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APPROXIMATE METHODS FOR TWO-PHASE TRAFFIC SIGNAL DESIGN AT ROAD INTERSECTIONS

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ABSTRACT

Traffic Management is a major problem at all the busy junctions and major road intersections throughout our country, India. The rapid growth of traffic at an intersection might cause problems like road accidents, traffic congestion, conflicts and bottleneck situations. Traffic signals are the most suitable method to monitor and control road traffic at an intersection. It can be achieved by providing automated volume based traffic signal system as and where required. Improvement of traffic performance in terms of safe and efficient movement of traffic at road networks and terminals can be accomplished by systematic traffic studies with its engineering implications. This includes planning and geometric design on one hand and the regulation and traffic control on the other. An intersection is a crucial point of conflict and congestion in road networks as far as the capacities of the urban road networks are concerned. The major problems like accidents and hazards can be minimized using proper traffic survey including the analysis and proper scientific interpretation of the geometric studies. A signalized intersection capacity mainly depends upon the physical factors such as roadway width, number of traffic lanes, geometric design of the roads, and phases of traffic signal. This paper aims at bringing out the effectiveness of the approximate methods in the design of Two-Phase Traffic Signals apart from the conventional methods like Webster's method or the method standardised by the Indian Road Congress (IRC), which are also some of the most effective but complex methods, to quickly arrive at a simple and effective design that will serve its intended purpose. The paper has been well illustrated with suitable examples as and when required in order to increase the comprehensiveness of the study.

KEYWORDS***: Road Intersection, Traffic Congestion, Traffic Signal, Pedestrian Signal, Approximate methods***

INTRODUCTION

Objects of traffic signals:

At intersections where there are a large number of crossing and right-turn traffic, there is possibility of several accidents as there cannot be orderly movements. On cross roads with two-lane two-way traffic, there are 16 crossing conflicts as illustrated in Fig. 1.

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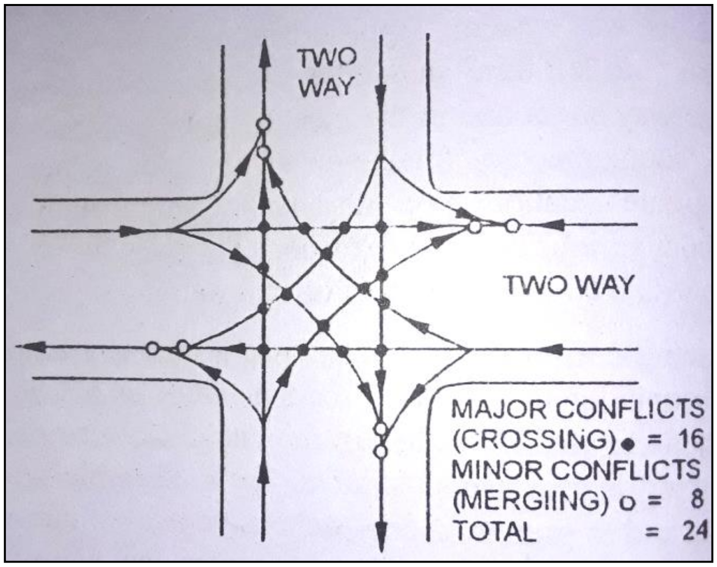

Fig. 1: Conflicts on cross roads with two-way traffic on both roads

The problem of such conflicts at the intersections gains more significance as the traffic volume increases. In such situations the earlier practice has been to control the traffic with the help of traffic police who stops the vehicles on one of the roads alternately and allows the traffic stream of the other road to cross or take right turn. Thus the crossing streams of traffic flow are separated by 'time- segregation'. In bigger cities, a large number of police personnel are required simultaneously to control the traffic during the peak hours at most of the junctions with heavy traffic flow. Therefore, traffic signals are made use of to perform this function of traffic control at road intersections.

