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Estimation of delay at signalized intersections for mixed traffic conditions of a developing country

R. Prasanna Kumar[1], **G. Dhinakaran**[2,*]

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Abstract

Delay is one of the principal measures of performance used to determine the Level of Service (LOS) at signalized intersections and several methods have been widely used to estimate vehicular delay. Very few studies only have been carried out to estimate delay at signalized intersections under mixed traffic conditions prevailing in developing countries like India. In the present study, various problems associated with delay estimation under mixed traffic conditions in a developing country (India) and the methods to over come them were discussed and an attempt was made to improve the accuracy estimating the same. Five isolated signalized intersections from a fast developing industrial city located in TamilNadu, India were chosen for the study. Site specific PCU values were developed considering the static and dynamic characteristics of vehicles. Saturation flow was also directly measured in the field for the prevailing roadway, traffic and signalized conditions and expressed in PCU/h. Control delay was also measured following HCM 2000 guidelines. Later, this was compared with that estimated from the theoretical delay model. Even after taking several measures, good correlation between observed and predicted delay could not be obtained. Therefore, in the present scenario field measured control delay was taken into account to define LOS. A new criteria for Indian cities recently published in the literature was used to assign LOS grades of study intersections and found to be better reflecting the field conditions.

Keywords: *Delay, Signalized intersections, Mixed traffic, PCU, Saturation flow, LOS.*

1. Introduction

The ability to accurately quantify vehicle delays at signalized intersections is a critical component for the planning, design and analysis of signal controls. As a result of random fluctuations in traffic flow and interruptions caused by traffic controls, delays that individual vehicles experience at a signalized approach are often subject to highly stochastic and time-dependant variation. Accurate estimation of the delays of individual vehicles at signalized intersections is also essential for road design [1]. Delay estimation at signalized intersections has been extensively studied in the literature and several methods for estimating vehicle delay at signalized intersections have been widely used. However, it seems that the exploration on the method for estimating the delay is still continuously conducted [2]. In addition to that most of the studies pertaining to delay estimation at signalized intersections were carried out for homogeneous traffic conditions prevailing in several developed countries and a few studies only were made for mixed traffic conditions of developing countries like India. Mixed traffic conditions of India are quite a bit different from that of other countries like China, Malaysia etc. A detailed description of the characteristics and problems associated with mixed traffic conditions prevailing in India have been presented in the subsequent section following literature review. Hence in the present research work an attempt was made to measure control delay at five identified signalized intersections.

2. Review of Literature

William [3] presented a simple and accurate technique for measuring vehicular delay on an approach to a signalized intersection. Precise definitions were established for four measures of performance: stopped delay, time-in-queue delay, approach delay and percentage of vehicles stopping and interrelationships among the four measure of performance were established. Hurdle [4] presented a paper to serve as a

* *Corresponding Author: gd@civil.sastra.edu*
1 Senior Assistant Professor, School of Civil Engineering, Sastra University, Thanjavur, India
2 Professor, School of Civil Engineering, Sastra University, Thanjavur, India

