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DELAY MODELLING AT URBAN UNCONTROLLED INTERSECTIONS

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Abstract : *Modelling traffic flow through urban uncontrolled intersections in developing countries like India is a complex process because of the high level heterogeneity of traffic and absence of major and minor concepts in traffic regulation schemes. Moreover, Indian codes have not been provided any relation which can be used to directly determine the delay at uncontrolled intersections under Indian traffic conditions.*

Uncontrolled intersections are vital points on urban roads, the performance of which will influence the traffic flow on entire network. Delays to vehicles at urban uncontrolled intersections depend upon the several factors, the most important among these being major road approach volume, type of turning movement, and vehicular composition. The average delay caused to vehicles is an important measure to evaluate the performance of uncontrolled intersections. The performance of an uncontrolled intersection is described by the service delay experienced by low priority movements. Under mixed traffic conditions, the traffic compositions, apart from the conflicting traffic volume and proportion of turning traffic are vital factors influencing the service delay. Most of the earlier studies conducted on this subject, pertain to homogeneous traffic environment, and only a few studies with limited scope have been conducted under mixed traffic conditions. In this study, the service delay models have been developed for three uncontrolled intersections located in the city. These models developed were found to be statistically and logically sound. The level of service for the uncontrolled intersections taken under the study has been evaluated using the estimated average service delays from the models developed

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Keywords: *Delay time, Vehicles, Intersection, Traffic Management*

1. INTRODUCTION

Uncontrolled intersections are the intersections which function without any priority assigned to the traffic on any of the intersecting roads, no control (neither STOP signs nor Police-controlled) and the traffic is of heterogeneous nature. These intersections are vital nodal points on urban roads, the performance of which will influence the traffic flow on entire network. Delays to vehicles at urban uncontrolled intersections depend on several factors. The most important among these being the major road approach volume, type of turning movement, and vehicular composition. The extent of intersection of these factors and their collective effect on delay caused to vehicles need to be studied in detailed for better traffic management at these intersections. Field studies due to resources constraint may not include all these, the limited samples that might be obtained will be sufficient to evaluate the effect of various parameters.

At uncontrolled intersections in the absence of indication of specific time intervals to each of the streams of traffic to cross the intersection, the drivers look for gaps and cross the intersections. In developing countries like India, in the absence of the concept of major and minor roads in traffic regulation schemes, vehicles approaching the intersections through all roads, on arrival; assume that equal right to enter the intersection. This has made the traffic situation at the uncontrolled intersection highly complex causing considerable delay to traffic. The delay experienced by vehicles is probably most desirable criteria based on which the performance of the uncontrolled intersection can be evaluated.

The present study was taken up with the following objectives:

1. To establish mathematical relations for service delay to the different types of vehicles for a priority movement at uncontrolled intersections

2. To develop the readily usable mathematical model, to estimate the service delay caused to the subject vehicles at urban uncontrolled intersections, considering interactions of various categories of vehicles under heterogeneous traffic environment.

3. To evaluate the performance of uncontrolled intersections based on the average service delay.

2. LITERATURE REVIEW

Unsignalized intersections make up a great majority of at-grade junctions in any street system. Stop and yield signs are used to assign the right-of-way, but drivers have to use their judgment to select gaps in the major street flow to execute crossings and turn movements at two-way and yield controlled intersections. Two methods are discussed in this section: HCM (2000) Delay method and Blunden's (1961) method.

2.1 HCM (2000) Delay method

The Highway Capacity Manual (HCM) 2000 (TRB, 2000) delay model, is one of the most commonly used time dependent delay models. HCM method involves the calculation of gap times – critical gap and follow-up times.

Critical gap is defined as the minimum time interval in the major-street traffic stream that allows intersection entry for one minor-street vehicle.

$$t_{c,x} = t_{c,base} + t_{c,HV} P_{HV} + t_{c,G} G - t_{c,T} - t_{3,LT} \quad \text{....................} \; (2.1)$$

Where, $t_{c,x}$ – Critical gap for movement x(s)

$t_{c,base}$ – Base critical gap

$t_{c,HV}$ – Adj. Factor for heavy vehicles

(1.0 for two-lane major streets,2.0 for four lane major streets)

P_{HV} – Proportion of heavy vehicles for minor movement

$t_{c,G}$ – Adj. Factor for grade

(0.1 for movements 9 and 12 and 0.2 for movements 7,8,10,11)