Traffic signals are automatic traffic control devices which could alternately direct the traffic to stop and proceed at intersections using red and green light signals as per the pre-determined time settings. The main requirements of traffic signals are:

i. To draw attention of the road users
ii. To enable them to understand the meaning of the light signal
iii. To provide sufficient time to respond
iv. To ensure minimum waste of time

The decision to install an automatic traffic control signal must be based on careful analysis of the existing traffic data and on sound engineering judgment. The major emphasis in the criteria for signal control is the volume of traffic entering the intersection and its crossing movements.

Advantages of Traffic signals

Properly designed traffic signals at intersections have the following advantages:

i. Provide orderly movement of traffic at the intersections
ii. The quality of traffic flow is improved by forming compact platoons of vehicles, provided all the vehicles move at approximately the same speed
iii. Reduction in accidents due to crossing conflict, notably the right angled collisions
iv. Traffic handling capacity is highest among the different types of intersections at-grade
v. Provide a chance to traffic of minor road to cross the continuous traffic flow of the main road at reasonable intervals of time
vi. Pedestrians can cross the roads safely at the signalized intersections
vii. When the signal system is properly co-ordinated, there is a reasonable speed along the major road traffic
viii. Automatic traffic signal may work out to be more economical when compared to manual control

Disadvantages of Traffic signals:

i. The rear-end collisions may increase
ii. Improper design and location of signals may lead to violations of the control system
iii. Failure of the signal due to electric power failure or any other defect may cause confusion to the road users
iv. The variation in vehicle arrivals on the approach roads may cause increase in waiting time on one of the roads and unused green signal time on other road, when fixed time traffic signals are used.

Types of Traffic signals:

The signals are classified into the following types:

a) Traffic control signals
b) Pedestrian signal

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c) Special traffic signal

The traffic control signals have three coloured lights which glow facing each direction of traffic flow namely, red, amber and green. The red light is meant for 'stop', the green light for 'go', and the amber or yellow light allows the 'clearance time' for the vehicles which enter the intersection area by the end of the green time to clear off the intersection, before the change-over to red signal light

Traffic control signals

Different types of traffic signals are in use in India namely, manually operated signals, fixed time automatic signals, and automatic traffic- actuated signals.

Each of manually operated signals is operated from a salient point at or near the intersection by a traffic police personnel; the signal phases may be varied depending on the traffic demand at that point of time.

The fixed time automatic traffic signal keeps repeating the same set of signal phases and the signal cycle time that has been set in the signal controller.

Traffic actuated signals are those in which the timings of the phase and cycle are changed according to traffic demand.

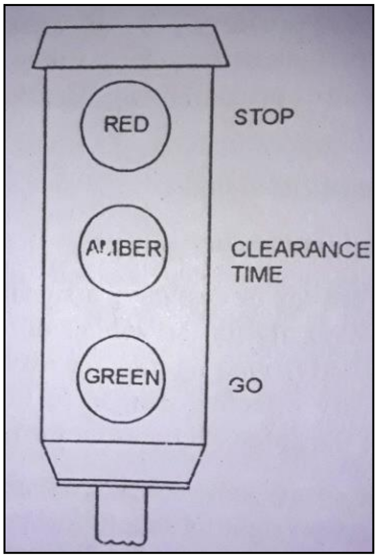

Fig. 2: Traffic signal head

RESULTS AND DISCUSSIONS

Objectives of signalized intersection design

Two important objectives of designing a signalized intersection are:

i. To provide sufficient intersection capacity for the volume of traffic entering the intersection from all the approach roads, and

ii. To minimize the overall delay to all the vehicles entering the intersection

The traffic control signal timings should be designed such that the cycle time should be optimum, keeping in view the actual traffic flow and the capacity flow on each approach road and the signal phases are apportioned depending on the respective volumes on each road. The cycle lengths are normally 50 to 70 seconds for two phase signal. Longer cycle lengths are in use for complex traffic flow and for more than two phases.