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primer for traffic engineers who are familiar with capacity estimation techniques but have not made much use of delay equations. It was noted that the methods available at that time either ignore the way in which the delay vary with the time or try to cope with the variation in ways that are more mathematical application of common sense than mathematical models of traffic signal system. He found that none of the models examined can be expected to give really consistent and accurate results. To obtain such results, one would not need just better models but better information about traffic patterns. Lin [5] evaluated the reliability of the HCM 1984 procedure, based on field data, and discussed needed modifications. Stopped delay was measured at seven intersections and compared with the HCM estimates of delay. It was found that the procedure tends to overestimate stopped delay at reasonably well-timed signal operations. The discrepancy between the HCM estimates and the observed delays was very large even when correct cycle length and green durations were used as inputs. Teply [6] examined two approaches for measuring delay, a time- space diagram and queuing diagram and explained various problems related to each and concluded that delay cannot be measured precisely. Dowling [7] tested the effect on accuracy of replacing most of the required field input data with the default values recommended by HCM. The average stopped delay was calculated for six signalized intersections. The results indicated that users could obtain reliable estimate of intersection LOS and delay using only field-measured turning movements, lane geometry, and signal timing plus the HCM-recommended defaults for rest of the required input data. Arasan and Jagadeesh [8] have studied the effect of heterogeneity of traffic on delay at signalized intersections from the data collected at three intersections of Chennai city. A probabilistic approach based on first-order second-moment method has been adopted to estimate the saturation flow and the delay caused to traffic, at signalized intersections, under heterogeneous traffic conditions and found that the delay estimated using the probabilistic approach was close to the observed values of delay. Braun and Ivan [9] studied the methods for determining the average stopped delay at signalized intersection. The average stopped delay encountered by vehicles at eight signalized intersections was measured during afternoon peak hour. The average stopped delay is then determined using the equations described in the 1994 version of the HCM. Average stopped delay was also computed using the 1985 HCM equations to identify improvements realized by applying these new techniques. During the field measurement, peak-hour flow rates are determined as well as intersection geometry and signal phasing. Then the stopped delay was calculated using 1985 HCM and the 1994 HCM equations. Error between field measurement and calculated values was examined and some explanations were given for the major difference. Some recommendations were also given concerning use of delay equations. Ko et al. [10] also examined the collection of signalized intersection delay data using vehicles outfitted with global positioning system (GPS) technology. Their technique included algorithms for analyzing speed profiles and acceleration profiles in order to automatically identify critical control delay points, such as deceleration onset points and accelerating ending points. This automated process permits the analysis of large data sets and provides consistent results. However, the approach experienced some difficulty in handling over-capacity conditions and closely spaced intersections.

3. Problems associated with delay estimation under Indian mixed traffic conditions

Mixed traffic systems operate very much differently as compared to homogeneous traffic systems, due to the wide variation in the operating and performance characteristics of the vehicles. The traffic in mixed flow is comprised of fast moving and slow moving vehicles or motorized and non-motorized vehicles. The motorized vehicles include cars, buses, trucks, auto-rickshaws (three-wheelers), scooters, and motorcycles (both two-wheelers); and the non-motorized vehicles include bicycles, human-powered or cycle-rickshaws, and animal-driven carts. The vehicles also vary in size, maneuverability, control, and static and dynamic characteristics. Mixed flow traffic does not move in single files. On the other hand, there is a significant lateral movement by the smaller sized motor vehicles. [11]. At intersections specifically, smaller vehicles use the lateral gaps between larger vehicles in an attempt to reach the head of the queue. In addition to the above mentioned drawbacks, the following are the other stumbling blocks in the accurate estimation of delay.

Saturation Flow (SF), an important input variable in the estimation of delay can not be determined accurately because of large cycle to cycle variations in traffic due to random arrivals, and due to non availability of any proven methodology to address this problem. Secondly there are no default parameters of base saturation flow, lost times established from extensive traffic engineering studies that can be taken in to the estimation of SF. In addition to the above problems in the estimation of SF, another major draw back is reliable values of Passenger Car Units (PCUs) are not readily available that can be used to commonly express SF. Although many researchers have given PCUs for expressing SF and delay under heterogeneous traffic conditions, none of them can be used in all types traffic situations to reliably estimate SF and delay, because these PCUs are subjected to major changes due to wide variations in volume, static and dynamic characteristics of vehicles in non lane based heterogeneous traffic prevailing in a developing country like India.

4. Methodology

4.1.Study Intersections

Five signalized intersections located in an industrially fast developing city located in Tamil Nadu, India were chosen for the present study. All of them are four legged isolated type, provided with pre timed signal control operating in four phases with permitted left turns. These study intersections were selected in such away that they have fair geometry (level gradient on all the approaches) and there is least interference to traffic by pedestrians, bus stops and parked vehicles etc. Average driving behavior was assumed and the condition of vehicles was assumed to be moderate. The traffic is highly

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heterogeneous in nature with poor observance of lane discipline. The composition of traffic consists of a large proportion of motorized two wheelers, a small percentage of auto rickshaws, cars and very smaller proportion of heavy vehicles. Layout of all the five study intersections showing the geometry and signal timings were presented in Figures 1 - 5.

