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Modelling Of Vehicular Delays In Mixed Traffic Situations At Signalized Intersections

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Abstract:

Vehicular delay is a measure of effectiveness or performance of signalized intersection making it essential to estimate. Delay is defined as an extra time spent by drivers against their expectation in a trip. Under homogeneous traffic and lane discipline conditions, conventional approaches to estimate delay such as Highway Capacity Manual delay model (USA), Webster's Delay model (UK) can be adopted. But for developing countries like India, where it is heterogeneous and no lane discipline conditions, other different sets of delay models are as Indo – HCM and Arpita delay model can be used to estimate delay. In this paper, three signalized intersections from Hyderabad city i.e. Kingkoti, Bachupally, and Miyapur were considered. *Delay from different models are being estimated. From correlation matrix, important independent parameters were obtained in order to develop a model (R^2 = 0.82) which helps in predicting the realistic delay values under heterogeneous and no lane discipline condition.*

Keywords: Vehicular Delay, HCM Model, Indo-HCM Model, Heterogenous Conditions, Signalized Intersections.

Introduction:

Handling the heterogeneous traffic is a difficult task for traffic engineers. Increase in traffic, lack of proper management of road traffic and lane discipline contributes to vehicular delay at signalized intersections. The term signalization refers to the installation of traffic signals from various approaches at intersections to control traffic movements. The different signalizing strategies are pre-timed, semi actuated and fully actuated. In a pre-timed signalization, after a fixed time space, a pre-defined signal period length repeats every approach in turn. Properly designed traffic signals enhance road safety and also reduce the delay of drivers by regularly providing vehicle traffic through various approaches and reducing the overall time spent by vehicles through intersections.Delay means the loss of time for a traveller during a crossing. It depends on different parameters such as vehicle composition, geometry of intersection, driver's behaviour, type of vehicles and space availability in terms of headway. Stopped delay, queue delay, acceleration–deceleration delay, and total delay. Efficiency and quality of traffic operation at signal-controlled intersections are assessed by vehicular delay.

Literature Review:

For signalized intersections, two methods are popular for measuring delay which are HCM model and Webster's delay models which are applicable for the countries like US, UK where they follow lane discipline and traffic is having homogenous in nature. But, Countries like India having heterogenous traffic conditions and lane discipline is very poor. Kumar and Dhinakaran (2013) [1], developed a model by considering field delay and defined LOS based on delay. Few researchers (kim and Benekohal (2005) [9], Kumar and Dhinakaran (2013) [1], Chaudhary and Ranjitkar (2013) [10]). Dion et al. (2004) [11] had observed that, when v/c ratio was approaching 0.7, difference in the estimated and field delay also started increasing. As we discussed earlier, webster's delay model was formulated for lane-based conditions so Raval and Gundaliya (2012) had modified Webster's model for non-lane model. Chaudhary and Ranjitkar (2013) [10], Arpita (2016) [7] found that webster delay model is overestimating delay. Indo – HCM can be used to estimate the delay for Indian traffic conditions which was developed by Central Road Research Institute (CRRI), New Delhi in the year 2017 as it is developed for non-lane-based discipline.

Methodology:

Data Collection & Extraction:

Study Locations:

Three study locations were selected for this study are signalized intersections in Hyderabad, Telangana, India. The three locations are Kingkoti Cross-roads, Bachupally cross roads, and Miyapur cross roads. Bachupally and Kingkoti cross roads were four legged and two lane each on each leg intersections, whereas Miyapur is of three-legged intersection, having 4 lanes on two legs and 5 lanes on one leg.