General principles of two-phase signal design

Let the two approach roads, designed as Road-1 and Road-2 have green, red and amber phases designated as G_1, R_1, A_1, and G_2, R_2 and A_2 respectively.

i. Stop time or red phase, R_1 for Road-1 of a signal is the sum of green phase and clearance interval or amber phases for the cross flow, i.e., $R_1 = (G_2 + A_2)$ at a two phase signal. During this interval, the pedestrian crossing time may also be incorporated for the road, if turning movements are not permitted

ii. Towards the end of red phase, there may be a short duration when the amber lights are put on along with red light signal in order to indicate 'get set' to go. This phase is the last part of red phase itself and may be called 'red-amber' or 'initial amber' phase. The vehicles are not allowed to cross the stop line during the red- amber period

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iii. Clearance time or clearance-amber phase is provided just after the green phase before the red phase, to fulfil the two requirements:
   a) To allow stopping time for approaching vehicle to stop at stop-line after the signal changes from green to amber and not to cross the line by the time the signal changes to red phase
   b) To allow clearance time for the vehicle which is approaching the stop-line at legal speed while the signal changes from green to amber, allowing sufficient time for the vehicle to cross the intersection area as it may not be possible for the vehicle to stop before the stop-line at that stage. Usually 2 to 4 seconds would be suitable for the amber phase so as to fulfil these two conditions.

iv. Go time or green time is decided based on the approach volume during peak hour and to enable the queued vehicles to clear off in most of the cycles

Approximate methods of Signal design:

There are two approximate methods or approximate design procedures generally employed in Traffic Signal design. They are

i. Trial Cycle method
ii. Approximate method based on pedestrian crossing requirement

The principles of the above two methods are hereby discussed as follows in detail.

I. Trial Cycle method

The 15-minute traffic count n_1 and n_2 on Road-1 and Road-2 are noted during the design peak hour flow. Suitable Trial cycle C_1 sec is assumed and the number of the assumed cycles in the 15 minutes or 15 × 60 seconds period is found to be $(15\times60)/C_1$, i.e., $(900)/C_1$. Assuming an average time headway of 2.5 sec, the green periods G_1 and G_2 of Road-1 and Road-2 are calculated to clear the traffic during the trail cycle.

$G_1 = \frac{2.5\, n_1 C_1}{900}$ and $G_2 = \frac{2.5\, n_2 C_2}{900}$

The amber periods A_1 and A_2 are either calculated or assumed suitably (3 to 4 seconds) and trail cycle length, is calculated as

$C_1' = (G_1 + G_2 + A_1 + A_2)$ sec

If the calculated cycle length C_1' works out to be approximately equal to the assumed cycle length C_1, the cycle length is accepted as the design cycle. Otherwise the trials are repeated till the trial cycle length works out to be approximately equal to the calculated value. The design procedure is explained with the aid of a suitable example as illustrated below.

Problem Statement: The 15-minute traffic counts on cross roads 1 and 2 during peak hour are observed as 178 and 142 vehicles per lane respectively approaching the intersection in the direction of the heavier traffic flow. If the amber times required are 3 and 2 seconds respectively for the two roads based on approach speeds, design the signal timings by trial cycle method. Assume average time headway as 2,5 seconds during green phase.

Solution:

Given 15-minute traffic counts $n_1 = 178$ and $n_2 = 142$, $A_1 = 3$ sec, $A_2 = 2$ sec, $H_t = 2.5$ sec

Trial (i)

Assume a trial cycle $C_1 = 50$ sec

Number of cycles in 15 min = $\frac{900}{50} = 18$

Green time for Road-1, allowing average time headway of 2.5 sec per vehicle,

$G_1 = \frac{178 \times 2.5}{18} = 24.7$ sec

Similarly for Road-2, $G_2 = \frac{142 \times 2.5}{18} = 19.7$ sec

Amber times A_1 and A_2 are 3 and 2 sec (given)

Total cycle length, $C = (G_1 + G_2 + A_1 + A_2)$
$= 24.7 + 19.7 + 3.0 + 2.0$
$= 49.4$ sec

As this is lower than the assumed trial cycle of 50 sec, another lower cycle length may be tried.