G – Percent grade divided by 100

$t_{c,T}$ – Adj. Factor for each part of a two-stage gap acceptance process

(1.0 for first or second stage; 0.0 if only one stage)

$t_{3,LT}$ – Adj. Factor for intersection geometry

(0.7 for minor street LT movement at three-leg intersection; 0.0 otherwise)

A driver's critical gap is the **minimum gap** that would be acceptable. A particular driver would

Reject any gaps < critical gap

Accept gaps >= critical gap

Follow-up time is the time between the departure of one vehicle and the next vehicle using the same major-street gap.

$$t_{f,x} = t_{f,base} + t_{f,HV} P_{HV} \quad \text{....................} \; \mathbf{(2.2)}$$

Where, $t_{f,x}$ – Follow-up time for minor movement x

$t_{f,base}$ – Base follow-up time

$t_{f,HV}$ – Adj. Factor for heavy vehicles

(0.9 for two-lane major streets,1.0 for four lane major streets)

P_{HV} – Proportion of heavy vehicles for minor movement

The gap acceptance method employed in the procedure used in determining the capacity of these intersections computes the potential capacity of each minor traffic stream in accordance with the following equations:

$$c_{p,x} = v_{c,x} \frac{e^{-v_{c,x} t_{c,x}/3600}}{1-e^{-v_{c,x} t_{f,x}/3600}} \text{....................} \; \mathbf{(2.3)}$$

Where, $c_{p,x}$ – Potential capacity of minor movement x (veh/hr)

$v_{c,x}$ – Conflicting flow rate for movement x (veh/hr)

$t_{c,x}$ – Critical gap for movement x (s)

$t_{f,x}$ – Follow-up time for minor movement x (s)

The movement capacity for the priority movement ‘x’ can be computed as

$$c_{m,x} = (c_{p,x}) f_x \text{ .... (2.4)}$$

Where, f_x – Capacity Adj. Factor for rank x movement

Control delay includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. For the purpose of field measurements, control delay is defined as the total elapsed time from the time a vehicle stops at the end of the queue to the time the vehicle departs from the stop line.

Average control delay for any particular minor movement is a function of the capacity of the approach and the degree of saturation.

For a 15-minute analysis period, an estimate of average total delay is given by below equation:

$$d = \frac{3600}{c_{m,x}} + 900T\left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}}\right] + 5 \text{ .... (2.5)}$$

The above equation assumes that the demand is less than capacity for the period of analysis. If demand exceeds capacity during 15-minutes, the period of analysis should be lengthened to include the period of oversaturation. The constant value of 5 sec/veh is included in the above equation to account for the deceleration of vehicles from free-flow speed to the speed of vehicles in queue and the acceleration of vehicles from the stop line to free-flow speed.

Estimation of queue length is an important consideration at unsignalized intersections. Probability distribution of queue lengths for any minor movement is a function of the capacity of the movement and the volume of traffic being served during the analysis period. The following figure-2.4 can be used to estimate the 95 percentile queue length for any minor movement at an unsignalized intersection during the peak 15-minute period. The expected total delay equals the expected number of vehicles in the average queue (numerically identical).

From the queue lengths obtained from the graph shown above, average control delay can be estimated for the each minor movement. The control delay for all the vehicles on a particular approach can be computed as the weighted average of the control delay estimates for each movement on the approach. Level of service (LOS) for an unsignalized intersection (TWSC) is determined by the computed or measured control delay and is defined for each minor movement. LOS is not defined for the intersection as a whole.

The analysis of TWSC intersections is generally applied to existing locations either to evaluate operational conditions under present traffic demand or to estimate the impact of anticipated new demand. The methodology yields a level of service (LOS) and an estimate of average total delay.

HCM (2000) Delay method is based on highly empirical considerations for these types of intersections (TWSC and AWSC) and the Indian conditions at uncontrolled intersections are quite different from those under which these equations were developed.

