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Modeling Passenger Car Unit and Delay at Signalized Intersections in Mixed Traffic Conditions

Jatoth Jithender[1], Arpan Mehar[2]

[1]Research Scholar, Transportation division, Civil Engineering Department, NIT, Warangal, Telangana, India, (jatoth.jithender@gmail.com)

[2]Assistant Professor, Transportation division, Civil Engineering Department, NIT, Warangal, Telangana, India, (arpanmehr400@gmail.com)

Abstract

The signalized intersections are essential nodes that directly affect the performance of the whole roadway network. The heterogeneous traffic at approaches signalized intersection makes traffic flow more chaotic. Evaluating the performance of signalized intersections is essential by taking queue length, PCU, delay, and capacity for improving the overall service quality. The guidelines followed in developed countries are not directly applicable in a country like India for practical evaluation of traffic operations. Therefore, it is necessary to analyze performance of intersections by making use of queued vehicles to develop PCU and delay models at signalized intersections in mixed traffic conditions. The present study analyzed queue length and developed a model to estimate PCU values, capacity, and delay by collecting field data from the approaches of signalized intersections in Warangal City using video graphic technic. The statistical distribution was carried out to show the significance of observed queue length, acceleration, and deceleration obtained from the field. Furthermore, new models proposed in the present study were also validated using field data, which confirms the successful validation of the models under mixed traffic conditions. The study recommends evaluating the level of service based on queue length and the proposed delay model at approaches of signalized intersections.

Author Keywords. Queue length, signalized intersection, passenger car unit, delay, mixed traffic.

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1. Introduction

Signalized intersections are the crucial nodes in the urban arterials as their traffic operations affect the overall efficiency of road networks. The quality of services is evaluated by using performance measures of queue length, delay, and capacity. The performance measures are quantified based on correct estimation of demand volume or intersection approaching volume. The quality of service defined for a signalized intersection may give false representation if demand volume is not estimated correctly under heterogeneous traffic conditions, hence traffic volume converted into a common equivalent volume by using passenger car unit of different vehicle types. Using the appropriate value of PCU for a vehicle type provides the correct measurement of traffic volume which employs other performance measures like capacity and delay. Delay is a measure of additional time spent on traversing the intersection, which directly affects the driver's experience. It is the maximum recurrently used amount of efficiency for signalized intersections which openly observed by a driver. The prediction of delay is multifaceted due to unsystematic entrance of vehicles, lost time due to acceleration, deceleration and waiting time of vehicles in the queue, over-saturation flow situations, etc. However, it can be quantified into various ways the maximum recurrently used customs of delay is a control delay at approaches signalized intersection. Control delay is the delay due to a regulator device, either a traffic flow signal or a STOP-sign. This is equivalent to deceleration delay, acceleration delay, and time spent in the queue. The delay can be estimated for individual vehicle type, as a mean of all vehicle types over a particular time period at approaches of a signalized intersection.

2. Literature Review

The heterogeneous traffic with different static and dynamic characteristics consist of various vehicle types in India. The share of the same road and analysis of traffic volume under heterogeneous conditions quite tricky, therefore to analyze the mixed traffic with existing facilities is to be converted from heterogeneous to uniform condition. The common practice to convert the traffic with consideration of various factors is PCU. The Highway Capacity Manual (HCM) presented the idea of PCU, which accounts for the effects of buses and trucks in the traffic flow (Transportation Research Board, 1965). Most of the authors investigated various methods to estimate PCU values by considering different parameters. Some of the popular methods to estimate Passenger Car Unit at approaches of signalized intersections are the delay method (Zhao et al., 2000; Rahman et al. 2003), head ratio technique (Greenshields et al., 1947; Lam, 1994; Molina, 1987; Saha et al., 2009), saturation flow ratio process (Demarchi and Setti, 2003, TRB, 2010) and regression method (Arasan and Jagadeesh, 1995; Branston and Van Zuylen, 1978; Kimber, 1985). The optimization technique (Radhakrishnan and Mathew, 2011) is an additional alternate practice to estimate PCU values by making use of approaching traffic to reduce deviation in maximum saturation flow conditions. The methods used to estimate PCU are considered only a few types of vehicles in the traffic stream. Evaluating headway in non-lane based traffic conditions in emerging nations is difficult, Even though the regression method and optimization techniques used in mixed road traffic conditions. Mohan and Chandra (2017) presented the queue clearance rate technique to estimate PCE at signalized intersections. The queue clearance rate technique was constructed on the real contact, which happens among the vehicles in a queue while dissipating the conflict zone of the intersection. The present study attempts to develop a model for predicting PCU at signalized intersections by involving various factors affecting it under mixed traffic conditions by making use of queued vehicles.