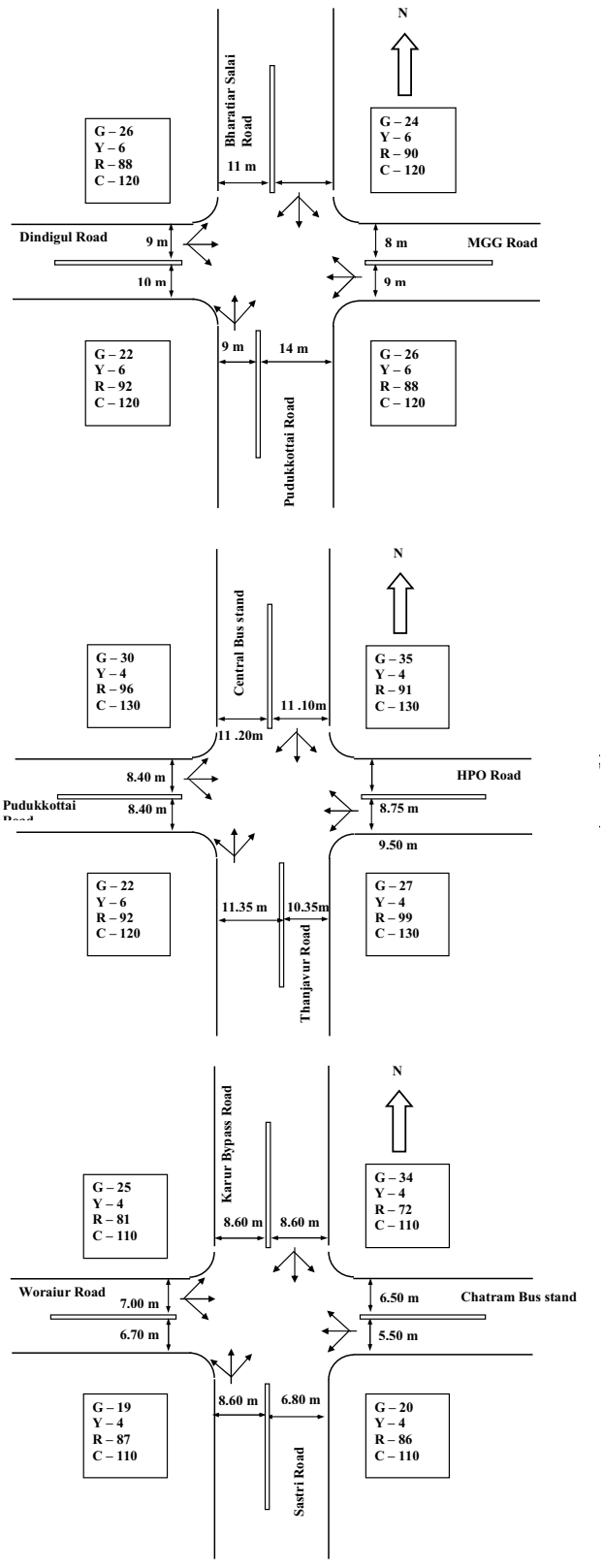

Fig. 1 Layouts of study intersection 1,2 and 3

4.2. Data collection and reduction

Traffic surveys were carried out at all the study intersections. As part of this, turning movement survey was conducted manually on typical week days after posting sufficient number of traffic enumerators to get the classified vehicle count of left turning, straight going and right turning movements and to arrive at the morning and evening peak hours. Later data were collected for the identified peak hours using video recording technique. The video camera was placed at a suitable vantage point near the intersection to record an unobstructed view of all approaches and turning movements. The video tapes were later converted to VCD and played on large screen monitor several times to extract classified volume of traffic, saturation flow, average control delay per vehicle etc.

4.3. Determination of Passenger Car Unit (PCU)

In the analysis of mixed traffic flow at signalized intersections, the knowledge of vehicular interaction when the traffic stream is discharged from the stop line during green phase of signal is critical in determining the capacity of the

