DETERMINATION OF INTERGREEN INTERVALS IN SIGNAL-TIME SETTINGS FOR HETEROGENEOUS TRAFFIC

BY

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ABSTRACT

In signal time settings, the time from the end of green light of the phase loosing right-of-way to the start of green light of the phase gaining right of way is termed as intergreen interval. Determination of intergreen interval is a crucial step in signal time design as it focuses directly on traffic safety. The main aim of the study reported here is to review the methodologies available for estimation of the intergreen interval in signal time settings, and apply them for estimation of intergreen interval for a signalized intersection carrying heterogeneous traffic to evaluate their suitability for applications to such traffic conditions. The three alternative methodologies considered are- (i) the probabilistic method (ii) the ITE method and (iii) the German method. The application of the three methods resulted in varying intergreen intervals for any given set of signal phases. Hence, it is suggested that the range of values of intergreen interval for each change of phase may first be fixed by taking the maximum and minimum of the values arrived at using the three methods. Then the exact duration of intergreen interval, with this range may be arrived at by field trials to ensure both capacity and safety.

1. INTRODUCTION

Signalized intersections are intended to permit conflicting movements of traffic streams to proceed efficiently and safely through the intersection space that is common to those movements. This is accomplished by separating the individual movements in time rather than in space. The various movements of traffic streams are collected, divided into compatible sets, and then allowed to move in turns, or in phases. Each phase of a signal cycle is devoted to only one set of movements. These movements are those that can proceed simultaneously without any major conflict. In signal-time setting, the time from the end of the green period of the phase losing right-of-way to the start of the green period of the phase gaining right-of-way is termed as the intergreen interval. Determination of intergreen interval is a crucial step in signal-time design. Whereas other aspects of signal timing focus on the efficiency of traffic moving through a signalized intersections, the intergreen interval focuses directly on safety, as it is associated with successive reassigning of right-of-way to conflicting traffic streams

The intergreen interval is characterized by an amber (yellow) warning indication, often followed by a red clearance indication. As the amber-signal indication serves as a warning to drivers that the next phase will soon be receiving the right-of-way, it should be long enough to allow vehicles that are away to come easily to a stop. The amber light duration and the associated red signal should also be sufficient to allow vehicles that are close to the intersection to continue and cross the intersection non-stop. If the intergreen interval is too short, only those vehicles that are close to the intersection will be able to pass through the intersection safely without stopping. Also, only those vehicles which are farther away from the intersection will have adequate time to respond to the signal and stop. Those who are in between will be in a "dilemma zone" and would not have enough time to stop or safely cross the intersection. Hence, the main objective in fixing the duration of intergreen interval and the included amber time is to eliminate the dilemma zone and to provide sufficient time for the drivers to opt either to stop at the stop line or to proceed and cross the intersection safely. The objective of the study reported here, is to review and list the alternative procedures available for estimation of intergreen interval in signal-time settings, and apply

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them for estimation of intergreen interval for a signalized intersection catering to highly heterogeneous traffic to evaluate their suitability for applications to such traffic conditions.

2. BACKGROUND

2.1 General

An early significant contribution in the estimation of intergreen interval was made by Gazis et al. (1960). Based on theoretical analysis that eliminated the dilemma zone, they developed an equation for finding the length of intergreen interval. The details are as follows. A driver approaching a signalized intersection during the amber period, will either have to stop at the stop line or cross the stop line, before the signal turns red, and proceed to clear the intersection. The stopping distance is the distance required for the vehicle to stop before entering the intersection. This distance can be calculated as,

$$X_s = tv + \frac{v^2}{2(a)} \qquad (1)$$

Where,

X_s = stopping distance in m; t = reaction time of drivers in s; v = approach speed in m/s; a = deceleration rate in m/s^2.

The crossing distance is the distance, on the approach, within which the vehicle can proceed to cross the intersection before the end of the intergreen interval. A vehicle intending to cross the intersection, therefore, has to travel a total distance equal to the sum of the crossing distance, the width of the intersection, and the length of the vehicle. Thus,

$$X_c = Iv - (W+L) \qquad (2)$$

Where,

X_c = crossing distance in m; I = intergreen interval in s; v = approach (also crossing) speed in m/s; W = intersection width in m; and L = length of the vehicle in m.

Elimination of dilemma zone is possible only when the stopping and clearing distances are equal. Accordingly, equating the two distances in equations (1) and (2), the required intergreen interval can be obtained as,

$$I = t + \frac{v}{2(a)} + \frac{(W+L)}{v} \qquad (3)$$

Where, I, t, v, a, W and L are as defined earlier.

