STOPPED DELAY TO CONTROL DELAY CONVERSION FACTOR FOR NON-LANE BASED HETEROGENEOUS TRAFFIC AT SIGNALIZED INTERSECTION

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ABSTRACT

Majority of the highway capacity manuals consider control delay as the service measure for assessing the operational conditions at signalized intersection. As sophisticated devices are required to measure the control delay from the field, the control delay values are estimated based on the field measured stopped delays. For this purpose, the United States Highway Capacity Manual 2010 (HCM 2010) uses a stopped delay to control delay conversion factor of 1.3. The Indian traffic is characterized by the presence of heterogeneous vehicle type and presence of loose lane discipline. Due to these fundamental differences, the direct applicability of the above value to Indian scenario may be questionable. Through this study, an attempt has been made to estimate the stopped delay to control delay conversion factor for Indian traffic condition. Racelogic VBOX GPS speed data recorder has been used for collecting the vehicle trajectory data. From the study, the stopped delay to control delay conversion factor is obtained as 1.19 for Indian traffic condition. This factor accounts for the acceleration and deceleration of the vehicles while traversing the intersection.

KEYWORDS

Stopped delay, control delay, VBOX, heterogeneous traffic, signalized intersection

1. INTRODUCTION

Level of Service (LOS) is a qualitative term describing the operational efficiency of any traffic facility. For signalized intersections, Highway Capacity Manual uses control delay as the service measure *(1–4)*. Stopped delay is defined as “the time that a vehicle spends for stopping on the approach of the intersection”. The vehicle arrival and departure pattern have a significant influence on the stopped delay. Ko et al. *(5)* stated that stopped delay does not represent the total effectiveness of the intersection. Control delay is defined as the delay caused by traffic control devices. In other words, it is “the difference between the travel time when a vehicle is affected by a traffic control and the travel time of the same vehicle traversing on the intersection without impedance at the desired free flow speed”. It includes stopped delay, time-in-queue delay and the acceleration and deceleration delay *(6, 7)*. As sophisticated devices are required to measure the components of control delay from the field, the control delay values are estimated based on the field measured stopped delays. For this purpose, the Highway Capacity Manual 2010 (HCM 2010) uses a stopped delay to control delay conversion factor of 1.3.

The Indian traffic is characterized by the presence of heterogeneous vehicle type and presence of loose lane discipline *(8)*. The direct applicability of the above value may be questionable because of the difference in the static and dynamic characteristics of the various vehicle types plying on the Indian roads and the difference in driver behavior. Also, previous studies carried out in different countries reported different relationship between stopped delay and control delay. The attempts resulted in significantly different relationships due to numerous reasons such as driver and traffic behavior and some site-specific reasons *(9, 10)*. Hence, through this study, an attempt has been made to estimate the stopped delay to control delay conversion factor for Indian traffic condition.

2. LITERATURE REVIEW

Attempts have been made from 1990's to measure control delay from the field. Ground-based time-lapse photography *(11)*, aerial time-lapse photography *(12)*, video-graphic technique *(13)*, and path tracing *(6, 10)* are some of them. These methods are time-consuming, laborious and costly. In the case of path tracing method, the screen lines are pre-specified and the observers trace the trajectories of the vehicles. The precision of this method depends on the number of screen lines *(5)*.

Through their study, Reilly and Gardner *(7)* found out that there exists a linear relation between the stopped delay and the control delay. Stopped delay was found to be 76 percent of control delay. Many researchers further examined the relationship between stopped delay and control delay. Olszewski *(6)* after studying the trajectory of vehicles found that delay ratio is a function of red time and acceleration-deceleration delay for uniform delay component, whereas for overflow delay component it depends on cycle time and degree of saturation. Data from three intersection approaches in Singapore form the basis of the study. Teply *(14)* found out that the delay ratio cannot be constant.

