third traffic data of both signalized intersections as shown in Fig. 7. The accuracy of this signalized intersection is good because of R square value is 0.5438.

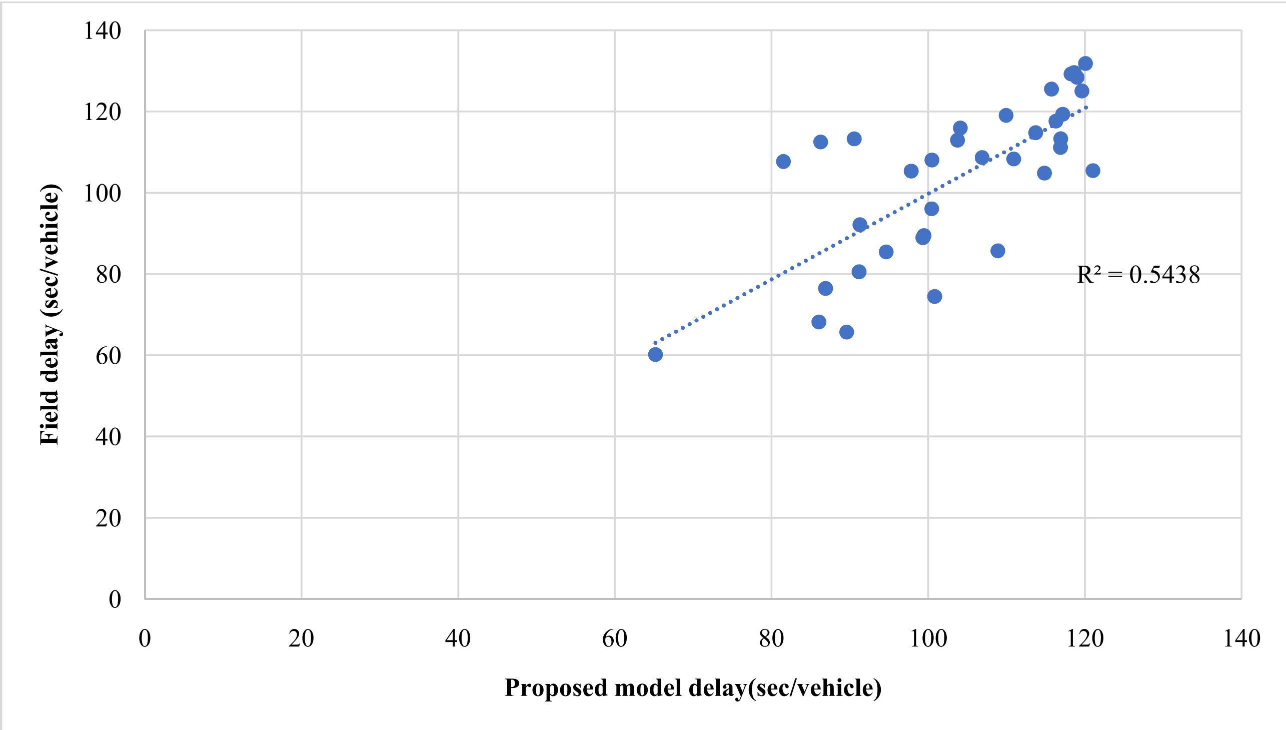

Fig. 7 Model validation between field delay and proposed model delay

Table 4.Detail of various intersection parameters

Intersection	Clock Time	S (veh/hr)	g/c	C (veh/hr)	V (veh/hr)	X=V/C	Rp	Range of platoon ratio
Dakbanglow Chowk	9 am to 11 am	4564	0.19377	905.06	1700.5	1.672	1.5983	0.97-2.2
	2 pm to 5 pm	6435.86	0.17729	1164.27	1937.22	1.674	1.42052	0.96-2
Hadtali Chowk	9 am to 11 pm	5789.53	0.4524	2581.44	2677.57	1.0401	1.1056	1-1.5
	2 pm to 5 pm	6218.64	0.34523	2125.67	2228.78	1.0504	1.05891	1-1.4

8. VARIOUS PARAMETERS FOR DELAY ESTIMATION

The delay model depends on various parameters, such as green time ratio (g/c), capacity(C), flow rate (V), platoon ratio (Rp), saturation flow rate(S), degree of saturation (V/C), cycle time(c). For present study these parameters are given in Table 4.