The equation of Gazis et al. (1960) has been modified by several researchers including Williams (1977); Parsonson and Santiago (1980); and Bissel and Warren (1981). A few researchers examined the accuracy of reaction time and deceleration rate for use in the equation (e.g. Chang et al. (1985); Oslon and Rothery (1972). Several studies have been conducted to determine the intergreen interval on empirical basis (e.g. Lin and Vijaykumar (1988); and Horst (1986). Sheffi and Mahmasani (1981), and Kikuchi and Riegner (1992) have studied the driver behavior on the onset of amber signal and suggested measures to ensure safe stopping and clearing by vehicles. Easa (1993) has proposed a reliability based design procedure for intergreen interval. In his study, he has considered the factors influencing intergreen interval as intercorrelated random variables, and has arrived at a solution through probabilistic approach. Arasan and Rao (1998) applied the methodology proposed by Easa (1993) to estimate optimum intergreen interval for a signalized intersection with highly mixed traffic, and found that the methodology gave satisfactory results. Retzko and Boltze (1987) have suggested a different approach, based on German practice, for determination of intergreen interval. As per this approach, the intergreen interval is calculated using the equation (25) given under the section German Method. From the review of literature, it is clear that there are three distinctly different methodologies available for estimation of intergreen intervals. These are: (i) the methodology suggested by Gazis et al. (1960), which has been adopted, with minor modifications, by Institute of Transportation Engineers(ITE), USA: (ii) the probabilistic approach suggested by Easa (1993); and (iii) the German methodology as suggested by Retzko and Boltze (1987), which is as per the guidelines of

German Road and Transportation Research Association (2003). The three methodologies are first briefly described in the following three sections. The application of these methodologies to estimate intergreen interval, at a selected signalized intersection with heterogeneous traffic, and the results, are discussed in the subsequent sections.

2.2 The ITE Recommended Method

The Institute of Transportation Engineers (ITE), USA, an advisory body on traffic and transport related matters, has recommended, based on the study of Parsonson and Santiago (1980), the use of the following equation for determination of intergreen intervals in signal-time settings:

$$y = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V} \qquad (4)$$

Where,

y = the intergreen interval in s; t = reaction time of driver in s; a = deceleration rate in ft/s^2; g = grade of approach, expressed as a decimal; W = width of the intersection in ft.; L = length of the vehicle in ft.; and V = approach speed of vehicle in ft/s.

It may be noted that equation (4) is a modified version of equation (3) with inclusion of gradient of the approach as an additional factor influencing intergreen interval.

2.3 The Probabilistic Method

As per this method, the factors influencing intergreen interval are considered to be co-related random variables. for probabilistic analysis, the first order second moment method is widely used, as it involves simple mathematics and is also reasonably accurate. In this method, the implied functional relationships are simplified by using a truncated Taylor series expansion. This method involves only the first and second moments of the variables, and the outputs are expressed in means and variances.

2.3.1 Stopping distance: The expected value and variance of the stopping distance, X_s of equation (1), namely, $E(X_s)$ and var (X_s) are obtained, as per Easa (1993), respectively, as

$$E(X_s) = \mu_v \mu_t + \frac{(\mu_v)^2}{2(\mu_a + Gg)} + cov(t,v) - \frac{\mu_v}{(\mu_a + Gg)^2} cov(a,v) + \frac{(\sigma_v)^2}{2(\mu_a + Gg)} + \frac{(\mu_v)^2 (\sigma_a)^2}{2(\mu_a + Gg)^3} \qquad (5)$$

$$var(X_s) = \left(\frac{\partial X_s}{\partial t}\right)^2 (\sigma_t)^2 + \left(\frac{\partial X_s}{\partial v}\right)^2 (\sigma_v)^2 + \left(\frac{\partial X_s}{\partial a}\right)^2 (\sigma_a)^2 + 2\left(\frac{\partial X_s}{\partial t}\right)\left(\frac{\partial X_s}{\partial v}\right) cov(t,v) + 2\left(\frac{\partial X_s}{\partial a}\right)\left(\frac{\partial X_s}{\partial v}\right) cov(a,v) \qquad (6)$$

Where, μ_v = mean of approach speed; μ_t = mean of reaction time; μ_a = mean of deceleration rate; σ_v = standard deviation of approach speed; σ_t = standard deviation of reaction time; σ_a = standard deviation of deceleration rate; cov(t,v) = covariance of reaction time and speed; and likewise for cov(a,v).The partial derivatives of (6),which are evaluated at the mean values of the variables, are given by

$$\frac{\partial X_s}{\partial t} = \mu_v \qquad (7)$$

$$\frac{\partial X_s}{\partial v} = \mu_t + \frac{\mu_v}{(\mu_a \;\; Gg)} \qquad (8)$$

$$\frac{\partial X_s}{\partial a} = \frac{-(\mu_v)^2}{2(\mu_a + Gg)^2} \qquad (9)$$

2.3.2 Crossing distance : The expected value and variance of the crossing distance, X_c of equation (2), namely, E (X_c) and var (X_c) are given by

$$E(X_c) = \mu_v - (W + \mu_L) \qquad (10)$$

$$var(X_c) = \left(\frac{\partial X_c}{\partial v}\right)^2 (\sigma_v)^2 + \left(\frac{\partial X_c}{\partial L}\right)^2 (\sigma_L)^2 \qquad (11)$$

Where, the partial derivatives are

$$\frac{\partial X_c}{\partial v} = I \qquad (12)$$

$$\frac{\partial X_c}{\partial L} = -1 \qquad (13)$$

In equation (11), the approach speed and vehicle length are assumed to be independent.