Quiroga and Bullock *(9)* used GPS receivers to track the vehicle trajectory. The study was conducted at two arterials in Florida. They found out a linear relation between the stopped delay and control delay at signalized intersection and the model is given by

$$stopped\ delay = 0.959\ control\ delay - 19.3 \quad (1)$$

Through a path tracing method using 12 screen lines, Mousa *(10)* attempted to find out the various components of control delay. For measuring the stopped delay, the author assumed a speed difference threshold of 1- 1.5 m/s as the stopping criteria. The developed model is given by

$$stopped\ delay = 0.58\ control\ delay - 2.31 \quad (2)$$

According to Quiroga and Bullock *(9)*, the constant term in the model represents the minimum deceleration and acceleration delay that need to occur before any stopped delay. The higher constant value in Quiroga and Bullock model compared to that of the Mousa model is due to the absence of non-stopped vehicles. Using the GPS speed data, Ko et al. *(5)* tried to measure the various components of control delay. Both the speed profiles and acceleration profiles of the vehicles are used for capturing the control delay components.

3. METHODOLOGY

Delay at signalized intersections were measured by means of Racelogic VBOX speed recorder and video graphic technique. Probe vehicle fitted with the VBOX is allowed to run repeatedly through the study corridor. Figure 1 shows the distance-time plot illustrating the various delay measure. It shows the trajectory of an unimpeded vehicle (moving at free-flow speed) and that of an impeded vehicle (delayed due to the control device). t_1 is the time when the vehicle starts decelerating, L_1 is the position of the vehicle at time t_1, the time interval t_2 to t_3 is the duration for which the vehicle is actually stopped, from t_3 the vehicle starts accelerating, t_4 is the time at which the vehicle crosses the stop line, t_5 is the time at which the vehicle re-accelerated back to the free flow speed and the acceleration ends, L_5 is the position of the vehicle at time t_5. Approach delay is "the horizontal (time) difference between the hypothetical extension of the approaching velocity slope and the departure slope after full acceleration is achieved". Control delay is the delay caused by the control device. The difference between the time taken by the impeded vehicles (due to control device) to cross the intersection and to that of the unimpeded vehicle gives the control delay. Also, the control delay is the summation of deceleration delay, stopped delay and acceleration delay. From Figure 1 stopped delay d_s can be obtained by

$$d_s = t_3 - t_2 \tag{3}$$

and the control delay d_c can be obtained by

$$d_c = t_5 - t_1 - \frac{(L_5 - L_1)}{V_f} \tag{4}$$

where V_f is the free-flow speed.