2.2 Blunden’s Method

The analysis of stop and yield-sign controlled approaches has been investigated by a number of researchers, especially Blunden (1961). The capacity of such intersections depends on the traffic flow in the major stream and the confidence of individual drivers to cross this major stream. In formulating an acceptable expression to calculate flow rate, the pattern of gaps in the major stream is assumed to follow a Poisson distribution. In addition, it is assumed that all drivers, on average, will accept a minimum gap. An expression that indicates the number of vehicles per hour that can be “absorbed” by major traffic stream is given by Blunden (1961) as in the following equation-2.4.

$$q_{max} = \frac{Ve^{-VT/3600}}{1-e^{-Vt/3600}} \text{ .... } (2.6)$$

Where, q_{max} = Maximum flow rate from the controlled approach

V = Total traffic volumes on the uncontrolled street in both directions

T = Minimum gap acceptable to the first driver on the side street

t = Additional time required for a second driver to follow the first driver into the intersection when a large gap occurs

While comparing the computed maximum flow rate from the above equation with the standard values of maximum flow rates, for the assumed values of T (5 to 8 s) and t (3 to 5 s), given by the Blunden, one could evaluate the performance of stop and yield-sign controlled intersections.
Literature on uncontrolled intersections with mixed traffic where large proportion of the traffic does not follow the rules of the road is extremely limited

Kyte et al. (1991) conducted an empirical study on delay and capacity of the minor approach of two-way stop controlled intersections. They described the capacity and delay characteristics at two-way stop controlled intersections, and concluded that service delay is mainly dependent on the volume of conflicting approaches, and that queue delay is mainly dependent on the volume of the subject approach. They divided total delay into two parts: service delay and queue delay. A linear equation was suggested for minor street service time based upon the volume on the conflicting approaches. However, they did not discuss how this relationship can be used in estimating total delay.

DATA COLLECTION

The data set pertaining to the independent variable and the dependent variable were obtained by conducting the traffic surveys at study intersections. Classified turning movement volume counts of vehicles of each of three groups i.e., light vehicles (two-wheelers, cars, auto-rickshaws, LCVs), heavy vehicles (buses, trucks, tractors, mini-bus/tempo vans) and non-motorized vehicles (cycles, cycle-rickshaws), for each direction of movements (LT, RT, and TH) at each of the approaches (three or four) were done simultaneously for 3hours in the morning session i.e., from 8.30AM to 11.30AM and for 3hours in evening session i.e., from 4.00PM to 7.00PM, on a typical working week day, for each of the intersection. It was observed that the traffic volume and vehicular composition of individual vehicles remained varied slightly during the survey period. For this turning movement volume count study, each enumerator is employed for each turning movement for each of the approaches of the intersections. For a three-legged intersection, 6 enumerators and for four-legged intersection, 12 enumerators are employed.

In order to study the service delay (delay experienced by a vehicle at the reference line), intersections located in city were selected. These intersection sites were in urban areas. But the effect of upstream junctions, on-street parking, or bus stops on arrival rate is negligible. An important traffic feature at all the three intersections was that the queue formation on the minor street approaches was very rare. One of the three intersections is of T-type and the remaining two were four legged.

As a part of delay study, at each intersection, data were collected by video recording technique on a typical weekday. The video camera was placed at a suitable vantage point near the intersection to record an unobstructed view of all approaches and turning movements and data were recorded for about 1hr to 2 hr depending upon the significant sample of vehicle type. The recorded video file was played in the laboratory several times to get the conflicting traffic volume count and the service delay experienced by each subject vehicle. Both crossing and merging types of conflicts were taken into account while noting the conflicting traffic for each maneuver during the data extraction process.

DATA EXTRACTION

Data extraction for the delay study was done using microscopic analysis as described by Kyte et al. (1991). The microscopic analysis requires the definition of the conflicting traffic flow as seen by each subject approach vehicle. Let t_0 = time of arrival of the subject approach vehicle at the reference line; t_d = time of departure of the subject approach vehicle; n = number of observed conflicting vehicles for the subject vehicle, including the conflicting vehicle passing just after departure of the subject approach vehicle; and t_n = time of arrival of nth conflicting vehicle at the reference point.

Conflicting flow rate = $\frac{n}{t_n - t_0}$

Service delay = $t_d - t_0$

The computation of service delay requires the identification of a reference line where the subject approach vehicles would stop. In a homogeneous and lane-disciplined traffic, the stop line is taken as the reference line for measuring the service delay. However, in a mixed traffic flow, the vehicles do not respect the stop line and tend to stop very close to the conflicting area. It was noticed during a preliminary study of recorded data that 50–60% of drivers did not respect the stop line at each of the sites. After observing the behavior of traffic carefully, reference lines where vehicles of each priority movement actually stopped were marked on the screen. The reference line for minor street vehicles was approximately a one-fourth lane width beyond the stop line, i.e., inside the major street.