2.3.3 Safety margin : The stopping distance X_s can be viewed as the demand, and the crossing distance X_c as supply. The difference between X_c and X_s is the safety margin F, which is given by

$$F = X_c - X_s \qquad (14)$$

Since X_c and X_s are random variables, F is also a random variable whose probability distribution is illustrated in Fig.1. Equation (14) is the limit state function. The safe state is represented by $F > 0$, the dilemma (failure) state by

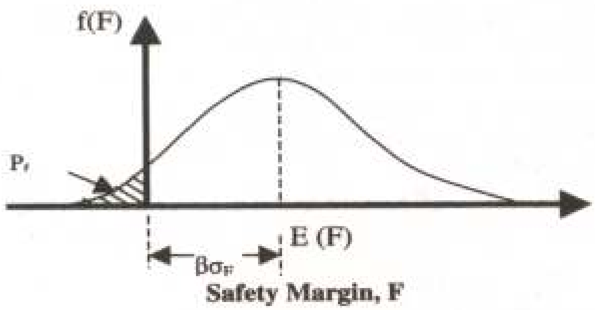


Fig. 1. Probability Distribution of the Safety Margin

$F < 0$, and the limit state by $F = 0$. The expected value and variance of F, E(F), and var(F) are:

$$E(F) = E(X_c) - E(X_s) \qquad (15)$$

$$var(F) = var(X_c) + var(X_s) - 2\,cov(X_s, X_c) \qquad (16)$$

Where, the expected values and variances of X_s are given, respectively, by (5)&(6), and those of X_c are given, respectively, by (10) & (11). The covariance of X_s and X_c, $cov(X_s, X_c)$, arises because X_s and X_c are the functions of speed v.

This covariance can be obtained using elementary probability as

$$cov(X_s, X_c) = IQ \qquad (17)$$

Where, Q is given by

$$Q = \left[\mu_t + \frac{\mu_v}{(\mu_a \quad Gg)}\right](\sigma_v)^2 + \mu_v\,cov(t, v) - \left[\frac{(\mu_v)^2}{2\,(\mu_a + Gg)^2}\right]cov(a, v) \qquad (18)$$

The number of standard deviations σ_F between the mean value of the safety margin, E(F), and the limit state, $F = 0$, is the reliability index β (Fig. 1.) That is,

$$\beta = \frac{E(F)}{\sigma_F} \qquad (19)$$

Where, σ_F = standard deviation of F, which equals the square root of var(F). The area where $F < 0$ represents the probability of failure (stopping distance exceeds clearing distance). A large value of β indicates that the probability of failure is small.If the probability distribution of F is assumed to be normal, an estimate of the probability of failure P_f is

$$P_f = \Phi(-\beta) = 1 - \Phi(\beta) \qquad (20)$$

Where $\Phi(-\beta)$ = area under the probability density function of the standard normal variate from $-\infty$ to $-\beta$. This area can be obtained from the tables of the standard normal variate found in probability textbooks. For example, for probabilities of failure of 1 % and 5 %, the reliability indices are 2.33 and 1.64 respectively. The probability of failure based on the normality assumption is referred to as the nominal probability of failure.

2.3.4 Closed form solution : The required intergreen interval can be found using (19). Since the numerator and denominator of this equation are functions of I, first both sides of the equation are squared. After some manipulations, a quadratic equaion in I is obtained, giving the following solution:

$$l = \frac{-B + \sqrt{B^2 - 4\,AC}}{2\,A} \qquad (21)$$

Where,

$$A = \frac{(\mu_v)^2}{\beta^2} - (\sigma_v)^2 \qquad (22)$$

$$B = 2\,Q - \frac{2\,\mu_v}{\beta^2}\left[(W) - \mu_L + E(X_s)\right] \qquad (23)$$

$$C = \frac{1}{\beta^2}\left(W + \mu_L + E(X_s)\right)^2 - var(X_s) - (\sigma_L)^2 \qquad (24)$$

Where, Q is given by (18). Equation (21) gives the required intergreen interval for a specified reliability index (or probability of failure) and gives means, variances, and correlation coefficients of v, t, a, and L. Note that $E(X_s)$ and var (X_s), which appear in (23) and (24) do not depend on L.

2.4 The German Method

Under this method, (the description of which is available in the English version of the "German Guidelines for Traffic Signals" (*14*), published in 2003) the time taken for different vehicular movements at signalized intersections forms the basis for estimation of intergreen interval. There are three time components, related to three different types of vehicular movements, considered for arriving at a value for intergreen interval. They are: (i) approach time (also termed as overrun time); (ii) clearing time; and (iii) entering time. The definitions of the three terms are as follows. ***Approach time*** is the time interval between the end of the green time (start of amber time) and the point of time at which the last vehicle of the ending green time passes the stop line. ***Clearing time*** is the time necessary for a vehicle of the ending green time that crosses the stop line, to drive through the clearing distance (the distance from the stop line to the far side of the point of possible conflict in the intersection area). ***Entering time*** is the time necessary for the first vehicle of the beginning green time to pass the entrance distance (the distance from the stop line to the near side of the point of possible conflict in the intersection area). The intergreen interval, as per German practice, is then calculated as,

$$T = t_a + t_c - t_e \qquad (25)$$

Where,

T = intergreen interval in s; t_a = approach time in s; t_c = clearing time in s; and t_e = entrance time in s. By equation (25), it is implied that the last vehicle of the ending green time must have just cleared the conflict point in the intersection area before the first vehicle of the beginning green time arrived at that point. The concept is depicted in Fig. 2.