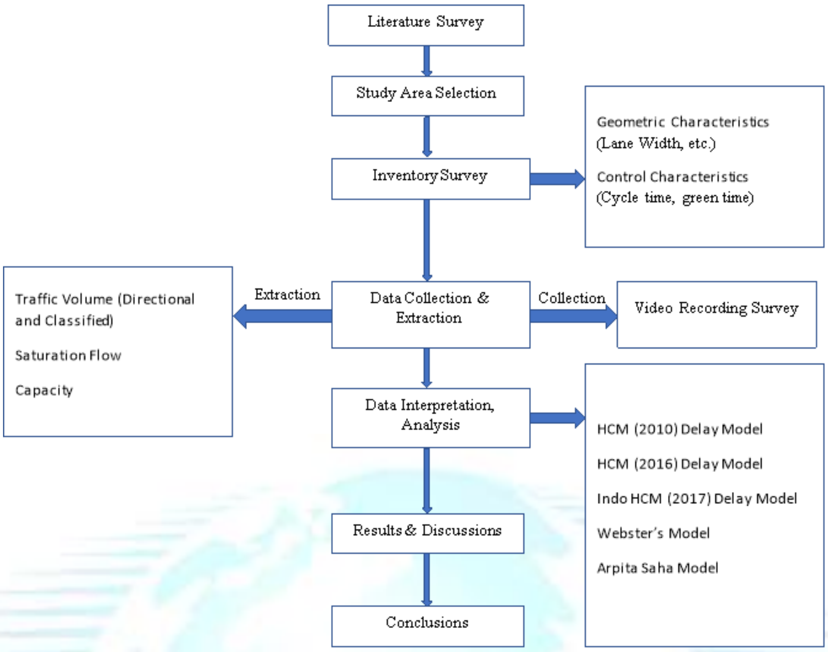

Fig 1: Pictorial Representation of Methodology adopted

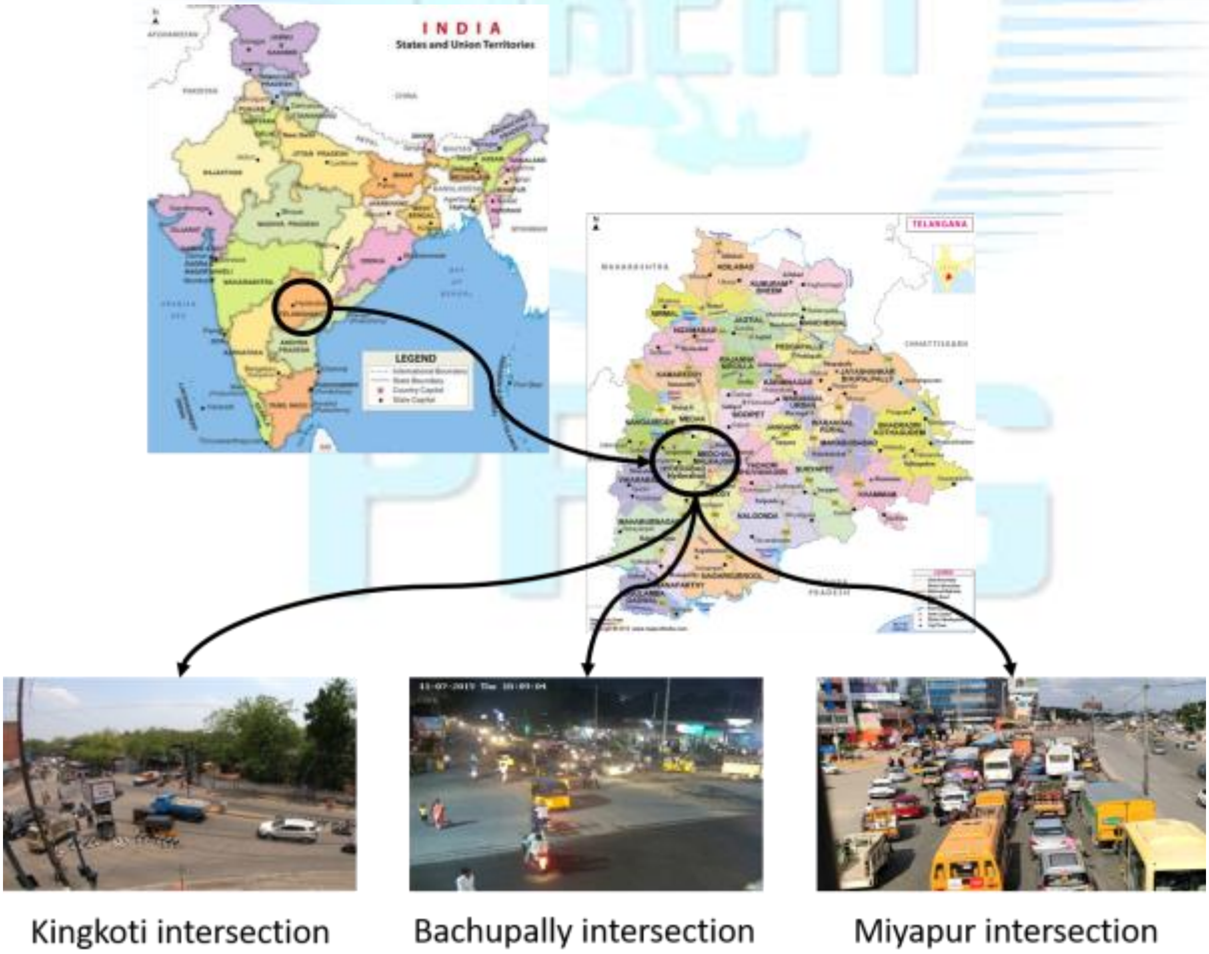

Fig 2: Elevated view of study locations

Parameters Considered are:

Parameters considered for the study are categorized below:

1) **Road Features**
    a. Number of lanes
    a. Approach Width
2) **Traffic Signal Features**
    a. Type of signal (Pretimed)
    a. Cycle Length
    b. Red, Amber and Green Lengths
3) **Traffic Features**
    a. Traffic volume along with directional and classified volumes
    a. Number of vehicles crossing green internal.

3.3 Estimation of parameters:

The estimation of required parameters like saturation flow, capacity is below:

a) Saturation Flow:

$$S = \frac{N}{g_e} \times 3600 \qquad \text{Eqn. 1}$$

where, S= saturation flow in (veh/hr) of green, g_e= effective green time (sec), N = number of vehicles crossing stop line during effective green time.

b) Saturation Flow (Indo – HCM):

$$USF = \begin{cases} 630; & w < 7.0m \\ 1140 - 60 * w; & 7.0 \leq w \geq 10.5\ m \\ 500; & w > 10.5\ m \end{cases} \qquad \text{Eqn. 2}$$

$$SF = w * USF \qquad \text{Eqn. 3}$$

USF = Unit base saturation flow rate (PCU/hr), w = effective width of approach (m), SF = Prevailing saturation flow

c) Capacity:

$$c = n \times S \times \left(\frac{g_e}{C}\right) \qquad \text{Eqn. 4}$$