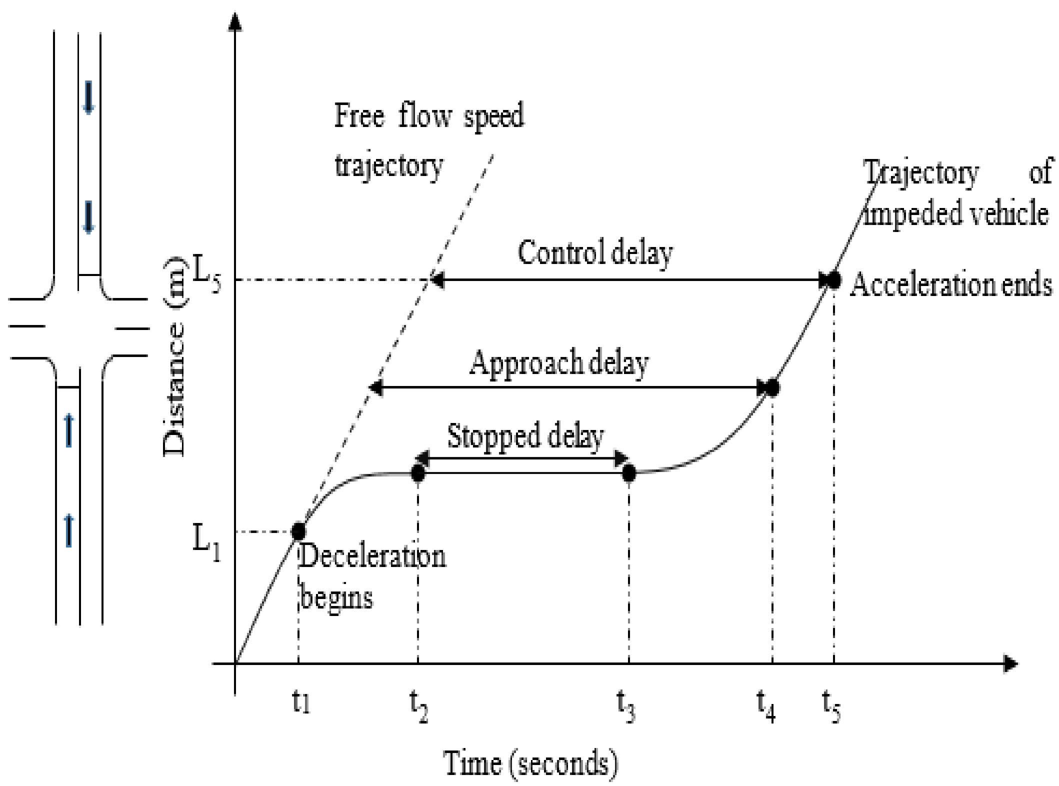

FIGURE 1 Distance-time diagram of a stopped vehicle at the signalized intersection

4. DATA COLLECTION

The study area for the estimation of stopped delay to control delay conversion factor includes three corridors, which covers fifteen signalized intersections within a roadway length of approximately 25 km. The traffic flow on these corridors is highly heterogeneous. Some intersections included in the study are having very good flow characteristics with wide approaches, flared geometry at the stop-line, well-maintained footpaths, and exclusive left-turn lanes. Whereas, traffic flow at some of the intersections are influenced by the pavement conditions, roadside activities and parking. Hence, this data represents the wide variation of traffic characteristics at the intersections prevailing in the Indian context. The probe vehicle was fitted with Racelogic VBOX SL3 20 Hz differential GPS speed data recorder. Approximately thirty runs were made on all the corridors during peak hours and off-peak hours.

5. STOPPED DELAY TO CONTROL DELAY CONVERSION FACTOR

To estimate the stopped delay to control delay conversion factor, the data obtained from the Racelogic VBOX SL3 20 Hz differential GPS speed data recorder was extracted using the VBOXTools software. Figure 2 shows the VBOX software interface. It consists of four windows in which the main window displays the vehicle trajectory for the entire run. The second window which shows the video player provides the information about the actual traffic condition when the survey was performed. The third window, which gives the graph data, provides information on speed, distance, latitude, longitude and number of satellites available at a particular location. The fourth window gives a graph map, which shows the path of the probe vehicle.

Figure 3 shows the speed and acceleration profile of a stopped vehicle at signalized intersection. Most of the previous studies assumed some thresholds for stopped delay. In the present study, there is no need of assuming any thresholds for stopped delay as from the speed and acceleration profile (shown in Figure 3) all the critical points explained in the methodology can be easily identified and extracted. For estimating the conversion factor, speed profile of the vehicle is carefully examined. Whenever there is a reduction in the speed, the trajectory data is crosschecked with the video data to ensure that the speed reduction is only because of the upstream intersection not because of any other obstructions. From the vehicle trajectory, the average speed of the vehicle crossing the intersection is noted down. Although the delay components are measured by manually examining the speed profiles of the vehicle, identifying when vehicles begin to decelerate or stop accelerating is not always a straightforward task. Hence, along with the speed profile, the acceleration-deceleration profile of the vehicle is also looked into. The time when which the vehicle reduces the speed because of the control device (t_1) and the time at which the vehicle regains the average speed (t_5) was noted. The time the vehicle will take to cover the same distance if moving at the average speed is calculated $\left(t = \frac{(L_5 - L_1)}{V_f}\right)$. The time difference ($t_5$-$t_1$) gives the time taken to regain the average speed. The time difference (t_5-t_1)-t gives the control delay. The time for which the vehicle is actually stopped due to the control device, i.e. the stopped delay (t_3-t_2) was also calculated. All the critical points from t_1 to t_5 were extracted for each run at the intersection using the VBOXTools software. The descriptive statistics of the extracted data are given in Table 1. The stopped delay is a function of signal timing, traffic composition and saturation flow *(10)*. Hence, depending upon the arrival of the vehicles with respect to the start of the red signal wide variation in the stopped delay value was observed.