Another most critical parameter is a delay, which cannot be predicted due to the random arrival and served vehicles at approaches of signalized intersections. Influence of numerous parameters such as indecisions and ambiguity, particularly in the mixed traffic conditions. Multiple models are established to estimate the delay at signalized intersections in uniform and stringent lane controlled road traffic (Webster 1958, Miller 1963, Akcelik 1981 and Teply et al. 1995). Among these methods, the maximum used one is Webster's traditional delay formula, which has been introduced in the United Kingdom (UK). The traffic flow condition in India is different from developed nations. The traffic flow is heterogeneous, and vehicles have substantial dissimilarities in physical and dynamic characteristics. At signalized intersections, the lack of lane discipline due to side movement of vehicles and vehicles incline to use adjacent gaps to reach the front of the queue. In these situations, the existing delay estimation technics counting the traditional delay formula mentioned by Webster (1958). Webster (1958) developed the delay formula in uniform traffic situations which will not give accurate prediction if directly applied to mixed traffic conditions. Therefore new models are constructed to estimate delay in mixed traffic conditions. Numerous authors improved

Webster's traditional delay model to include over-saturated traffic flow conditions and developed models for predicting the accurate delay at signalized intersections. Robertson model (Hurdle 1984), Akcelik's model (Roess et al., 2006), and the HCM 2010 model. Later, Arasan and Jagadeesh (1995) applied a probabilistic method to predict the delay due to mixed traffic at signalized intersections. The study mainly focused on through traffic at approaches of signalized intersection. Arasan and Naidu (1999) estimated the average delay under heterogeneous traffic flow conditions. The developed model considered the various factors influencing delays such as green time, saturation flow rate, and cycle length. The developed model overestimated delay values compared with the observed delay obtained from the field. Mousa (2002) developed a model to estimate control delay and stopped delay of vehicles at approaches signalized intersections under heterogeneous traffic conditions. Field data was collected using path tracing approach to obtain speed profiles of individual vehicle types. Darma et al. (2005) estimated the control delay values at signalized intersection, which are influencing it by using SIDRA and TRANSYT-7F soft wares based on HCM methodology. Murat (2006) conducted a comparison of Fuzzy logic and artificial neural network methods to develop delay models. The methods used to estimate delay values in the study compared with observed delay values obtained from the field. Hoque and Imran (2007) researched to modify Webster's delay model under mixed traffic conditions in Bangladesh. The adjustment term was presented to Webster's model under diverse traffic conditions for estimating delay accurately. In this study, the inconsistency of acceleration-deceleration delay was not included while developing the model. Murat et al. (2014) developed the relationship between queue length and control delay. Multiple Linear Regression model designed to assess accurate delay. The study not considered the factor influencing queue length. Hence, the present research developed a new model to estimate control delay with various factors affecting it such as deceleration, waiting time in the queue, acceleration, and the average number of vehicles standing in the queue.

3. Field Data Collection and Extraction

The field data was collected at selected signalized intersections in Warangal City, India. Two four-legged intersections were selected with major and minor stream approaches. The layout and geometry of both intersections are entirely dissimilar. The selected signalized intersections are namely Ku Crossroad junction and Kazipet junction. The Google map view and a snapshot of selected intersection approaches are shown in (**Figure 1**) and (**Figure 2**).