Trial (ii)

Assume a trial cycle $C_2 = 40$ sec

Number of cycles in 15 min = $\frac{900}{40} = 22.5$

Green time for Road-1, allowing average time headway of 2.5 sec per vehicle,

$G_1 = \frac{178 \times 2.5}{22.5} = 19.8$ sec

Similarly for Road-2, $G_2 = \frac{142 \times 2.5}{22.5} = 15.8$ sec

Amber times A_1 and A_2 are 3 and 2 sec (given)

Total cycle length, $C = (G_1 + G_2 + A_1 + A_2)$
$= 19.8 + 15.8 + 3.0 + 2.0$
$= 40.6$ sec

As this is higher than the assumed trial cycle of 50 sec, another higher cycle length may be tried.

Trial (iii)

Assume a trial cycle $C_3 = 45$ sec

Number of cycles in 15 min = $\frac{900}{45} = 20$

Green time for Road-1, allowing average time headway of 2.5 sec per vehicle,

$G_1 = \frac{178 \times 2.5}{20} = 22.25$ sec

Similarly for Road-2, $G_2 = \frac{142 \times 2.5}{20} = 17.75$ sec

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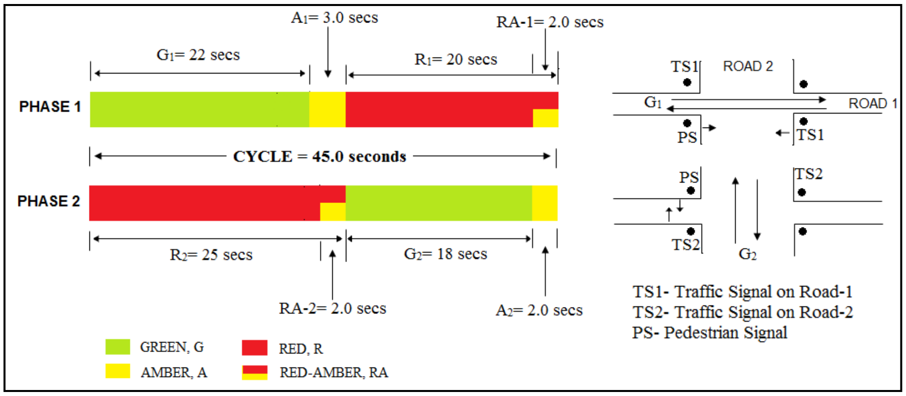

Fig. 3: Typical Phase Diagram and details of Traffic Signal Setting using Trial Cycle Method

Amber times A_1 and A_2 are 3 and 2 sec (given)
Total cycle length, $C = (G_1 + G_2 + A_1 + A_2)$
$= 22.25+17.75+3.0+2.0$
$= 45.0$ sec
Therefore, the trial cycle of 45 sec may be adopted with the following signal phases:
$G_1 = 22.25$, say adopt $G_1 = 22$ sec
$G_2 = 17.75$, say adopt $G_2 = 18$ sec
Adopt $A_1 = 3$ sec, $A_2 = 2$ sec
Total cycle length, $C = (G_1 + G_2 + A_1 + A_2)$
$= 22.0 + 18.0 + 3.0 + 2.0$
$= 45.0$ sec
A typical layout of traffic control signals with pedestrian signals at the intersection of cross roads and the traffic signal phase settings for a single cycle time of 45 sec are shown in Fig. 3.