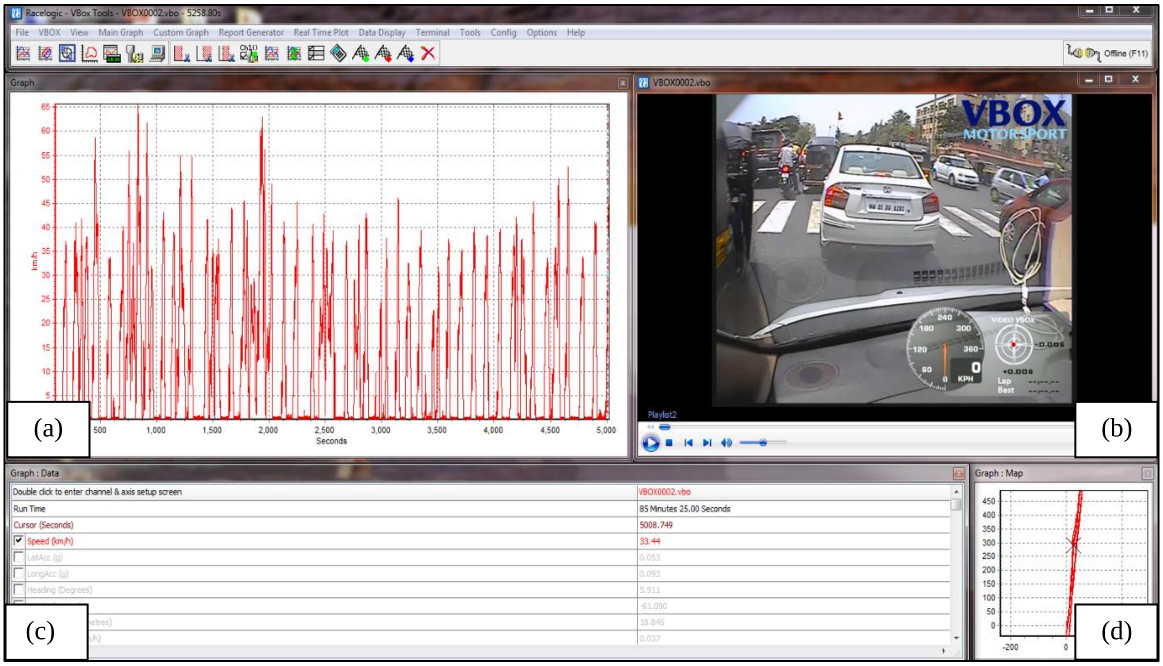

FIGURE 2 (a) Main window displaying speed against time (b) Video player window (c) The graph data (d) Graph map showing the path of vehicle

TABLE 1 Descriptive Statistics of the Stopped Delay and Control Delay Data

	Minimum	**Maximum**	**Mean**	**Standard Deviation**
Stopped delay (sec)	6.84	128.50	50.41	31.99
Control delay (sec)	14.06	139.41	63.82	35.62