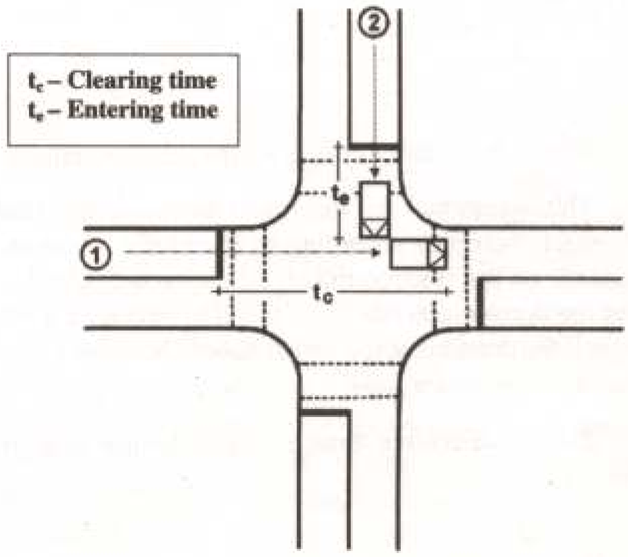


Fig. 2. Clearing and entering times with respect to the point of conflict

2.4.1 Approach time : On the start of amber, stopping of an approaching vehicle is possible if a definite distance, d_s up to the stop line, is available at the moment of the decision to stop the vehicle. This means,

$$d_s = vt_{re} + \frac{v^2}{2\,b} \qquad (26)$$

Where,

d_s = distance up to the stop line in m; v = approach speed of vehicle at the moment of the end of the green time/the beginning of the amber interval in m/s; t_{re}= reaction time in s; and b = deceleration rate in m/s^2.

Assuming that the speed of the last vehicle of the ending green time does not change in the intersection area, the approach time is calculated as

$$t_a = \frac{d_{t1}}{v} \qquad (27)$$

Where,

d_{t1} = distance up to the stop line, in m, at the moment of the end of green time; and v = speed of the vehicle in m/s. Driving through the intersection is allowed if $d_{t1} \leq d_s$. Therefore, the maximum approach/overrun time is given as

$$t_a = \frac{d_s}{v} = t_{re} + \frac{v}{2b} \qquad (28)$$

Where, the notations are as for the earlier equations.

This means that the maximum approach time that considers behavior according to the traffic situation, depends on the reaction time t_{re}, the approach speed v, and the deceleration rate b. To avoid overrunning a red signal, the duration of the amber should be equal to the maximum approach time.

2.4.2 Clearance time : The clearance time is given as

$$t_c = \frac{d_c}{v_c} \qquad (29)$$

Where, d_c = clearing distance in m; and v_c = clearing speed in m/s.

Conflicts do not occur, if it is assumed, while determining intergreen time, that clearing ends only when the last clearing vehicle has passed the conflict area. So, the clearing distance d_c is the distance between the stop line and the end of the conflict area plus the length L of the vehicle. The length of the clearing vehicle may be taken as 6m. The clearing speed v_c is that speed with which the last clearing vehicle drives over the clearance distance d_c The maximum value of clearing speed is equal to the speed limit at the intersection. If lower clearing speeds than the existing speed limit are assumed, a smaller approach time is to be used, because, slower vehicles are better able to react to amber light.

2.4.3 Entering time : Distinction is made between two cases in the behavior- "start from stopping" and "flying start". In both cases, the entry time depends on the speed v_e, when crossing the stop line, in relation to the beginning of the green time. The entering distance is the distance between the stop line and the beginning of the conflict area. It depends only on the geometry of the intersection.

According to German standards, for the "flying start" case, the entering time is calculated as follows.

$$t_e = \frac{d_e}{v_e} \qquad (30)$$

Where, t_e = entering time in s; d_e = entering distance in m; and v_e = the speed limit at the intersection area.

For the case "start from stopping", t_e is calculated as

$$t_e = \sqrt{\frac{2\,(d_e + d_o)}{b}} - t_{RY} \qquad (31)$$

Where, d_o = distance of the position of vehicle from stop line, at the time of start, in m; b = acceleration rate in m/sec^2; t_{RY} = duration of red-amber period in s; and t_e and d_e are as for equation (30)

3. STUDY INTERSECTION

3.1 General

The signalized junction of Dr. Radhakrisnan Road with Kamarajar Road, in the eastern part of Chennai (formerly Madras) city, India, was chosen for the study. The layout of the intersection, with relevant geometric details indicated therein, is shown in Fig. 3. The traffic signal installed at the junction is a three phase fixed time signal with a cycle time of 135 s. The traffic flow (phase) diagram and the timing diagram for the signal are depicted in Figs. 4 and 5 respectively. It can be seen that pedestrian movement, at least in one leg of the intersection, is permitted in each phase. The green signal for pedestrian traffic starts along with the green for the associated vehicular movement, in all the three phases of the intersection. However, the green for pedestrian movement ends before the end of green for the associated vehicular movement because of the high pedestrian-clearance-time requirement.

