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Development of Delay Model at Intersections - A Case Study of Ahmedabad City

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***Abstract*- Delay is the one of the most vital design criteria utilized for performance evaluation of signalized intersections. It plays a vital role in planning, designing and control of signalized intersections. The accurate measurement of delay at intersections is of prime importance when determining the LOS of the road. In pre-timed control, vehicle delays can be minimized or reduced by proper design of signal timings and phasing. Vehicle delays incorporate numerous parameters, for example, signal timing, number of phases, vehicle headways, saturation flow, queuing etc. Among these parameters vehicle queue is formed by unbalanced signal timings or unexpected demand values. On the other hand, composition of vehicles can be effective on queue forming especially in discharging case. This paper discusses the estimation of stopped type of delay at Memco and Pakwan intersections of Ahmedabad city, the commercial capital of Gujarat state. The delay is calculated by counting the number of vehicles in queue during the red time. Models are developed for the calculation of delay considering the composition of vehicles, road width, cycle time, green time and red time. Many researchers have also developed models for estimation of delay for homogeneous condition of traffic, so those values do not match with field data. The developed models give the values near to the observed values. It can be used for the heterogeneous traffic condition.**

I. INTRODUCTION

The growth of traffic congestion in the road network of vast urban communities in developing countries like India is a serious concern from the point of view of traffic engineers. The congestion at the junctions is mostly crucial because the performance of junctions affects the performance and productivity of the whole road network significantly. To reduce conflicts and ensure orderly movement of traffic at the urban intersections, it is a common practice to introduce fixed time traffic signals at uncontrolled or priority controlled or traffic police controlled intersections if the conditions warrant their choice. There are a number of criteria to assess the performance and level of service of signalized intersections among which delay is used most widely. The reason is that the meaning of delay is generally well understood and drivers can experience it directly.

The urban roads of India carry the heterogeneous traffic which is the combination of various vehicles like Cars, Buses, Trucks, Motor cycles, Light commercial vehicles, Heavy commercial vehicles, Auto rickshaw etc. As per the Highway Capacity Manual, delay is defined as the difference between the travel time actually experienced and the reference travel time that would result during ideal conditions.

II REVIEW OF LITERATURE

Webster's Delay Model (1958), He developed a model for homogeneous traffic conditions of European countries. The model developed by Webster in 1958 is the basic delay model for signalized intersections. Webster assumes that arrivals are random and departure headways are uniform, and his expression is as follows:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{1/3} x^{(2+5\lambda)} \quad (1.1)$$

Where,

d = Average delay per vehicle on the particular approach of the intersection,
c = Cycle length,
q = Flow,
λ = Proportion of the cycle which is effectively green for the phase under consideration and
x = Degree of saturation (volume to capacity ratio).

HCM Delay Model (2010), The control delay for a given lane group can be calculated by:

$$d = d1+d2+d3 \quad (1.2)$$

$$d_1 = \frac{0.5c(1-(g/c))^2}{1-[Min(1,X)(g/c)]} \quad (1.3)$$

$$d_2 = 900T[(X-1)+\sqrt{(X-1)^2+\frac{8klX}{cT}}] \quad (1.4)$$

Where,
d = control delay, s/veh,
d1 = uniform delay component, s/veh,
d2 = overflow delay component, s/veh,
d3 = delay due to pre-existing queue, s/veh,
T = analysis period, h,
X = v/c ratio,
C = cycle length, s,
k = incremental delay factor for actuated controller settings; 0.50 for all pre-timed controllers,
l for upstream filtering/metering adjustment factor;
1.0 for all individual intersection analyses,
c = capacity, veh/h,
P = proportion of vehicles arriving during the green interval and
fp = supplemental adjustment factor for platoon arriving during the green.

Varia, H.R. (1995) published a research paper on "Optimization of Signal Cycle Time and its Implication on Delay and other Operational Parameters". Optimum Signal cycle time was designed to reduce the overall delay. It was an attempt to measure the delay for different cycle times by various methods. The results show that overall delay is lesser for shorter cycle length. Stopped delay reduces at higher departure volumes for longer green intervals, as delay is distributed over more non stopped vehicles. For the same cycle length, delay decreases with the increase in g/c ratio on a particular arm of intersection. Similarly for same green time in different cycle lengths, delay decreases with increase in g/c ratio. Reduction in delay depends more on effective green time than g/c ratio when volume capacity to ratio is more than 0.7. Stopped delay reduces at higher departure volumes for longer green intervals., For $X<0.9$, observed delay is closer to the results of Webster's Delay. However Akcelic's model gives a result closer to the observed delay even for $X>1$. Akclik's formula can be used for delay estimation in Indian conditions.