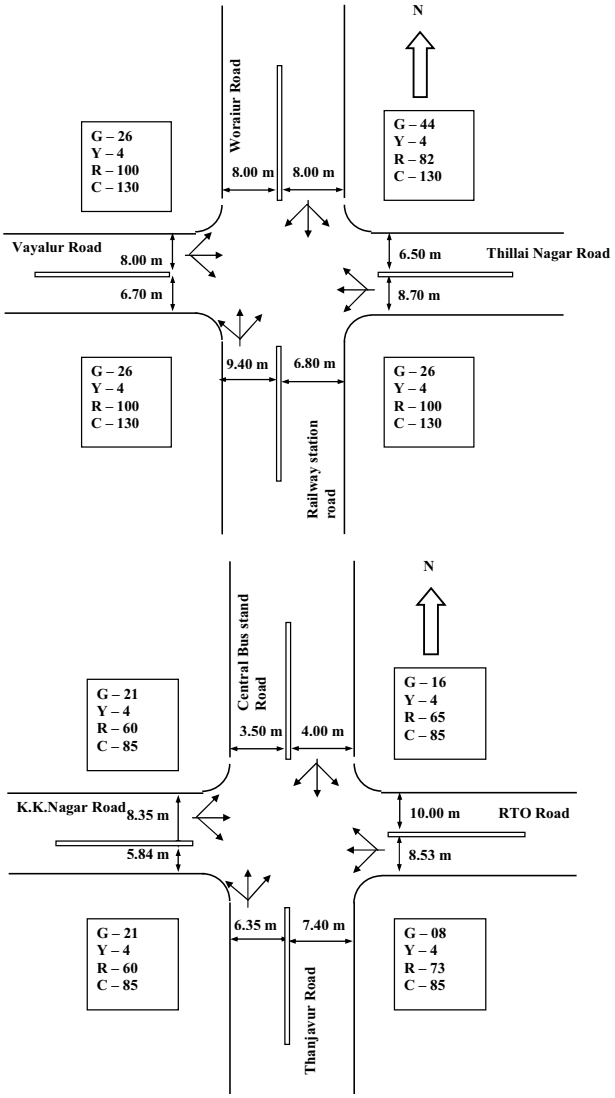

Fig. 2 Layouts of study intersection 4 and 5

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intersection. The change in size and acceleration capability of car will have a major influence on PCU, saturation flow and as a result in delay also [12]. It is a fact that the PCU for a vehicle depends on several factors affecting the traffic stream characteristics. However for a given intersection location some of the parameters such as roadway conditions, control conditions, climatic and environmental conditions remain more or less the same during the analysis period. Hence cycle to cycle variations in terms of composition, volume and stream characteristics must be able to explain the dynamism in the PCU value of different types of vehicles. Although several methods for estimation of PCU at signalized intersections were available, the one developed by Chandra and Kumar [13] (based on speed ratio and space occupancy ratio) was found to give more realistic idea of PCU. Hence in the present study PCU s were developed from the field data using the following equation in order to improve the accuracy of delay estimation.

$$PCUi = \{[Vc/Vi]/ [Ac / Ai]\} = \{[ti/ tc]/ [Ac / Ai]\} \quad (1)$$

Where

PCU_i= Passenger Car Unit of vehicle type *i*

V_c = Average clearing speed of car in m/s

V_i = Average clearing speed of vehicle type i in m/s, which is the speed at which the vehicles traverse the intersection space.

t_c = Average clearing time of car, s

t_i = Average clearing time of vehicle type i in s and Ac and Ai are the projected rectangular area of car and vehicle type *i* respectively

To make the analysis more meaningful all those vehicles having similar characteristics were grouped together. They have been divided into four categories such as car, heavy vehicle, motorized three wheeler and two wheeler having average projected rectangular areas of 5.8 m^2, 23.0 m^2, 3.85 m^2 and 1.44 m2 respectively. [12]

The introduction of several small sized cars of having better speed, acceleration capabilities has resulted in a considerable reduction in the average projected rectangular area of car in the last decade. Previously it was about 7.82 m^2 and now it has been reduced to 5.8 m^2 [12]. Hence it is believed that the PCU values obtained in this analysis yield better results for the present study. The PCU values thus determined at different approaches of study intersections were presented in Table 1. Traffic volumes at the approaches of study intersections during the peak hours were then converted to PCU using the above values. The volumes are thus expressed in PCU/h.

4.4. Saturation Flow

Saturation Flow (SF) is an important traffic performance measure used in the design and control of signalized intersections. SF under mixed traffic conditions is influenced by various factors such as vehicle mix, driver behaviour, public transport, road side activity etc. Therefore to improve the accuracy of delay estimation under mixed traffic conditions these parameters should be estimated based on the local prevailing road way, traffic, signalization conditions and hence require a different approach to the analysis [14]. The following procedure was adopted to measure SF in the field.