(a) Ku crossroad Junction (b) Kazipet Junction

Figure 1: Google Map View of Approaches of Selected Intersections

(a) Ku crossroad (b) Kazipet

Figure 2: Snapshot of Approaches of Selected Intersections.

The videography method was used to record the operation of traffic from the appropriate vantage point. Video recording was performed for a total of 6 hours at the intersections from 6:00 AM to 9:00 AM and from 3:00 PM to 6: PM, respectively. Recorded data was extracted by playing the video files on a widescreen LED display in the traffic analytics lab. The field queue length was observed at the site in each cycle by noting the number of vehicles joining in the queue at approaches of signalized intersections. A classified volume count was made to measure traffic volume that comprises different vehicle types such as two-wheeler (2w), Three-wheeler (3w), Car, Bus, Light Commercial Vehicle (LCV), and Truck. Field observation was made on geometric and control details of selected intersection such as approach width, cycle length, green time, and red time. The observed field data such as geometric and control details of selected intersection is given in (**Table 1**).

Location	Intersection Name	Approach name	Approach width (m)	Cycle length (s)	Green time (s)
Warangal	kazipet	Hyderabad road	8.5	136	35
		Somidi road	6.0	136	20
		Hanamakonda road	9.0	136	35
		Station road	6.5	136	30
	Ku crossroad	Karimnagar road	12.0	138	32
		Mulugu road	7.5	138	27
		Hanamkonda road	10	138	32
		Hyderabad road	8.5	138	27

Table 1: Geometric and Control Details of the Selected Signalized Intersections

Furthermore, Video graphic method was used for collecting the field control delay with the sum of deceleration delay, time in queue delay, and acceleration delay. The number of counts was made for each vehicle type to obtain average control delay seconds per vehicle at the approach of signalized intersections. Approaching volume, observed control delay, and the average number of vehicles standing in the queue at approaches of selected signalized intersections are given in (**Table 2**).

Intersection Name	Approach name	Average approach volume (Veh/hr)	Observed control delay (Sec/Veh)	Average queue length (Veh)
kazipet	Hyderabad road	2560	110	83
	Somidi road	548	117	36
	Hanamakonda road	2867	121	76
	Station road	765	106	49
Ku crossroad	Karimnagar road	2257	116	42
	Mulugu road	1160	113	40
	Hanamkonda road	2404	126	56
	Hyderabad road	1427	112	47

Table 2: Approaching Traffic Flow, Observed Control Delay, and Queue Length of the Selected Signalized Intersections.

The classified volume count was made for each 15 minutes interval to understand the proportion of different types of approaching vehicles with the variation of their composition covering the peak hour of the weekday. The percentage of vehicle types, as observed in the field locations, is given in (**Figure 3)** and (**Figure 4**).

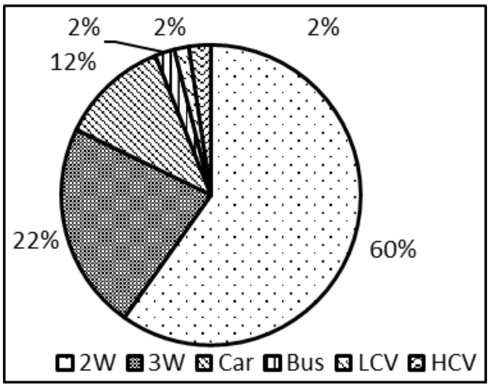

Figure 3: Composition of Vehicle Types at Ku Crossroad

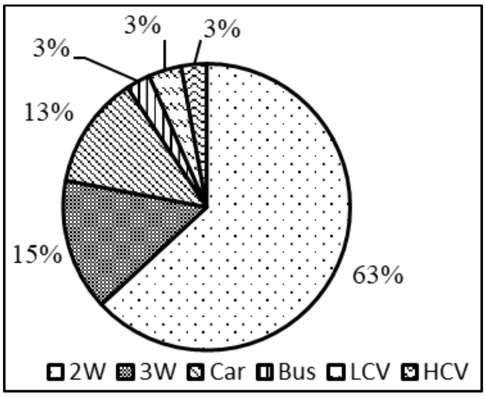

Figure 4: Composition of Vehicle Types at Kazipet

4. Statistical analysis of data

The number of vehicles standing in a queue at the approaches of intersections was observed during each cycle. The distribution of observed queue length was analyzed to understand the queuing behavior. The frequency of queue length was observed on different approaches of selected intersections by selecting appropriate class intervals. The distribution profiles of queue length data as developed for intersection approaches are shown in (**Figure 5)** and (**Figure 6**).