Where, c = capacity (veh/hr), C = cycle time (secs), g_e= effective green time (secs), n = No. of lanes

Intersection Inventory:

Geometrical Characteristics: The approach width of each location is shown in Table 1

Table 1: Geometrical Characteristics of each location

Intersection	**Approach Width (m)**			
Direction	**North**	**East**	**West**	**South**
KingKoti Crossroads	8.8	7.3	7.33	5.75
Bachupally Cross Roads	9	8	7	7
Miyapur Cross Roads	10	16.25	15.6	-

Control Characteristics: The Table 2 depicts about the cycle time (secs), total green time (secs), effective green time (secs) and no of observed cycles(Nos) at each location.

Table 2: Control Characteristics of each location

Intersection	Cycle Time (Secs)	Total Green Time (Secs)				Effective Green Time (Secs) (Acceleration Lost Time : 2 Secs) (Deceleration Lost Time: 2 Secs)				No. of Observed Cycles
Direction	-	**North**	**East**	**West**	**South**	**North**	**East**	**West**	**South**	-
KingKoti Crossroads	126	25	50	15	30	21	46	11	26	168
g/C	-	-	-	-	-	0.167	0.365	0.087	0.206	-
Bachupally Cross Roads	169	36	48	48	39	32	44	44	35	126
g/C	-	-	-	-	-	0.189	0.260	0.260	0.207	-
Miyapur Cross Roads	252	90	88	70	-	86	84	66	-	84
g/C	-	-	-	-	-	0.341	0.333	0.261	-	-

PCU Values considered in study:
Table 3 indicates the passenger car unit value for different classes of vehicles as per Indo – HCM 2017 Manual.