N.G. Raval & P. J. Gundaliya (2012) proposed "Modification of Webster's delay formula using modified saturation flow model for non-lane based heterogeneous traffic condition."The Webster's formula is unsuitable for heterogeneous non lane based mixed traffic. The first & second terms in the formula are theoretical and the third term is empirical. The third term in Webster's Equation is empirical adjustment factor which was given for UK conditions. Webster's classical delay formula is modified, so that it can be used in the non-lane based heterogeneous traffic condition of Indian cities. Regression analysis was used for relationship and statistical tests were applied. It is observed that proportion of two-wheelers is more in the traffic, so it is included in the adjustment factor in the delay's formula. The mathematical form of the model was,

$$7.82Q+0.057c+7.5x+3.98\lambda+2.35tw-25.55 \quad (1.5)$$

Where,
adj = Adjustment term for the model;
Q = Vehicle arrival rate (PCU/sec);
c = Cycle time is seconds;
x = Degree of Saturation;
λ = Effective green ratio;
tw = Percentage two-wheelers.
The statistical analysis was carried out for validation.

Yetis Sazi Murata et.al. (2013) published a research paper on "Investigation of Cyclic Vehicle Queue and Delay Relationship for Isolated Signalized Intersections". The relationship of cyclic vehicle queue and vehicular delay was investigated considering different signal timings and phase sequencing. The MuLReD (Multiple Linear Regression Analysis based Delay Estimation) model was developed and significance of the model is proved by statistically.

$$D = -0.260-0.919b+1.17c+1.113d+0.651e \quad (1.6)$$

As a result of comparisons, Mean Square Error (MSE) values for Akcelik Equation and the MuLReD Model were determined as about 112 and 7 respectively. It was also concluded that, Average Entering Time, Red Time, Number of Vehicles in Queue, Average Discharging Headway are N the most effective parameters on vehicle delays.It was concluded MuLReD model can be used as a reliable estimation model for vehicle delays at isolated signalized intersections.

III OBJECTIVE OF STUDY

Following are the objectives of the research:

- To estimate the delay under heterogeneous conditions in the study area.
- To study the effect of vehicle composition, cycle length and signal timings on delay.
- To develop a linear regression model for delay.
- To compare the observed delays with the delays obtained from different models.

- To validate the developed model using statistics.

IV. METHOD FOR MEASURING DELAY

A. Field Measurement of Stopped Delay

The simplest method of measuring traffic volumes is by means of counts made by observers stationed at roadside. The survey should begin at the start of the red indication associated with the subject lane group and, ideally, when no initial queue is present. If the survey period does start with an initial queue present, then these queued vehicles need to be excluded from subsequent queue counts. The stopped vehicles need to be counted for every 15 or 20 seconds interval (composition wise).With the data observations, the data should be summed by column, added and multiplied by the sampling interval to yield an estimate of total stopped delay (veh-sec). If this value is divided by the total discharged vehicles during that time, then it gives stopped delay per vehicle.

V. DATA COLLECTION

Traffic surveys were conducted to collect data on delay along with vehicular composition at the selected intersections. Inventory surveys were conducted for gathering primary information regarding road geometry including road width, number of lanes, lane marking, medians, service lane etc. The surveys were conducted on normal working days during morning and evening peak hours where the delay at the intersections is maximum.

TABLE1
OBSERVED DELAY AT MEMCO INTERSECTION DURING MORNING AND EVENING PEAK HOURS

Morning Peak Hours			
Approach	Cycle Time (seconds)	Green Time (includes amber time) (seconds)	Delay (seconds/ vehicle)
Naroda	186	72	80
Memco	186	39	94
Over bridge	186	36	84
Bapunagar	186	39	92
Average delay per vehicle			87.5
Evening Peak Hours			
Naroda	175	62	73
Memco	175	42	70
edover bridge	175	34	87
Bapunagar	175	37	77
Average delay per vehicle			76.8

TABLE2
OBSERVED DELAY AT PAKWAN INTERSECTION DURING MORNING AND EVENING PEAK HOURS

Morning Peak Hours			
Approach	Cycle Time (seconds)	Green Time (includes amber time) (seconds)	Delay (seconds/ vehicle)
Thaltej	240	80	78
Vastrapur	240	45	89
Bopal	240	40	97
Iscon	240	75	86
Average delay per vehicle			87.5
Evening Peak Hours			
Thaltej	230	75	91
Vastrapur	230	35	100
Bopal	230	40	91
Iscon	230	80	90
Average delay per vehicle			93

VI. COMPOSITION OF VEHICULAR TRAFFIC

A. Pakwan Intersection

Following vehicles composition is observed during morning and evening peak period for the Pakwan intersection. Traffic composition is presented in the form of pie chart.

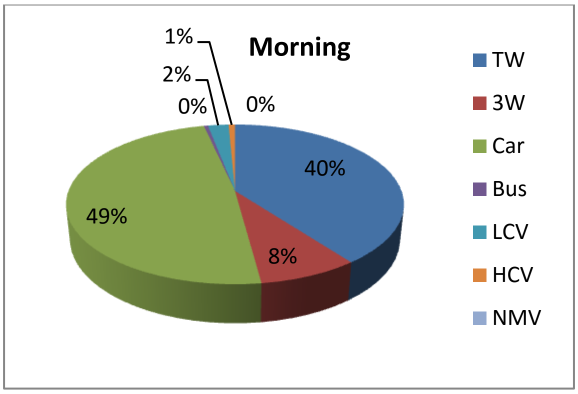

Fig.1 Average traffic composition at Pakwan intersection (morning peak hours)