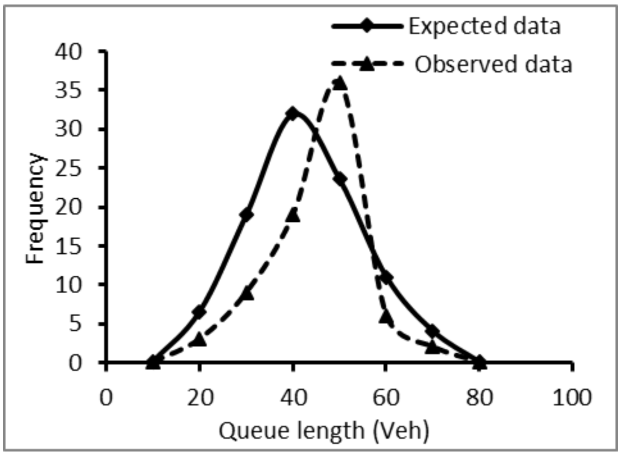

Figure 5: Frequency Analysis at the Approach of Hyderabad Road

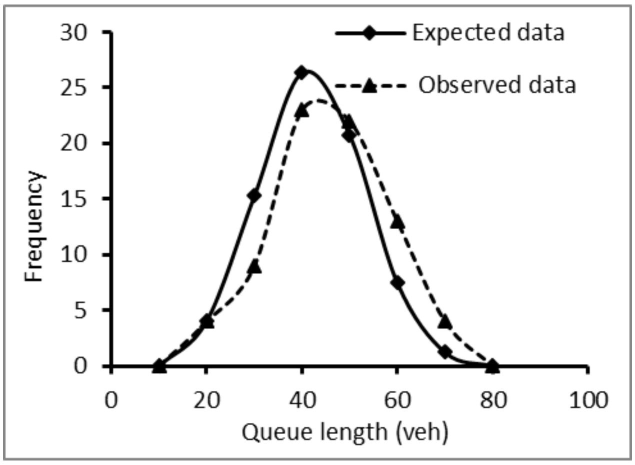

Figure 6: Frequency Analysis at the Approach of Hanamakonda Road

The Chi-Square test was performed at the 5% significance level to check whether the observed data fit a normal distribution. The statistical p- values estimated for each non-parametric test range between 0.505 to 0.970 which showed the distribution of observed queue length at approaches are not conforming with the normal distribution. The percentage of vehicle type two-wheeler varies from 32% to 63% which may also be the reason for affecting the queuing behaviour. The measured queue length obtained from the field at different approaches of selected intersection followed the various type of distribution which is given in (**Table 3**).

Distribution type	Intersection name							
	kazipet				Ku crossroad			
	Hyderabad road	Somidi road	Hanamakonda road	Station road	Karimnagar road	Mulugu road	Hanamkonda road	Hyderabad road
Beta4							Beta4	
Fisher-Tipp	Fisher-Tipp	Fisher-Tipp						
GEV					GEV			
Poisson						Poisson		
Gamma			Gamma					Gamma
Wei bull				Wei bull				
p-value	0.790	0.676	0.970	0.521	0.899	0.995	0.505	0.539

Table 3: Distribution Analysis of the Selected Signalized Intersections

Furthermore, a graphical representation of five-number summary for measured queue length is analyzed to understand the operation of traffic flow. The graphical profiles of queue length data at approaches of selected intersections are shown in (**Figure 7**) and (**Figure 8**).