Table 3: Passenger Car Unit Value for each Type of Vehicle

Category of Vehicle	Passenger Car Unit Value
Bike (2W)	0.4
Auto (3W)	0.5
Car (4W)	1
Bus	1.6
Truck	1.6

Directional Peak Traffic Volume, Capacity, Saturation Flow, X= v/c:
Table 4 indicates the directional peak traffic volume (veh/hr) , capacity (veh/hr), saturation flow (veh/hr) and X (volume/capacity ratio) for each location.

Table 4: Directional Peak Traffic Volume, Capacity, Saturation Flow, X= v/C

Intersection	Volume (Veh's/hr)				Saturation Flow (Veh's/hr)				Capacity (Veh's/hr)				X = v/c			
Direction	**N**	**E**	**W**	**S**	**N**	**E**	**W**	**S**	**N**	**E**	**W**	**S**	**N**	**E**	**W**	**S**
KingKoti Crossroads	506	1560	288	546	2235	2314	2326	1876	745	1690	406	774	0.68	0.92	0.71	0.71
Bachupally Cross Roads	931	1288	1404	1149	3857	3534	3525	4193	1461	1840	1940	1737	0.64	0.7	0.72	0.66
Miyapur Cross Roads	2788	2714	3479	-	5427	5327	7508	-	5556	5327	5899	-	0.5	0.51	0.59	-

3.7 Compositions of Vehicles (%):
Table 5 indicates the compositions of the vehicles(bike, auto, car , bus and truck) for each location.

Table 5: Compositions of Vehicles (%)

Intersection	Kingkoti Intersection					Bachupally Intersection					Miyapur Intersection				
Direction	**Bike**	**Auto**	**Car**	**Bus**	**Truck**	**Bike**	**Auto**	**Car**	**Bus**	**Truck**	**Bike**	**Auto**	**Car**	**Bus**	**Truck**
North	61	8	26	3	2	55	12	22	0	11	36	7	42	9	6

East	56	16	22	4	2	57	15	19	2	8	45	5	37	8	5
West	56	10	28	2	3	60	6	14	2	18	37	7	41	7	7
South	61	13	18	5	2	51	16	22	8	3					

Data Analysis:

Level of service of a signalized intersection is analysed based on the delay experienced by a vehicle. Delay can either be measured by observing the waiting time of a vehicle directly, or by comparing the travel times.

Highway Capacity Manual Model (2016):

The HCM 2016 model (TRB 2016) estimates the average control delay per vehicle (dc):

$$d_c = d_1(PF) + d_2 + d_3 \qquad \text{Eqn. 5}$$

$$d_1 = PF * \frac{0.5*C*(1-\frac{g}{C})^2}{1-[\min(1,X)*\frac{g}{C}]} \qquad \text{Eqn. 6}$$

$$PF = \frac{1-P}{1-\frac{g}{C}} * \frac{1-y}{1-\min(1,X)*P} * [1 + y * \frac{1-P*\frac{C}{g}}{1-\frac{g}{C}}] \qquad \text{Eqn. 7}$$

$$y = \min(1,X) * \frac{g}{C} \qquad \text{Eqn. 8}$$

$$d_2 = 900 * T * [(X_A - 1) + \sqrt{(X_A - 1)^2 + \frac{8*k*l*X_A}{c_A*T}} \qquad \text{Eqn. 9}$$

$$X_A = \frac{v}{c_A} \qquad \text{Eqn. 10}$$

Where, d = control delay (s/veh), d_1 = uniform delay assuming that arrivals are uniform (s/veh), d_2 = incremental delay that arrivals are random and oversaturation (s/veh) assuming no initial queues at the beginning of the analysis period, d_3 = initial queue delay (s/veh), PF = Progression Adjustment Factor, Y = flow ratio, P = Proportion of vehicles arriving during the green interval, C = Cycle Length (Secs), g = Effective green time (Secs)

Highway Capacity Manual Model (2010):