4.5. Field Measurement of Saturation Flow

Video recorded data was used to measure saturation flow. The observation point selected was stop line. Digital stopwatch was used to measure the time in seconds. The data was retrieved separately for straight on and right turning traffic streams, by playing the VCD repeatedly. The saturation flow was then measured by making classified count of all the vehicles crossing the stop line, as a continuous group, during the effective green time of a signal phase. The counting was started after three seconds (observed start up lost time) from the start of the green indication. The counting was stopped when the continuity in the flow of vehicles broke (at which point the saturation flow condition ceases). The duration of the green time over which the counting was done and the classified count of vehicles, were recorded in the data sheet. As it was not possible to count all classified vehicles at a time, VCD was replayed a number of times and every time vehicles of one or two types were counted. The same procedure was repeated for each cycle of recorded duration. The traffic flow was then converted into PCU by using the location specific PCU values developed in the study. Saturation green time (T) was divided by the total of different types of vehicles, converted into PCU to get the saturation head way. Saturation flow rate was then determined by dividing the saturation headway into the number of seconds in an hour, to yield units of PCU per hour. The average of 30 observations was taken as the saturation flow rate.

To remove some field data that may reflect some extreme types of driving behavior and consequently bias the estimation results, it was decided to keep only those data points that lie within the range of 2 standard deviations as suggested by Jenish Joseph and Gang-Len Chang [15]. This way, about 5% of the total observed headways have been removed from the original data set. The Saturation Flow thus estimated on all the approaches of study intersections was presented in Table 2.

4.6. Field Measurement of Control Delay

Control delay was measured by the method the suggested in HCM 2000 [16], which is based on direct observation of

Table 1 PCU values at the approaches of study intersections

Name of Intersection	Direction	PCU for			
		Two Wheeler	Auto	Heavy vehicle	Bicycle
Intersection – 1	NS	0.21	0.59	5.86	0.14
	EW	0.21	0.64	5.55	0.15
Intersection – 2	NS	0.22	0.59	5.07	0.19
	EW	0.23	0.64	3.16	0.19
Intersection – 3	NS	0.23	0.60	4.59	0.19
	EW	0.25	0.60	4.59	0.19
Intersection – 4	NS	0.18	0.59	5.55	-
	EW	0.20	0.70	5.60	-
Intersection – 5	NS	0.29	0.60	4.50	0.24
	EW	0.24	0.70	5.15	0.19

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vehicle in queue counts at the intersection. In this method, the number of vehicles in queue is recorded at regular interval of 10 to 20 seconds. This number is then multiplied by the interval length, resulting in total vehicle seconds of delay on the approach over the analysis period. This total is then divided by the total volume of vehicles passed through the approach over the analysis period, resulting in the delay per vehicles at an approach. This value is then multiplied by the correction factor of 0.9 to account for the overestimation of delay by this method. The resultant number is time-in-queue per vehicle. Estimated acceleration/deceleration delay is added to time-in-queue. The resultant delay is control delay for particular approach. By using the above field procedure suggested in HCM 2000, control delay was measured at all the approaches of the five study intersections and presented in Table 2.

4.7. Determination of Control delay from HCM 2000 delay model

The data needed for the estimation of control delay fall into three main categories viz geometric, traffic and signalization. Geometric conditions are factors describing the geometry of intersections such as number of lanes, lane width, grade etc. Green time and cycle length are typical parameters of signalization conditions. All the above-mentioned details of study intersections have been collected as described in the previous sections of this article and the same are shown in the layout drawings from Figures 1 to 5. Traffic conditions include traffic volumes, saturation flow rate, arrival type etc. The methodology of estimating saturation flow under mixed traffic conditions is also explained in section 4.5. The various symbols used in this study are consistent with those in HCM 2000.

The average control delay per vehicle for a given approach is given by the equation

$$d = d_1 PF + d_2 + d_3 \quad (2)$$

In the present study $PF = 1.0$, since all the study intersections are isolated type and d3 is considered as zero as there was no observed queue existing prior to the analysis period. Control delay estimated by HCM 2000 delay model at different approaches of study intersections was given in the Table 2.