The equivalent PCUs of different vehicle categories do not remain constant under all circumstances. Rather, these are a function of the physical dimensions and operational speeds of the respective vehicle classes. In urban situations, the speed differential amongst different vehicle classes is generally low, and as such the PCU factors are predominantly a function of the physical dimensions of the various vehicles. Nonetheless, the relative PCU of a particular vehicle type will be affected to a certain extent by increase in its proportion in the total traffic.

PEAK HOUR FLOW RATES

The peak-hour flow rates for different turning movements (TH, LT, and RT) for each approach and total approach flow rates for all the three intersections has been presented through below tables. Vehicular composition of the subject vehicles considered for the delay study at all the low-priority movements (minor RT, major RT, and minor TH) and their variations at different intersections are presented below through pie-charts, as shown in the following figures. The layout of the three intersections has been shown in the figures

Table Peak Hour Flow rates of Ghatkesar Junction

Approach	**Movement**	**Peak Hour Flow Rate**		**Approach Flow Rate**	
		Veh/hr	**PCU/hr**	**Veh/hr**	**PCU/hr**
UPPAL	TH	2140	1693	2741	2459
	LT	241	350		
	RT	360	416		
GANAPUR	TH	218	262	991	1181
	LT	464	574		
	RT	309	345		
BHONGIRI	TH	1400	1751	1696	2149
	LT	149	208		
	RT	147	190		
GHATKESAR Bye-pass	TH	414	572	1209	1586
	LT	315	414		
	RT	480	600		

MODEL DEVELOPMENT

The analysis was done separately for four categories of subject vehicles: 2W, Car, Auto and HV and for two types of movements i.e., right turn from minor (Minor RT) and right turn from major (Major RT) at T-intersection. At four-legged intersections, through traffic from a minor (Minor TH) street was also analyzed in addition to the right turns from major and minor streets.

The regression analysis using “Curve Estimation” between the service delay (*Ts*, s) (dependent variable) and the corresponding conflicting traffic volume (CT, veh/s) (independent variable), for each subject vehicle for each of the three types of low priority movements (minor RT, major RT, minor TH), was done using the well-known statistical package, IBM® SPSS Statistics V-19. The data points showed an exponential trend and the mathematical equation fitted through the data points for each subject vehicle. The goodness of fit of the model was assessed by the coefficient of determination (R^2) value and the other statistic measures like F-ratio, t-statistic.

Delay is a fundamental parameter in the economic analysis of highway investments. Delay caused to vehicles is important measure to evaluate the performance of urban uncontrolled intersections under mixed traffic conditions. Although the users' perception of quality of service may be difficult to measure, delay is a widely used quality of service measure for intersections. The vehicular composition, apart from traffic volume and proportion of turning traffic, is a vital factor in influencing the extent of delay caused to vehicles. Most of the earlier studies on delay to vehicles at urban uncontrolled intersections have been conducted under homogeneous traffic conditions, and the few studies that have been conducted under mixed traffic conditions being limited in scope. Therefore, there is a need to comprehensively analyse the delay caused to vehicles at urban uncontrolled intersections and develop the appropriate models to estimate the delay.

In this study, curve fitting for the anticipated exponential model has been developed for each subject vehicle (2W, Car, Auto, HV) for all the low priority turning movements (Minor RT, Minor TH, Major RT), taking the three uncontrolled intersections, one three-legged (or T) intersection and two 4-legged intersections, located in Warangal city, as a case study. The models were developed using the well-known statistical package, IBM® SPSS Statistics V-19. The data points showed an exponential trend and the mathematical equation fitted through the data points for each subject vehicle. The goodness of fit of the each model was assessed by the coefficient of determination (R2) value and the other statistic measures like F-ratio, t-statistic.

CONCLUSIONS

Based on the field studies and the subsequent modelling process, the following conclusions have been drawn:

A simple readily usable mathematical model of service delay, caused to each subject vehicle at an urban uncontrolled intersection under mixed traffic conditions, has been developed.

For each uncontrolled intersection, an aggregate service delay model has been developed, to serve as a useful tool for performance evaluation of such intersections.

Models revealed that with increase in the conflicting flow rate, the service delay was also increased significantly.

Average service delay for Ghatkesar junction was found to be less, as the peak hour conflicting flow rate is less compared to the intersections

Average service delay was found to be more for Heavy vehicles (HV) category, irrespective of the movement, at all the three intersections

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