The HCM 2010 model (TRB 2010) estimates the average control delay per vehicle (dc):

$$d_c = d_1(f_{pf}) + d_2 + d_3 \qquad \text{Eqn. 11}$$

$$d_1 = \frac{0.5*C*(1-\frac{g}{C})^2}{1-[\min(1,X)*\frac{g}{C}]} \qquad \text{Eqn. 12}$$

$$f_{pf} = \frac{(1-P)f_P}{1-\frac{g}{C}} \qquad \text{Eqn. 13}$$

$$d_2 = 900 * T * [(X_A - 1) + \sqrt{(X_A - 1)^2 + \frac{8*k*l*X_A}{c_A*T}} \qquad \text{Eqn. 14}$$

$$X_A = \frac{v}{c_A} \qquad \text{Eqn. 15}$$

Where, d = control delay (s/veh), d_1 = uniform delay assuming that arrivals are uniform (s/veh), d_2 = incremental delay that arrivals are random and oversaturation (s/veh) assuming no initial queues at the beginning of the analysis period, d_3 = initial queue delay (s/veh), f_{pf} = adjustment factor in coordination systems for the effect of progression quality, f_p=progression adjustment factor, C = Cycle Length (Secs), g = Effective green time (Secs)

Indo - Highway Capacity Manual Model (2017):

The Indo - HCM 2017 model (CRRI 2017) estimates the average control delay per vehicle (d):

$$d = 0.9 * d_1 + d_2 + d_3 \qquad \text{Eqn. 16}$$

$$d_1 = 0.5 * C * \frac{(1-\frac{g}{CY_{TIme}})^2}{(1-\min(X,1)*\frac{g}{CY_{TIme}})} \qquad \text{Eqn. 17}$$

$$d_2 = 900 * T * \left[(X-1) + \sqrt{(X-1)^2 + \frac{4*X}{c_{SI}*T}} \right] \qquad \text{Eqn. 18}$$

Where,

d = Control delay, (sec/PCU), g = effective green time (in Secs), CY_Time = Overall cycle time (in Secs), T = Analysis Period (in Hours), X = Degree of saturation, C_{SI} = Capacity of the candidate signalized intersection (in PCU/hr)

Webster's Delay Model:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2v(1-X)} - 0.65 * \left(\frac{c}{v^2}\right)^{\frac{1}{3}} * X^{2+5\lambda} \qquad \text{Eqn. 19}$$

Where, d= average delay per vehicle on the approach (s/veh), g = effective green time (Secs), C = Cycle time (Secs), v = flow (veh/s), λ = proportion of cycle which is effectively green for the phase under construction, X = degree of saturation, S = saturation flow (Veh/s)

Field Delay (HCM Method):

Field delays are determined through the implementation of vehicles in queue counts at fixed intervals and the preparation of formulas and correction factor applications as per the HCM 2010 worksheet.

Delay estimated as,

$$d = d_{vq} + d_{ad} \qquad \text{Eqn. 20}$$

d = control delay per vehicle; d_{vq} = time in queue per vehicle and d_{ad} = acceleration / deceleration correction delay.

$$d_{vq} = 0.9 * \left(I_s * \frac{\Sigma V_{iq}}{V_{Tot}} \right) \qquad \text{Eqn. 21}$$

I_s = survey count interval (s); ΣV_{iq} = total vehicle in queue and V_{tot} = total vehicles arriving.

$$d_{ad} = FVS * CF \qquad \text{Eqn. 22}$$

$$FVS = \frac{V_{stop}}{V_{Tot}} \qquad \text{Eqn. 23}$$

Vstop = stopped vehicles count; Vtot = total vehicles arriving and CF = acceleration / deceleration correction factor (HCM 2016).