4.8.Aggregated Delay Estimation

The above procedure for delay estimation yields control delay per vehicle for each approach. As per HCM 2000 the control delay for the intersection as a whole can be obtained by computing the weighted averages, where the approach delay are weighted by the adjusted flows in the approach. Control delays on the approaches can be aggregated using the Equation 3.

$$di = \sum d_A v_A / \sum v_A \quad (3)$$

Where
d_i = delay per vehicle for the intersection, s/ PCU
d_A = delay for approach A, s/PCU
v_A = Adjusted flow for approach A, PCU/h

Aggregate delay thus calculated for all the study intersections are furnished in Table 2.

Table 2 Saturation flow measured from study intersections

Name of Intersection	Approach	SF* (PCU/h)	Delay As per HCM 2000 Model	Field Delay in s/PCU	Aggregate Delay s/PCU
Intersection – 1	EB	8049	47.29	24.27	23.11
	WB	6128	45.80	22.40	
	NB	5346	43.61	20.16	
	SB	8388	44.51	23.84	
Intersection – 2	EB	5632	45.90	23.27	26.71
	WB	6392	58.18	33.57	
	NB	5489	62.92	24.17	
	SB	6963	43.89	21.38	
Intersection – 3	EB	3986	45.97	19.60	14.64
	WB	4580	45.43	14.82	
	NB	3738	37.59	16.65	
	SB	4801	35.28	20.84	
Intersection – 4	EB	4754	48.87	20.84	22.05
	WB	2329	47.65	19.16	
	NB	4919	52.24	24.66	
	SB	5996	46.69	18.74	
Intersection – 5	EB	4034	43.70	14.28	13.53
	WB	5551	29.21	12.69	
	NB	2055	33.94	13.96	
	SB	965	53.39	12.58	

*SF for the combined straight on and right turning movements of traffic

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5. Level of Service (LOS)

Level of Service (LOS) for signalized intersections in HCM 2000 was defined in terms of average control delay, which is a measure of driver discomfort, frustration, fuel consumption, and increased travel time. Levels of service are defined to represent reasonable ranges in control delay.

HCM 2000 defined LOS criteria for signalized intersections. However from the studies carried out by Bhuyan and Rao [17] on signalized intersections, it was found that intersection delay ranges for LOS categories valid in Indian context are much higher and are approximately two times to those values mentioned in HCM 2000. Hence LOS for the study intersections was assigned according to the above criteria as given in Table 3.

Following the above mentioned criteria study intersections 1, 2 and 4 are operating at LOS "B" with average control delay per intersection 23.11, 26.71 and 22.05s/PCU respectively. Where as the other two intersections namely Intersection 3 and 5 are operating at LOS "A" with average control delay of intersection 14.64 and 13.53 respectively. It is to be mentioned here that for defining the operating LOS of the study intersections the control delay measured from the field was taken as the criteria. As the difference between measured delay and theoretical delay is quite high, one single adjustment factor for the HCM delay procedure cannot be developed as pointed out by Aloysius Tjan and Ria Sujoto [18]. Therefore in the present study theoretical delay was not used for deciding LOS.

6. Conclusions

From analysis of results and observation of traffic characteristics the following conclusions are drawn.

• Selection of an appropriate method of PCU estimation can significantly improve the accuracy of delay calculations.

• SF was measured directly from the field and expressed in PCU /h using the above site specific PCUs obtained for various locations. HCM 2000 assumes that the saturation flow rate begins after the passing of fourth vehicle in the queue. (This is approximately equal to 10 seconds of displayed green time). But for mixed traffic conditions prevailing in Indian cities due to nonobservance of lane discipline and the advantage of size and maneuverability of various small sized vehicles it was found that count for measurement of saturation flow can be started immediately after 3 seconds after the start of green. Also to improve the reliability of SF data points falling outside the range of 2 standard deviations were removed from the analysis.

• Even after taking the measures mentioned above a good correlation between measured delay and delay estimated from HCM 2000 delay model could not be obtained at all the approaches of study intersections. This point also reestablishes the finding of Teply that delay can not be precisely measured and a perfect correlation between observed and predicted delay could not be obtained easily. Therefore in the present scenario it was found that field measured delay can only be taken as criteria for defining the operating LOS of study intersections under the prevailing roadway, traffic and signalization conditions.

• A new LOS criteria for signalized intersections of Indian cities which was found to be more appropriate for Indian cities as per Bhuyan and Rao was used in this study to define LOS. From field observations of prevailing traffic conditions also it was found that the above criteria reflect the true conditions.