There are six vehicular traffic streams involved at the junction as illustrated in Figure 4. Consider, for example, determination of intergreen interval between phases I and II. It can be seen that there are three streams of traffic (streams 1, 2, and 3) involved in phase I. Phase II contains two traffic streams, namely, streams, 4 and 5. When the green for phase I ends, streams 1, 2, and 3 and the pedestrian stream P_3 will loose the right of way; and the vehicular streams, 4 and 5, along with the two pedestrian movements, namely, P_1 across Dr. Radhakrishnan Road, and P_2 from the median to curb, across the Southern leg of Kamaraj Road, will get green. It can be seen that stream 4 of phase II is conflicting with the ending vehicular streams 2 and P_3 of phase I. Also, streams 5 of phase II is conflicting with the ending pedestrian stream P_3 of phase I. The pedestrian movement P_1 across the Southern leg of Kamaraj Road will be the conflicting movement with stream 1; and the pedestrian movement P_2 across Dr. Radhakrishnan Road will be conflicting with stream 2. Hence, it is important that the last vehicle of stream 1 had cleared the pedestrian crossing area on Kamaraj Road before the pedestrians entered the crossing area. The same logic holds good for stream 2 also. In addition the ending stream 2 of phase I will conflict with the starting stream 4 of phase II. Thus, there are four sets of conflicting movements involved in this case. The intergreen interval for this case will be the higher of the four values, calculated for the cases. Subject to the exact green time required for the involved pedestrian movements. On the same lines, the conflicting streams for other combinations of phases can be identified for the purpose. A summary of the relevant details, for the study junction, is given in Table 1.

3.2 Traffic Data

The traffic on Indian roads is highly heterogeneous comprising vehicles of wide ranging static and dynamic characteristics. The traffic at the study junction comprised the following types of vehicles: (i) Bicycles; (ii) Motorized two-wheelers comprising motorcycles, scooters, and mopeds; (iii) Auto-rickshaws – three wheeled motorized vehicles to carry a maximum of three passengers; (iv) Cars, including, jeeps and small vans; (v) Light Commercial Vehicles, comprising large passenger vans and small goods vehicles; (vi) Buses; and (vii) Trucks. Animal-drawn vehicles and other types of slow moving vehicles were prohibited at the signalized junction. There was no separate signal provided for bicycles, and they have to follow the signals of motorized traffic. As we are concerned with only the motorized vehicles for the present study (bicycles being a slow vehicle, can come to a stop even with a very short warning period, and hence are not relevant to the scope of the work) a classified count of all the motorized vehicles, during peak traffic period, was made. The percentage composition of the different types of motorised vehicles is given in column (3) of Table 2.

The factors affecting the duration of intergreen intervals are: (i) approach speed of vehicles; (ii) deceleration rate of vehicles; (iii) length of vehicles; (iv) reaction time of drivers; and (v) width of intersection. Hence, data on all these factors are necessary to accurately determine the intergreen interval. The data of approach speed on vehicles was collected by measuring the spot speed of vehicles approaching the junction. Observers with hand-held RADAR speed meters were positioned on the approach, at a distance of about 50 m from the stop line on the upstream side of the intersection. The observers chose carefully the vehicles of different categories when they approached the intersection at normal speed, unhindered by the presence of other vehicles, and measured the speeds of such vehicles by directing the meter towards the selected vehicles. A total of 600 speed observations, covering the different categories of vehicles, were made. The mean and standard deviation of the speeds of the different