II. Approximate method based on pedestrian crossing requirement:

The following design procedure is suggested for the approximate design of a two-phase traffic signal unit at cross roads, along with pedestrian signals:

a) Based on pedestrian walking speed of 1.2 m per second and the roadway width of each approach road, the minimum time for the pedestrian to cross each road is also calculated

b) Total pedestrian crossing time is taken as the sum of the minimum pedestrian crossing time and the initial interval for pedestrians to start crossing, which should not be less than 7 sec. During this period when the pedestrians will be crossing the road, the traffic signal shall indicate red or 'stop'.

c) The red signal time is also equal to the minimum green time plus amber time for the traffic of the cross road

d) The actual green time needed for the road with higher traffic is then increased in proportion to the ratio of approach volumes of the two roads in vehicles per hour per lane

e) Based on approach speeds of the vehicles, the suitable clearance interval between green and red period, i.e., clearance amber periods are selected. The amber periods may be taken as 2, 3, or 4 seconds for low, medium, and fast approach speeds

f) The cycle length so obtained is adjusted for the next higher 5 sec interval; the extra time is then distributed to green timings in proportion to the traffic volumes

g) The timings so obtained are installed in the controller and the operations are then observed at the site during peak traffic hours; modifications in signal timings are carried out if needed.

The design of a simple two-phase signal is illustrated by an example given below.

Problem Statement: An isolated traffic signal with pedestrian indication is to be installed on a right angled intersection with road A, 18 m wide and road B, 12 m wide. During the peak hour, traffic volume per hour per lane of road A and road B are 275 and 225 respectively. The approach speeds are 55 and 40 kmph, on roads A and road B respectively. Assume pedestrian crossing speed as 1.2 m per sec. Design the timings of two-phase traffic and pedestrian signals by the approximate method.

Solution:

Given: widths of road A = 18 m and of road B = 12 m, traffic volumes on road A = 275 and on road B =

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225 vehicles/ lane/ hour, Approach speeds on road A = 55, and on road B = 40 kmph, Pedestrian crossing speed = 1.2 m/sec

Design of two-phase traffic control signals:

Pedestrian crossing/ clearance time for Road A = $\frac{18}{1.2}$ = 15 sec

Pedestrian crossing/ clearance time for Road B = $\frac{12}{1.2}$ = 10 sec

Adding 7 sec for initial walking period, minimum red time for traffic of road A, R_A is (15 + 7) = 22 sec and that for road B, R_B is (10 + 7) = 17 sec

Minimum green time, G_B for traffic of road B, based on pedestrian crossing requirement = 22 – 3 = 19 sec

Minimum green time, G_A for traffic of road A, based on pedestrian crossing requirement = 17 – 4 = 13 sec

The minimum green time calculated for road A is with respect to pedestrian crossing time required for the narrower road B. As road A has higher traffic volume per lane than road B, the green time of road A has to be higher than that of road B; the increase may be in proportion to the approach volume of road A with respect to that of road B.

Let G_A and G_B be the green times and n_A and n_B be the approach volume per lane

Using the relation, $\frac{G_A}{G_B} = \frac{n_A}{n_B}$

Green time, G_B for traffic is taken as the minimum value = 19 sec as obtained from pedestrian crossing criterion for the wider road A

Green time, G_A for traffic of road A may be increased in proportion to the higher traffic volume using the relation