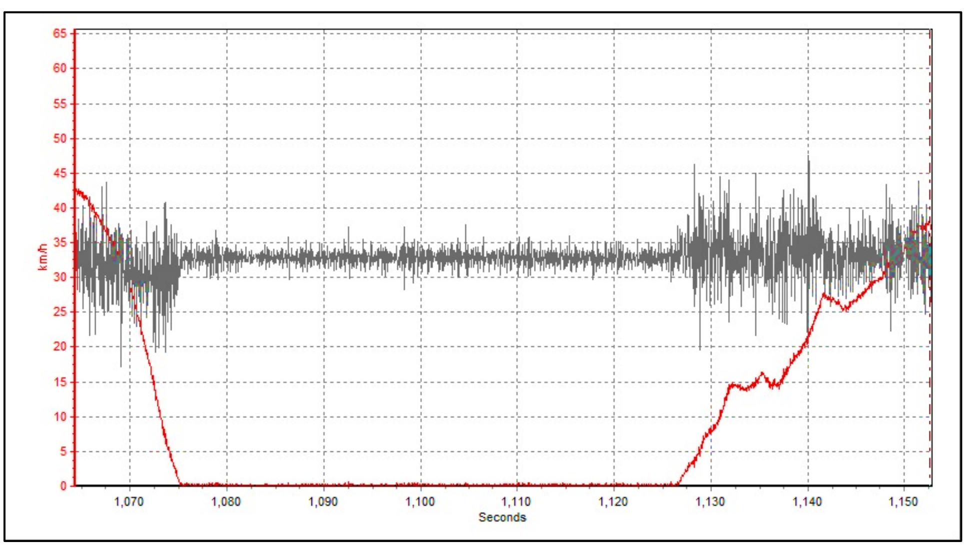

FIGURE 3 Speed and acceleration profile of a stopped vehicle at signalized intersection

Regression analysis was used to establish the relation between the control delay and stopped delay. The regression coefficient gives the stopped delay to control delay conversion factor. The observations with the difference between control delay and stopped delay less than 6 seconds was omitted as these observations pertain to the aggressive driving behavior of high order. The coefficient of determination of the model is 0.93 and the model is statistically significant at 5% significance level (F value - 4570.88, P value – 0.00). The regression coefficient, which is the stopped delay to control delay conversion factor is obtained as 1.19. This indicates that the stopped delay at the study intersections is about 84% of the control delay. Figure 4 shows the correlation between the stopped delay and control delay.

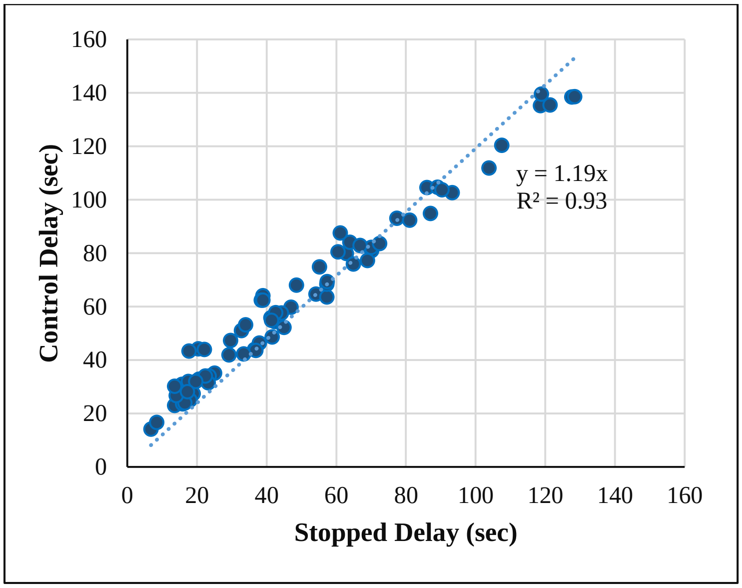

FIGURE 4 Relation between stopped delay and control delay

6. CONCLUSION

Delay is the most commonly used service measure at signalized intersection as it represents the driver's discomfort and frustration. Even though few studies have been carried out to study the relation between stopped delay and control delay, attempts resulted in significantly different relationships due to numerous reasons such as driver and traffic behavior and some site-specific reasons. Hence, the use of HCM recommended value of 1.3 to Indian traffic is questionable. Hence, there is a need for estimating the stopped delay to control delay conversion factor for Indian traffic condition. In view of this, the authors have estimated the relation between the stopped delay and control delay based on the data obtained using VBOX speed data recorder.

From the vehicle trajectory data, the critical points required for the calculation of the stopped delay and control delay are extracted manually. As the critical points are derived from the speed and acceleration profile of the vehicle, no assumption was made for the threshold of stopped delay. Hence, the stopped delay calculated through this study is based on the actual condition observed from the field. Regression analysis was used to establish the relation between the control delay and stopped delay. The stopped delay to control delay conversion factor for Indian traffic condition is obtained as 1.19. Through the study, it was found out that the stopped delay is 84% of the control delay.

The probe vehicle considered in the study for the estimation of stopped delay to control delay conversion factor is medium sized car. As the deceleration-acceleration of the different vehicle type varies, further research can be carried out to see whether the developed relation is applicable to other modes also. Also, the study has been carried out at three-corridors only. The analysis can be carried out for more samples to get robust results.

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