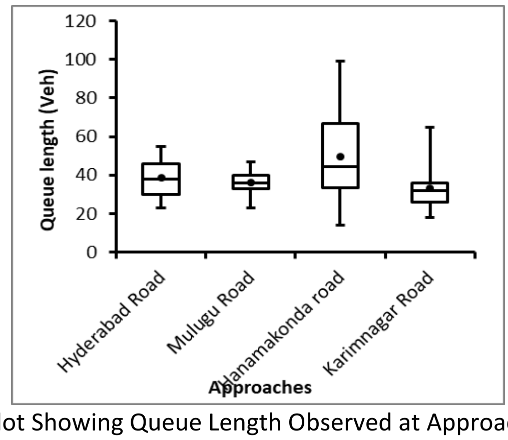

Figure 7: Box Plot Showing Queue Length Observed at Approaches of Selected Ku Crossroad Intersection

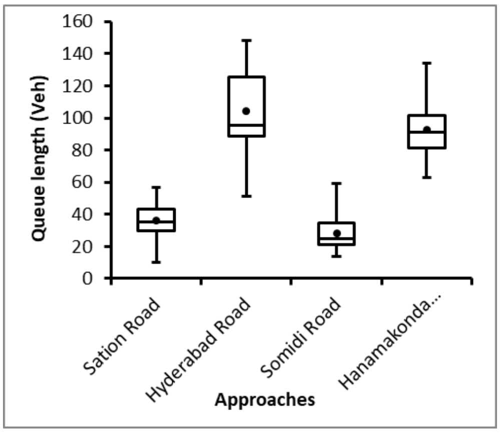

Figure 8: Box Plot Showing Queue Length Observed at Approaches of Selected Kazipet Intersection

5. Acceleration and deceleration analysis

The number of vehicles joining in a queue at the approaches of intersections observed during each cycle at 70-100 meters away from the stop line. The entire stretch is divided into appropriate known class intervals. The time taken to cross each interval noted down during each cycle with classified vehicle types. Later, with known distance and time, acceleration and deceleration of vehicle types are calculated. The distribution of observed acceleration and deceleration is analyzed to understand the behavior of vehicle types. Chi-Square test performed at the 5% significance level to check whether the observed data fit a normal distribution. The statistical p- values estimated for each non-parametric test range between 0.056 to 0.882, which showed the distribution of acceleration and deceleration calculated at the approaches, are not conforming to normal distribution. The measured acceleration and deceleration obtained from the field at different approaches of selected intersections are followed the various type of distribution, which are given in (**Table 4**).

Distribution type	**Acceleration**					**Deceleration**				
	2w	3w	Car	LCV	HCV/Bus	2w	3w	Car	LCV	HCV/Bus
Beta4	Beta4	Beta4	Beta4	Beta4	Beta4	Beta4	Beta4		Beta4	
Logistic								Logistic		
Normal										Normal
p-value	0.192	0.761	0.522	0.882	0.442	0.056	0.389	0.328	0.132	0.329

Table 4: acceleration and deceleration distribution analysis of the selected signalized intersections

6. Estimation of PCU

The number of vehicles in the queue during the start of red time to the end of red time was observed during a signal cycle length at every approach of signalized intersections. Vehicle types dimensions are considered for developing a model to estimate PCU values. The different vehicle types dimensions and the ratio of average longitudinal standstill distance to average lateral standstill distance of vehicle types also found which are shown in (**Table 5**).

Vehicle types	**Average longitudinal standstill distance (m)**	**Average lateral standstill distance (m)**	**Length (m)**
2w	0.4	0.55	1.20
3w	0.54	0.6	4.48
Car	0.7	0.65	5.36
LCV	1.4	0.67	12.81
HCV	1.65	0.75	29.52
Bus	1.5	0.69	24.54

Table 5: Measured Longitudinal Standstill Distance, Lateral Standstill Distance, and the Length of Vehicle Types Details at Approaches of Selected Signalized Intersections

The measured queue length, longitudinal standstill distance, and lateral standstill distance are shown in(**Figure 9**).