Table 3 Delay ranges for LOS categories of signalized intersections

LOS	Control Delay Per vehicle (s/veh)
A	≤ 20
B	> 20-50
C	> 50-80
D	> 80-120
E	> 120-170
F	> 170

Source: Bhuyan and Rao [17]

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References

[1] SU Yuelong, WEI Zheng, CHENG Sihan, YAO Danya, ZHANG Yi , LI Li (2009), "Delay Estimates of Mixed Traffic Flow at Signalized Intersections in China" Tsinghua Science and Technology, Volume 14, Number 2, April 2009.

[2] Yusria Darma, Mohamed Rehan Karim, Jamilah Mohamad and Sulaiman Abdullah," Control Delay Variability at Signalized Intersection based on HCM Method", Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 945 - 958, 2005.

[3] Reilly, W. R. and Gardner, C. C. (1977), "Technique for Measurement of Delay at Intersections" ", Transportation Research Record 644, TRB, National Research Council, Washington, D.C., pp. 1-7.

[4] Hurdle VF, (1984) "Signalized intersection delay models – A primer for the uninitiated", Transportation Research Record 971. pp 96-105.

[5] Lin, Feng-Bor (1989), "Application of 1985 Highway Capacity Manual for Estimating Delay at Signalized Intersections", Transportation Research Record 1225, TRB, National Research Council, Washington, D.C., pp. 18 -23.

[6] Teply, S. (1989), "Accuracy of Delay Surveys at Signalized Intersections", Transportation Research Record 1225, TRB, National Research Council, Washington, D.C., pp. 24-32.

[7] Dowling, R. G. (1994), "Use of Default Parameters for Estimating Signalized Intersection Level of Service", Transportation Research Record 1457, TRB, National Research Council, Washington, D.C., pp. 82-95.

[8] Arasan, T. V. and Jagadish, K. (1995), "Effect of Heterogeneity of Traffic on Delay at Signalized Intersections", Journal of Transportation Engineering, ASCE, Volume 121, No.4.pp. 397-404.

[9] Braun, S. M. and Ivan, J. N. (1996), "Estimating Approach Delay Using 1985 and 1994 Highway Capacity Manual Procedures", Transportation Research Record 1555, TRB, National Research Council, Washington, D.C., pp. 23-32.

[10] Ko J, Hunter M, and Guensler R. Measuring Control Delay

[Downloaded from ijce.iust.ac.ir on 2026-10-16]

Using second-by-Second GPS Speed Data", Transportation Research Board 86th Annual meeting compendium of papers TRB 2007.
[11] Maini P, Khan S. Discharge characteristics of heterogeneous traffic at signalized intersections. Proceedings of fourth International Symposium on Highway Capacity 2000; 258–270.
[12] Chandra, S and Molla, D. (2010), " Change in Vehicular Interaction and Saturation flow at Signalized Intersections over time" Highway Research journal, Indian Roads Congress, New Delhi. Volume 3. No1. Pp.69-76.
[13] Chandra, S and Kumar, U. (2003) "Effect of Lane Width on Capacity under Mixed Traffic Conditions in India", Journal of Transportation engineering ASCE, Volume 129, No.2, pp.155-160.
[14] Md Hadiuzzaman, Md Mizanur Rahman and Md Ahsanul Karim. (2008), "Saturation Flow Model at Signalized Intersection for Non-lane Based Traffic" Canadian Journal of Transportation volume 2, Part 1. pp.78-90
[15] Jenish Joseph and Gang-Len Chang.(2005), " Saturation Flow Rates and Maximum Critical Lane Volumes for Planning Applications in Maryland" Journal of Transportation engineering ASCE, Volume 131, No12. pp.946-952.
[16] Highway Capacity Manual. Transportation Research Board 2000.
[17] Bhuyan, P.K and Krishna Rao, K.V.(2011), "Application of GPS and Clustering Techniques in defining LOS Criteria of Signalized Intersections for Indian Cities" Highway Research journal, Indian Roads Congress, New Delhi. Volume 4. No1. Pp.69-75.
[18] Aloysius Tjan and Ria Sujoto (2008), "Verification of HCM 2000 Delay Equation on a Ideal Signalized Junction in Bandung" (Junction of Asia Afrika And Tamblong) Proceedings of the Eastern Asia Society for Transportation Studies, Vol.4, October, 2003.pp583-595.

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