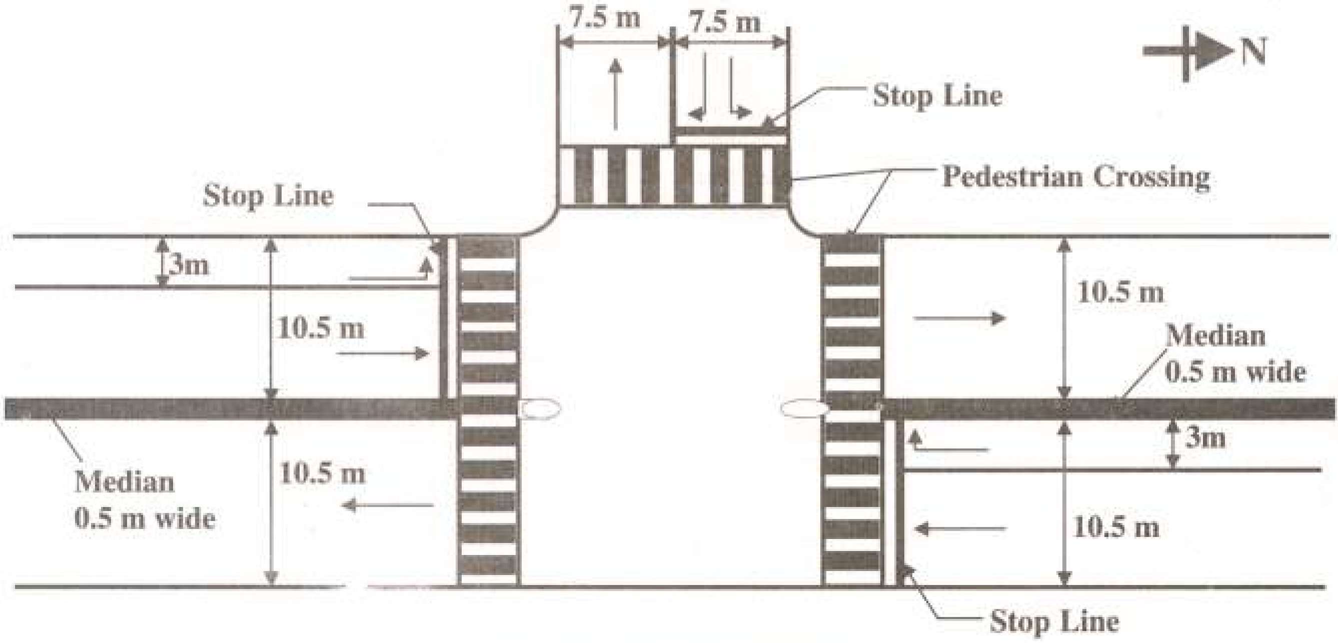


Fig. 3. Layout of the Study Junction

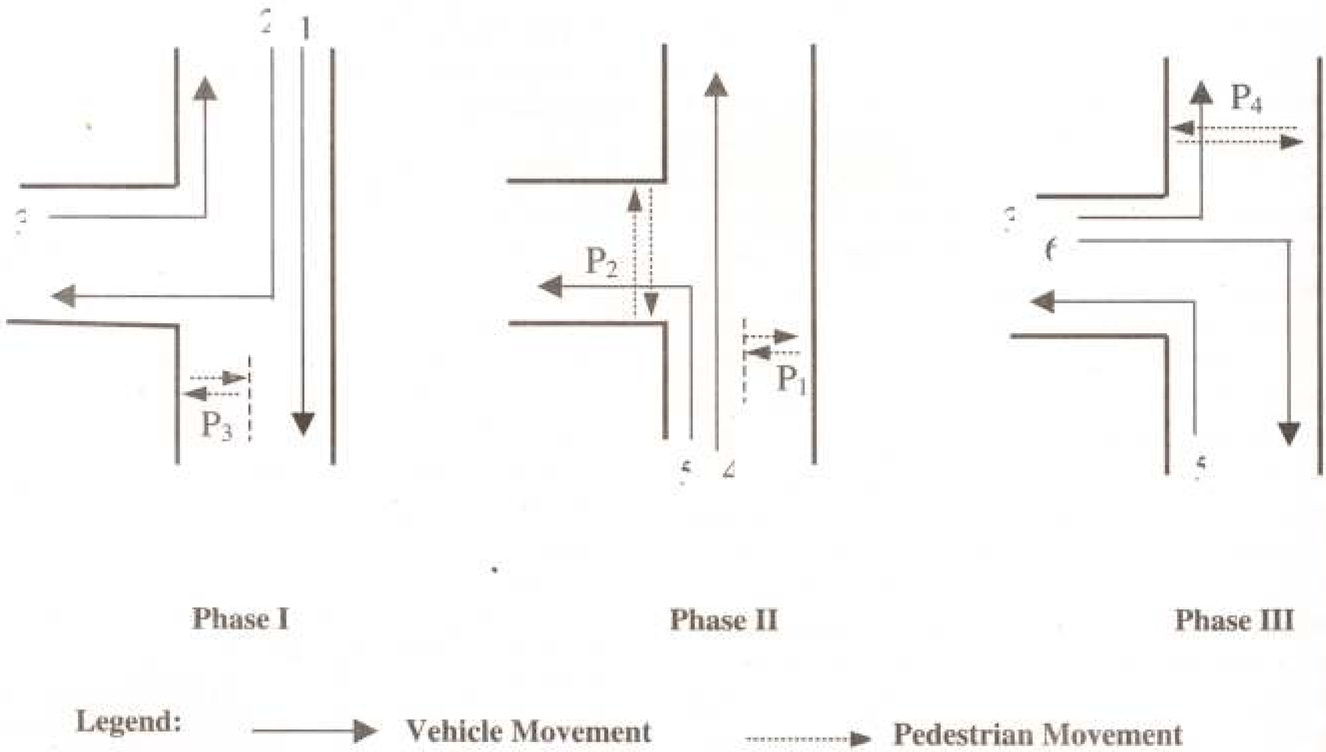
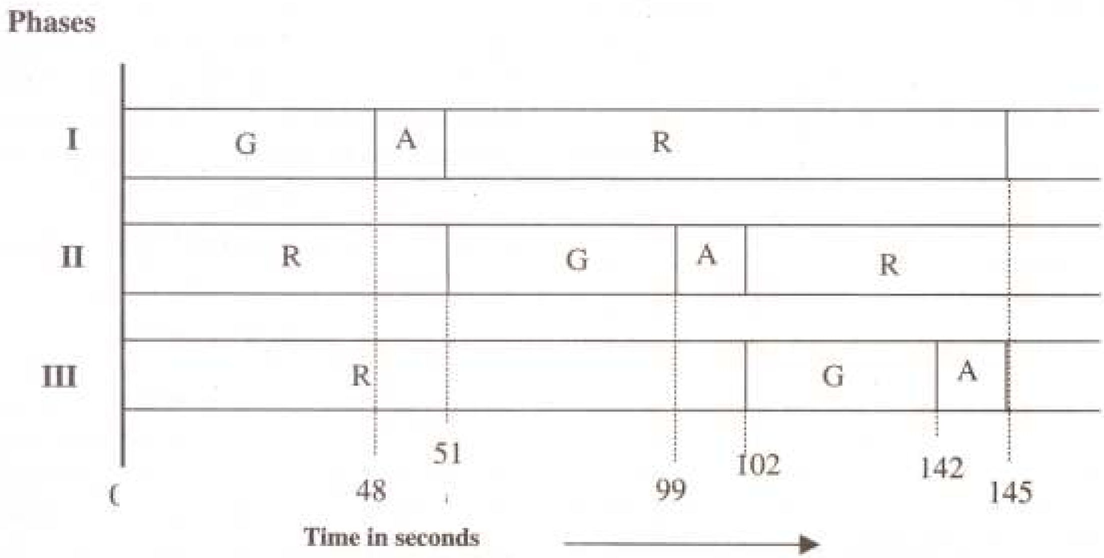