(a) measured queue length (b) standstill distance measuerd

Figure 9: Measured (a) Queue Length, and (b) Standstill Distance of Selected Approaches of Intersections

The PCU of vehicle type is given in the following equation 1.

$$\text{PCU of vehicle category i} = \left(\frac{Qi}{Q}+\frac{Wi}{WC}\right) *\left[\left(\frac{Dl}{Dt}\right)\right]i \quad (1)$$

Where Qi is the number of ith type vehicles in the queue, Q is the total number of vehicles present in the queue, Wi is the width of ith vehicle type, Wc is the width of the standard car, Dl is the average longitudinal standstill distance of the ith vehicle, Dt is the average lateral standstill distance of the ith vehicle.

A brief comparison of model PCU values obtained in the present study and other popular technic estimated PCU values are given in (**Table 6**).

Vehicle Type	2w	3w	car	L.C.V	H.C.V/ Buses
Model PCU values	0.6	0.8	1	2.2	3.8
IRC SP 41 PCU values	0.5	0.5	1	1.5	3
INDO HCM PCU values	0.4	0.5	1	1.1	1.6

Table 6: Comparison of Proposed Model PCU Values and Other Popular Methods

7. Estimation of capacity

The capacity at approach of signalized intersection is calculated based on INDO-HCM (2017) methodology. According to INDO-HCM capacity is calculated based on green time, cycle length, and saturation flow rate. The saturation flow rate is estimated based on the INDO-HCM saturation flow rate equation given in the manual, which uses only approach width as an influencing variable. The field saturation flow rate was observed at each 5 seconds interval during the green time. Later, the saturation flow rate converted from vehicles per hour to PCU per hour by taking PCU values of INDO-HCM and the proposed model. INDO-HCM capacity compared with a field capacity of estimated PCU values from the proposed model and INDO-HCM are given in (**Table 7**).

Intersection name	Name of the approach	INDO-HCM (2017) Capacity (PCU/hr)	Field Capacity with INDO-HCM PCU values (PCU/hr)	Field Capacity with model PCU values (PCU/hr)
kazipet	Hyderabad road	1331	810	994
	Mandi road	787	229	287
	Hanamakonda road	1297	964	1274
	Station raod	1191	445	540
Ku crossroad	Karimnagar road	1241	816	1042
	Mulugu road	954	494	509
	Hanamkonda road	876	780	799
	Hyderabad road	1056	509	529

Table 7: Comparison of Estimated Capacity with the Outcome of the Proposed Model and INDO-HCM PCU Values

PCU values estimated in the present study using the proposed model are given significant results for calculating the field capacity. The filed capacity calculated from INDO-HCM PCU values underestimating compared to INDO-HCM capacity.

8. Modeling control delay

The various factors influencing control delay are analyzed based on using the field data collected from the intersection approaches I, II, III, IV, and V. The several factors such as queue length, acceleration, deceleration, traffic volume, and effective red time are analyzed to check their correlation with field observed control delay. The factors stated above are found to be influencing the control delay measured in the field are given in (**Table 8**), and those are further used for developing a multi regression model of control delay.

Intersection Name	Approach name	Approach ID Number	Observed delay Sec /veh	Average acceleration (m/s2)	Average deceleration (m/s2)	Red time (sec)
kazipet	Hyderabad road	I	110	0.40	0.56	96
	Somidi road	II	117	0.25	0.54	112
	Hanamakonda road	III	121	0.44	0.68	96
	Station road	IV	106	0.27	0.51	102
Ku crossroad	Karimnagar road	V	116	0.13	0.46	104
	Mulugu road	VI	113	0.54	0.71	108
	Hanamkonda road	VII	126	0.58	0.73	104
	Hyderabad road	VIII	112	0.19	0.45	108

Table 8: Parameters Influencing on Control Delay

After many trials, the best-fit model is proposed, which provides a very accurate estimation of average control delay seconds per vehicle for the given approach of intersection. The proposed model for estimating control delay is given in equation (2)

$$d = 55.55 + 0.03\times Q - 71.39\times Ac + 135.05\times Dc + 0.04\times R \qquad R2=0.784 \qquad (\mathbf{2})$$

Where, d= average control delay seconds per vehicle Q= queue length (veh), Ac = acceleration (m/s2), Dc= deceleration (m/s2), R= Red Time (sec).