Table 6 indicates the summary of different delay models for individual approach at Kingkoti Intersection

Table 6: Different delay models for each approach at Kingkoti Intersection

Models	**KingKoti Intersection**			
	East	**South**	**West**	**North**
Field Delay	19.64	8.74	13.42	11.459
HCM 2016	37.765	21.264	27.161	22.150
Webster's	38.309	46.444	55.948	49.336
HCM 2010	38.139	23.523	29.146	23.094
Indo HCM 2017	29.127	41.234	51.596	42.916
Arpita Saha	21.898	5.054	-29.336	-2.6871

Table 7 indicates the summary of different delay models for individual approach at Bachupally Intersection

Table 7: Different delay models for each approach at Bachupally Intersection

Models	**Bachupally Intersection**			
	West	**East**	**South**	**North**
Field Delay	22.567	20.134	14.555	10.445
HCM 2016	25.645	23.816	21.026	19.310
Webster's	56.961	56.531	61.558	63.150
HCM 2010	27.079	25.277	23.502	20.413
Indo HCM 2017	55.16	51.356	61.610	59.433
Arpita Saha	24.004	22.464	16.015	11.298

Table 8 indicates the summary of different delay models for individual approach at Miyapur Intersection

Table 8: Different delay models for each approach at Miyapur Intersection

Models	**Miyapur Intersection**		
	West	**North**	**East**
Field Delay	50.23	36.427	39.324
HCM 2016	48.185	33.477	35.172
Webster's	81.183	65.972	67.456
HCM 2010	49.997	35.78	37.243
Indo HCM 2017	76.711	63.69	59.351
Arpita Saha	54.435	41.734	43.012

Correlation Matrix:

Table 9 indicates the correlation coefficients between the variables, correlation matrix is used to summarize the data.

Table 9: Correlation Matrix for the developed model

	Field Delay	Proportion of vehicles in green interval (P)	*LOG.VOLUME (V)*	*LOG.CAPACITY (c)*	*g/C*	*NO.OF LANES*
Field Delay	1					
Proportion of vehicles in green interval (P)	-0.69	1.00				
LOG.VOLUME (V)	0.86	-0.71	1.00			
LOG.CAPACITY (C)	-0.89	0.62	0.90	1.00		
g/C	0.58	-0.67	0.80	0.75	1.00	
NO.OF LANES	0.92	-0.57	0.73	0.82	0.52	1.00

From the above table, it is clearly understood that the values between ±0.5 to ±1.00 are strongly correlated, ± 0.30 to ± 0.40 is moderately correlated and below ± 0.30 is low correlated. It is clearly understood that all the variables are having strong correlation and hence consider for development of model.

Model Development:

Linear Regression model was developed using R Software by taking field delay as dependent variable and Proportion of vehicles during green interval (P), vehicular volume, capacity, g/C Ratio, number of lanes as independent variables. The R-Squared of the developed model is 0.82 and observed standard error as 3.01.

The Developed Model based on Field delay:

Field Delay = -54.24 – 0.176 (P) + 58.58 (Log. Volume) – 37.20 (Log.Capacity) -42.38 (g/C) + 11.77 (No. of Lanes)

Eqn. 24

Results and Discussions:

The following are the results from the study:

Table 10: Aggregated Intersection delay values for 3 locations.

Models	**Kingkoti Intersection**		**Bachupally Intersection**		**Miyapur Intersection**	
	Delay (Sec/Veh)	**LOS**	**Delay (Sec/Veh)**	**LOS**	**Delay (Sec/Veh)**	**LOS**
Field Delay	15.545	A	17.616	A	42.649	C
HCM 2016	30.8806	B	22.8032	B	39.6867	D
Webster	43.5164	-	59.1593	-	72.3128	-
HCM 2010	31.869	B	24.4308	B	41.729	D
Indo HCM 2017	36.0439 (Sec/PCU)	C	56.5199 (Sec/PCU)	C	67.4228 (Sec/PCU)	D
Arpita Saha	9.34893	A	19.1859	B	47.0402	C

Conclusions:

Following conclusions are drawn from

1. As the PF (Multiplicative Factor) value is included in the HCM 2016 model, the delay is improved in comparison with HCM 2010. (As flow ratio is considered in calculation in PF)
2. Arpita saha delay model is seem to be more realistic when compared to other models. (For Moderate to High Volume Roads)
3. For low volume intersections, Arpita saha delay model underestimates the control delay.
4. Webster and Indo-HCM models are overestimating the delay as there is no PF involved.

5. Field delay can be easily calculated from the developed model using Proportion of vehicles during green interval (P), Vehicular Volume, Capacity, g/C Ratio, Number of Lanes, as these parameters are easy to extract compared to field delay calculation from HCM Method.

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