Fig. 4. Phase Diagram for the Signal Cycle.



Legend : A- Amber; G- Green; and R- Red

Fig. 5. Timing diagram for signal setting

TABLE 1. BASIC DETAIL OF CONFLICTING TRAFFIC STREAMS

Involved Phases		Conflicting Streams		Width of Intersection* (m)	Clearing Distance@ (m)	Entering Distance# (m)
Ending Phase (1)	Starting Phase (2)	Ending Stream (3)	Starting Stream (4)	(5)	(6)	(7)
I	II	1	P_1	37	40	0
		2	4	45	38	16
		2	P_2	45	38	0
		P_3	4	11	11	2
II	III	4	P_4	37	36	0
		4	6	37	27	16
		P_1	6	11	11	47
III	I	6	1	45	32	16
		6	2	45	32	16
		P_4	1	23	23	2
		P_4	2	23	23	2
		5	P_3	26	9	0

* Width of intersection measured as the distance from the stop line to the farthest edge of pedestrian crossing marking on the down stream side of the intersection for the ending stream; @ Distance from the nearest stop line to the point of conflict plus vehicle length;

* Distance from the nearest stop line to the point of conflict; P_2-Pedestrian traffic across Dr.Radhakrisnan Road; P_1-Pedestrian traffic on the eastern half of Southern leg of Kamaraj Road; P_3- Pedestrian traffic on the western half of Southern leg of Kamaraj Road; and P_4- Pedestrian traffic across the Northern leg of Kamaraj Road.

categories of vehicles are presented in columns (4) and (5), respectively, of Table 2. For determining the intergreen interval, a single representative approach-speed value and the corresponding standard deviation is required. Hence, the weighted mean value of the speeds of the different categories of the vehicles was calculated using the mean speed values; and the corresponding percentage proportion of the vehicles. The weighted mean speed, thus, obtained is 37.12 km/h. The standard deviation of the approach speed was calculated as 7.22 Km/hr.

Based on earlier studies (e.g. Wortman and Matthias (1983); Oslon and Rathery (1972), the mean deceleration rate of the vehicles in the traffic streams was taken as $3 m/s^2$; and the standard deviation was taken as $0.6 m/s^2$ (20% of the mean value). The acceptable deceleration rate, determined through the studies, falls in the range of 2.1-3.6 m/s^2. Considering the relatively lower approach speed of vehicles at the study junction, it was presumed that a mean deceleration rate of $3 m/s^2$ is an acceptable safe value for the traffic condition prevailing at the study site. The reaction time of drivers of vehicles approaching signalized intersections, as reported in most studies, including the study of Wortman and Matthiyas (1983), falls in the range of 0.7 to 1.5 s. For the present study, the reaction time of drivers was taken as 1 s, with a standard deviation of 0.2 s (20% of the mean). The value, coincidentally, is the same as the one adopted by the Institute of Transportation Engineers, USA. The mean length of the different categories of vehicles at the study site is given in column (2) of Table 2.The weighted mean value of the length of the length of vehicles was calculated based on the proportion of the different types of vehicles. The mean value, thus obtained, is 2.88 m. The standard deviation of the length was taken 0.58 m (20% of the mean value).

4. CALCULATION OF INTERGREEN INTERVAL

4.1. ITE Method

The intergreen interval between the three different signal phases (Fig. 5), by this method, was calculated using equation (4). Since the approaches to the intersection are level, the value of g (gradient), to be used in the equation, was taken as zero. The reaction time of the drivers was taken as 1 s. The mean approach speed and the deceleration rate were taken as 10.3m/s and 3 m/s^2 respectively. The mean length of the vehicle was taken as 2.88 m. For pedestrian traffic, the speed, and deceleration rate were taken respectively as 1.2 m/s and 0.6 m/s^2. The length (equivalent to the length of vehicle) was taken as 0.5 m. The value of the width of intersection was taken from column (5) of Table 1, by choosing the appropriate value, based on the involved phases and critical traffic streams. The value of amber time was obtained by adding the values of the first two terms of equation (4); and the value of the last term of the equation gives the all-red period. The calculated values of the amber and intergreen times, respectively, are given in columns (8) and (5) of Table 3.