9. Validation of model

Validation is a necessary stage in modeling which denotes the amount at which the model conforming to an actual system. The models in the present study calibrated with 70% of the data and validated with remain 30% of the data. The relationship for estimating control delay, as developed in the present study, was tested and validated with field data collected on three other approaches such as VI, VII, and VIII. Average control delay was estimated using Equation (2) based on the inputs from field data. A 45-degree line chart is used for validation of the model to represent it graphically. The validation chart constructed with a 45-degree line is shown in (**Figure 10**). The statistical Chi-square test was conducted at 5% significant level to compare two average control delays estimates a p-value of 0.901, which is found to be greater than 0.05 that showed a successful validation of the model developed in the present study.

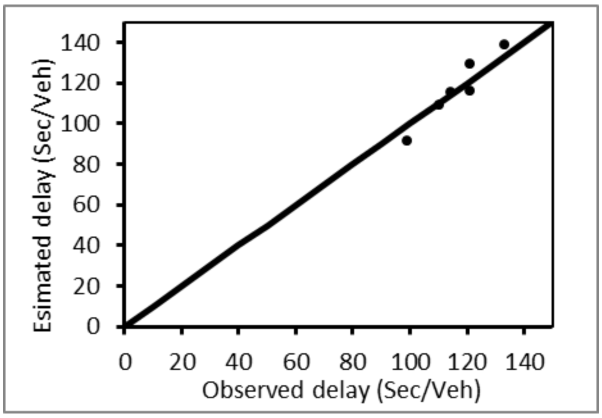

Figure 10: Validation of Proposed Control Delay Model

Furthermore, the proposed model control delay values compared with outcomes popular methods such as HCM (2010) and IND-HCM (2017). The statistical techniques Mean Absolute Percentage Error (MAPE) (Equation 4) and Percentage error (Equation 5) are used to compare the results of estimated control delays from different methods and observed control delay.

$$MAPE = \frac{1}{n} \left| \frac{Y_{\exp} - Y_{pred}}{Y_{pred}} \right| \times 100 \quad (3)$$

$$PercentageError = \frac{(Y_{pred} - Y_{\exp})}{Y_{\exp}} \quad (4)$$

Where, Yexp=field observed delay values, Ypred= model estimated values, n= number of observations.

The comparison between estimated control delay and observed control delay is given in (**Table 9**).

Intersection Name	Approach name	Approach ID Number	Observed control delay (Sec /veh)	Control delay INDO-HCM (2017) (Sec /Veh)	Control delay HCM (2010) (Sec /Veh)	Model control delay (Sec /veh)
Ku crossroad	Mulugu road	VI	113	138	168	110
	Hanamkonda road	VII	126	135	183	129
	Hyderabad road	VIII	112	129	162	114

Table 9: Comparison Between Estimated Control Delay and Observed Control Delay

Both the methodology of HCM (2010) and IND-HCM (2017) are overestimating the control delay values as compared to observed control delay. The delays estimated in the present study using the proposed model are closer to the observed delay obtained from the field. Hence, the present study may helpful for evaluating the level of service at approaches of signalized intersections.

10. Conclusions

The new models are developed in the present study for estimating Passenger Car Unit and delays by making the use of queued vehicles at approach of signalized intersections. The control delay model developed in the present study showed close relation with observed delay values obtained from the field compared to HCM and Indo HCM delay values. Both HCM and Indo HCM delay models are overestimating the delay values under heterogeneous traffic conditions due to considering a single acceleration and deceleration factor irrespective of the speed range. Models proposed in the present study are successfully validated using statistical evidence. The results of the present study also compared with the outcomes of other popular methods and filed observed values, hence the present study showed the significance of the proposed models. The study recommends evaluating the level of service based on queue length and the proposed delay model at approaches of signalized intersections. The present study is limited to four-legged intersections by taking only two numbers of intersections. Therefore it can be extended to three-legged intersections by taking more number of intersections to capture the actual conditions from the field.

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