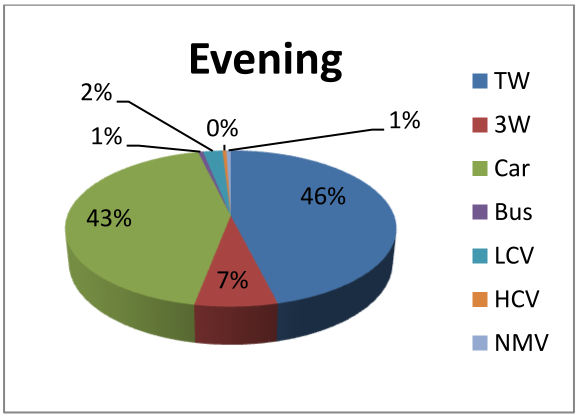

Fig.2 Average traffic composition at Pakwan intersection (evening peak hours)

From fig 1 and fig2, it is observed that about 43% vehicles are cars and 46% vehicles are two wheelers. It also affects delay at the intersection.

B. Memco Intersection

Following vehicles composition is observed during morning and evening peak period for the Memco intersection. Traffic composition is present in the form of pie chart.

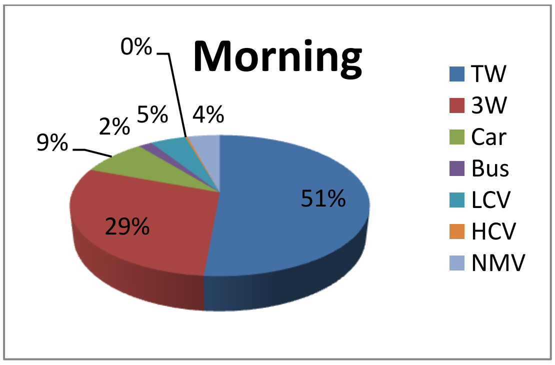

Fig.3 Average traffic composition at Memco intersection (morning peak hours)

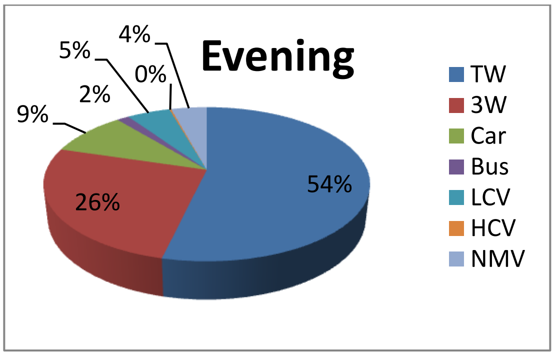

Fig.4 Average traffic composition at Memco intersection (evening peak hours)

From fig 3 and fig 4, it is observed that about 54% vehicles are two wheelers and 26% vehicles auto. It also affects delay at the intersection.

VII. DEVELOPMENT OF MODEL

A. MODEL 1:

Delay Model 1 is developed considering Traffic Composition, Approach width and Red Time.

D = 0.25 RT - 0.45W – 237B + 82CAR + 122A + 26TW

Where,

D = Delay in sec/veh

RT = Red time in seconds;

W = Width of approach;

TW = Proportion of two-wheeler in percentage;

A = Proportion of auto rickshaw in percentage;

CAR = Proportion of car in percentage;

B = Proportion of Bus in percentage;

R square Value = 0.997

B.MODEL 2

Delay Model 2 is developed considering Red time and Road width

D = 0.55RT-0.99W

Where,

D = Delay in seconds/veh;

RT = Red time (seconds);

W = Width of road in m;

R square Value = 0.992

C.MODEL3

Delay Model 3 is developed considering Green Ratio, Vehicle Composition and Road Width

D = -42GR – 192B + 134CAR + 159A + 67TW – 0.32W

Where,

D = Delay in seconds/veh;

GR = Green Ratio;

B = Proportion of Bus in percentage;

CAR= Proportion of car in percentage;

A = Proportion of auto rickshaw in percentage;

TW = Proportion of two-wheeler in percentage;

W = Width of road in m;

R square Value = 0.997

VIII. CONCLUSIONeS

Followings are the major conclusions of study

- It is observed that delay is more due to longer cycle time. Also if the proportion of green allotted to a particular approach is less, vehicles have to stand in queue for a longer period of time as the Red time increases. So, the stopped delay increases in such case.
- For the same cycle length, delay decreases with the increase in g/c ratio on a particular leg of the intersection. Similarly for the same green time in different cycle lengths, delay decreases with increase in g/c ratio.
- Mathematical models are developed for calculation of delay under heterogeneous conditions of Indian traffic using multiple linear regressions.
- Model1 can be used to determine the delay if road width, traffic composition and red time are known. It shows good correlation with the observed delay.
- Model2 can be used to determine the delay if road width and red time are known. It shows good correlation with observed delay.
- Model3 gives good correlation with the observed delay. It considers the effect of Green Ratio (g/c) ratio, Road width and traffic composition to determine the stopped delay.

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