9. COMPARISON OF DELAY MODELS

The proposed delay model is more superior to other popular models available in literature as per results shown in Table 5. It is observed that the proposed model yields the best results with an average estimated error of 3.63% followed by the Reilly's method 7.7% error. The HCM 2010, Webster, Arpita Saha and Modified Webster models yield the estimated error of 42.6%, 42%, 38.88% and 13.61% respectively. The superior performance of the proposed delay model is primary governed by the following factors.

- HCM 2010 and Webster's models are developed under homogeneous traffic condition, hence HCM 2010 model's result is over-estimated and Webster model's result is under-estimated in case of long cycle time.
- Arpita Saha's model is developed by modification of HCM 2010; hence on reducing Mean Absolute Percentage Error (MAPE) platoon ratio increases and its results are under estimated for long cycle time with high platoon ratio.
- Reilly and Modified Webster models yield results as considerable Mean Absolute Percentage Error (MAPE) value with over-estimated delay. But Reilly's model is more satisfactory as compared to Modified Webster's model because Reilly's model considered over delay and uniform delay separately.

Based on the above discussion, it is quite clear that the proposed model for heterogeneous traffic conditions is superior to previous models developed for homogeneous and heterogeneous traffic conditions.

Table 5: Comparison of field delay with different type of existing models

Intersections	**Clock Time**	**Observed field delay (sec/veh)**	**Webster's method (sec/veh)**	**HCM 2010 method (sec/veh)**	**Modified Webster's method (sec/veh)**	**Arpita Saha's method (sec/veh)**	**Proposed delay model (sec/veh)**	**Railly's method (sec/veh)**
Dakbanglow chowk	9 am to 11 am	109.082	77.185 (29.24)	160.785 (47.4)	134.105 (23)	73.154 (32.93)	110.42 (1.25)	121.74 (11.6)
	2 pm to 5 pm	115.7565	85.022 (26.55)	176.87 (52.8)	139.85 (20.8)	80.7686 (30.22)	119.44 (3.2)	127.56 (10.2)
Hadtali chowk	9 am to 11 am	99.343	42.513 (57.2)	58.58 (41.03)	100.98 (1.65)	50.258 (49.4)	90.61 (8.8)	93.233 (6.15)
	2 pm to 5 pm	91.032	41.002 (54.95)	64.441 (29.21)	99.248 (9.02)	51.88 (43)	92.24 (1.33)	93.623 (2.85)
Average error			42	42.58	13.61	38.88	3.63	7.7

Note: Figures in parentheses represent mean absolute percentage error (MAPE) in estimation.

10. CONCLUSIONS

Intersection is most common place in a road network for traffic handling in which vehicles have to face significant delay while traveling. There are several models available for estimation of delay at signalized intersections. Among them HCM and Webster's delay models are most popular and widely used. These models are based on homogeneous and lane-based traffic conditions. In India traffic condition are highly heterogeneous with poor lane discipline. In present study these conventional approaches provide results with more error. To address this issue, the present study proposed an improved model for computation of delay at signalized intersections based on platoon ratio. The field delay was based on queue length where queue length was measured in field by Simpson's one third rule with cycle time of five second intervals and area between these gives total field delay in seconds. An individual field delay was obtained by dividing total field delay with total number of vehicles crossing the stop line of traffic signal in an individual cycle time, and delay is represented as seconds/vehicle. Field delay is compared with proposed delay model and different type of existing models. The conventional delay models overestimate or underestimate the delay. This is due to mixed traffic, poor lane discipline, long cycle time, high platoon ratio, and different driving behavior in India.

Despite the superior performance of proposed model, it is expected that overall performance of proposed model will not be affected by the presence of stop line and red-light violation.

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