TABLE 2. VECHICULAR CHARACTERISTICS PERTAINING TO THE STUDY JUNCTION

Vehicle Type (1)	Mean length (m) (2)	Percentage Composition (3)	Mean Approach Speed (km/h) (4)	Standard Deviation (5)
Motorized two-wheeler	1.8	55	36.9	7.3
Car	4.2	23	39.2	7.2
Auto-rickshaw	2.6	15	34.8	6.1
Light Commercial Vehicles	5.0	3	39.2	7.4
Bus	10.8	3	34.8	6.3
Truck	10.3	1	37.6	8.5

4.2 Probabilistic Method

The intergreen intervals, under this method, were calculated using equation (21) and the other related equations to compute the values of the different terms involved in it. The values of the involved variables were taken as for the ITE method. In addition, the standard deviation of the variables, were used as and when appropriate. Equation (21) gives the value of the intergreen interval only; and there is no specific methodology suggested to calculate the amber time. Hence, the amber time to be adopted can be taken as the one calculated by ITE method. The adopted values of the amber time, and the calculated values of the intergreen interval, are given, respectively, in columns (8) and (7) of Table 3.

4.3 German Method

The calculation of intergreen intervals, under this method, was done using equations (28), (29) and (30). The values of the different factors involved in these equations were considered as for the ITE method. However, the clearing and entering distances, given in columns (6) and (7) respectively, of Table 1, were considered, instead of the width of intersection given in column (5) of the table. The duration of amber was calculated using equation (28).It can be seen from equation (28) that the amber time is a function of the reaction time, mean speed and deceleration rate. Thus the value of amber time works out to a constant value of 3.4 seconds for all the cases. The clearing and entering times were calculated using equations (29) and (30) respectively.

The calculated values of intergreen time are given in column (6) of Table 3.

5. CONCLUDING REMARKS

In this study, the ITE method, the Probabilistic method and the German method have been applied to determine intergreen interval and amber time for a signalized road junction. A scrutiny of the calculated intergreen intervals for the study intersection (Table 3) reveals the following: (i) the critical value of amber time calculated for the three cases varies from 2.7 s to 3.4 s, and it can be taken as 3 s for application purpose; (ii) the intergreen interval calculated by probabilistic method is the highest in all the three change intervals. This is because of the inclusion of standard deviation of the influencing factors and the coefficient of correlation between them in the analysis; (iii) The values of intergreen interval calculated by both ITE and German methods are nearly the same for cases with pedestrian traffic as one of the conflicting streams and this is because

TABLE 3. CALCULATED VALUES OF INTERGREEN INTERVAL BY THE DIFFERENT METHODS

Involved Phases		Conflicting Streams		Intergreen Interval (s)			Amber time (s)
Ending Phase (1)	Starting Phase (2)	Ending Stream (3)	Starting Stream (4)	ITE method (5)	German method (6)	Probabilistic method (7)	(8)
I	II	1	P_1	6.6	6.3	7.0	2.7
		2	4	7.4	4.9	8.2	2.7
		2	P_2	7.4	7.1	8.2	2.7
		P_3	4	11.4	11.3	17.1	2.0
II	III	4	P_4	6.6	6.3	7.0	2.7
		4	6	6.6	3.8	7.0	2.7
		P_1	6	11.4	7.3	17.1	2.0
III	I	6	1	7.4	5.5	8.2	2.7
		6	2	7.4	5.5	8.2	2.7
		P_4	1	22.8	21.7	32.8	2.0
		P_4	2	22.8	21.7	32.8	2.0
		5	P_3	4.5	3.6	5.6	2.7

P1-Pedestrian traffic on theeastern half of Southern leg of Kamaraj Road; P2-Pedestrian traffic across Dr. Radhakrisnan Road; P3-Pedestrian traffic on the western half of Southern leg of Kamaraj Road; and P4 - Pedestrian traffic across the Northern leg of Kamaraj Road of the reason that for pedestrian traffic, the crossing distance is nearly equal to the width of intersection, and the entering distance is zero/ nearly zero; and (iv) The value of intergreen interval calculated for the cases with ending pedestrian streams is high in all the three change intervals, and this is because of the reason that the crossing time required for pedestrian traffic is more due to low speed. This problem can be tackled by advancing the start of amber for the ending streams of pedestrian traffic.

In the light of the fact that the intergreen intervals determined by the three methods vary, it is suggested that the range of intergreen interval, for each change of phase, may first be fixed by taking the maximum and minimum values among the three values of intergreen intervals arrived at by the three methods. Then, the optimum duration of intergreen interval, for each of the cases, may be arrived at by closely monitored field trials/ simulated experiments with different intergreen intervals within the range, to ensure both capacity and safety.

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