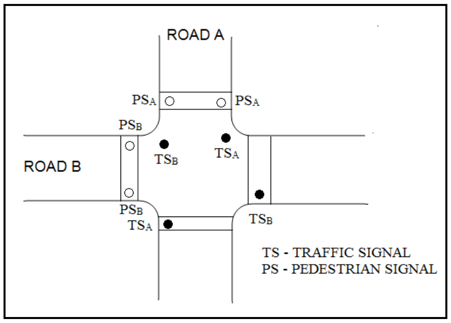

Fig. 4(a): Placement of Traffic control and Pedestrian control signal

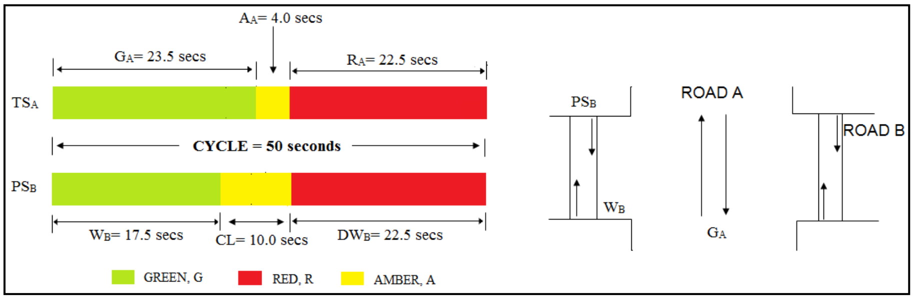

Fig. 4(b): Traffic and Pedestrian Signal time settings for PHASE 1

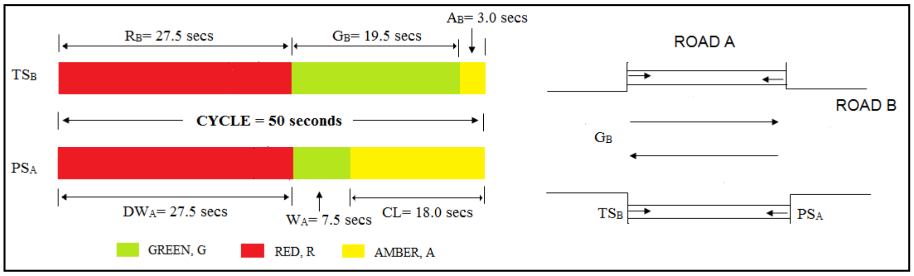

Fig. 4(c): Traffic and Pedestrian Signal time settings for PHASE 2

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$G_A = \frac{n_A}{n_B} G_B = \frac{275}{225} \times 19 = 23.2$ sec
Based on the approach speed of 55 kmph for road A, amber period, $A_A = 4$ sec
For road B with approach speed 40 kmph, amber period, $A_B = 3$ sec
Total cycle length, C $= (G_A + A_A + R_A)$
$= (G_A + A_A + G_B + A_B)$
$= 23.2 + 4 + 19 + 3$
$= 49.2$ sec
Therefore adopt signal cycle length of 50 sec
The additional period of (50 – 49.2) = 0.8 sec is distributed to green timings in proportion to the approach traffic volume. Therefore the revised signal phases are:
$G_A = 23.2 + 0.44 = 23.64$ sec, say 23.5 sec
$G_B = 19.0 + 0.36 = 19.36$ sec, say 19.5 sec
$R_A = G_B + A_B = 19.5 + 3.0 = 22.5$ sec
$R_B = G_A + A_A = 23.5 + 4.0 = 27.5$ sec
Therefore cycle time, C = 23.5 + 19.5 + 4 + 3 = 50 sec
Design of pedestrian signals:
Do not Walk (DW) period of pedestrian signal at road A (PS_A) is the red period of traffic signal at B
For PS_A, $DW_A = R_B = 27.5$ sec
For PS_B, $DW_B = R_A = 22.5$ sec
Pedestrian clearance intervals (CI) are of 15 and 10 sec respectively, for roads A and B for crossing. The walk time (W) is calculated from the total cycle length
For PS_A, $W_A = 50 – (27.5 + 15) = 7.5$ sec
For PS_B, $W_B = 50 – (27.5 + 15) = 17.5$ sec
A typical layout of traffic control signals with pedestrian signals at the intersection of cross roads is shown in Fig. 4(a). A phase diagram may be drawn incorporating the above values of traffic and signal time settings, as shown in Fig. 4(b) and 4(c).

CONCLUSION

Thus, the entire study has reflected the simplicity and the comparatively easier methodology involved in the approximate methods, namely, the Trial Cycle method and the approximate method based on the requirements of the pedestrian crossings, to arrive at an effective but quite simple design of Two-Phase Traffic Signal at road intersections. Hence they can be utilized to prevent accidents and other mishaps that are continuously increasing day by day at road intersections due to ineffective governance and the lack of proper implications of the Traffic Signal Design.

So if we see from all the different aspects and considerations, it is worth studying the approximate methods in the design of Traffic Signals in intricate details, an earnest and petite example being this discussion.

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