Chapter 41

Traffic signal design-I

41.1 Overview

The conflicts arising from movements of traffic in different directions is solved by time sharing of the facility. The advantages of traffic signal includes an orderly movement of traffic, an increased capacity of the intersection and requires only simple geometric design. However the disadvantages of the signalized intersection are it affects larger stopped delays, and the design requires complex considerstions. Although the overall delay may be lesser than a rotary for a high volume, a user is more concerned about the stopped delay.

41.2 Defintions and notations

A number of definitions and notations are there to be understood in signal design. They are discussed below:

1. Cycle: A signal cycle is one complete rotation through all of the indications provided.
2. Cycle length: Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of of green for one approach till the next time the green starts. It is given by the symbol "C".
3. Interval: Thus it indicates the change from one stage to another. There are two types of intervals - change interval and clearance interval. *Change interval* which is also called the yellow time indicates the interval between the green and red signal indications for an approach. *Clearance interval* which is also called "all red" is included after each yellow interval indicating a period during which all signal faces show red and is used for clearing off the vehicles in the intesection.
4. Green interval: It is the green indication for a particular movement or set of movements and is denoted by G_i.
5. Red interval: It is the red indication for a particular movement or set of movements and is denoted by R_i.
6. Phase: A phase is the green interval plus the change and clearance intervals that follow it. Thus it is the assigning of conflicting movements into separate groups. It allows a set of movements to flow and safely halt the flow before another set of movements.
7. Lost time: It indicates the time during which the intersection is not effectively utilized for any movement.

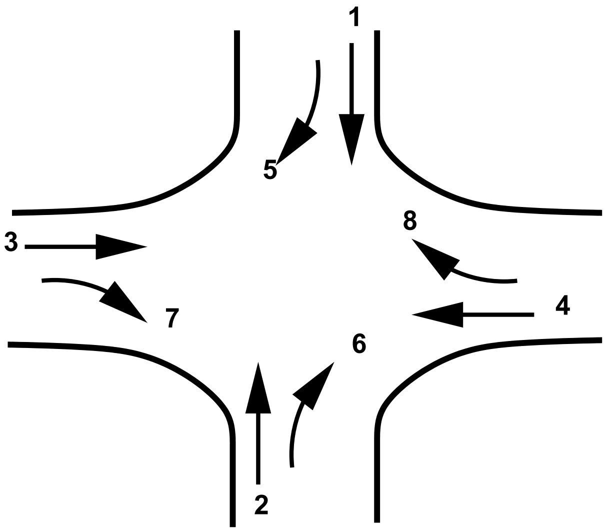

Figure 41:1: Four legged intersection

For eg, when the signal for an aproach turns from red to green, the driver of the vehicle which is in the front of the queuee, will take some time to percieve the signal (usually called as reaction time) and some time will be lost here before he moves. That reaction time is referred to as the lost time.

41.3 Signal design procedure

The signal design procedure involves six major steps. They include the phase design, determination of amber time and clearance time, determination of cycle length, apportioning of green time, pedestrian crossing requirements, and the performance evaluation of the above design.

The objective of phase design is to separate the conflicting movements in an intersection into various phases, so that movements in a phase should have no conflicts. If all the movements are to be separated with no conflicts, then a large number of phases are required. In such a situation, the objective is to design phases with minimum conflicts or with less severe conflicts.

There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, flow pattern especially the turning movements, the relative magnitudes of flow. Therefore, a trial and error procedure is often adopted. However, phase design is very important because it affects the further design steps. Further, it is easier to change the cycle time and green time when flow pattern changes, where as a drastic change in the flow pattern may cause considerable confusion to thedrivers. To illustrate various phase plan options, consider a four legged intersection with through traffic and right turns. Left turn is ignored. See figure 41:1

The first issue is to decide how many phases are required. It is possible to have two, three, four or even more number of phases.

41.3.1 Two phase signals

Two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in figure 41:2, non-conflicting through traffic 3 and 4 are grouped in a single phase and non-conflicting

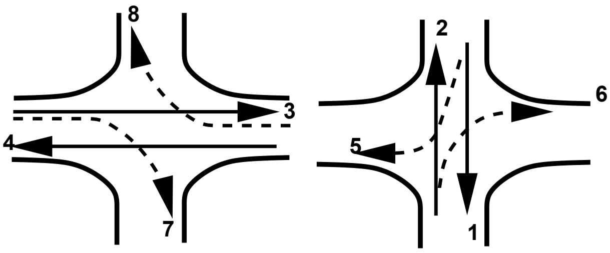

Figure 41:2: Two phase signal

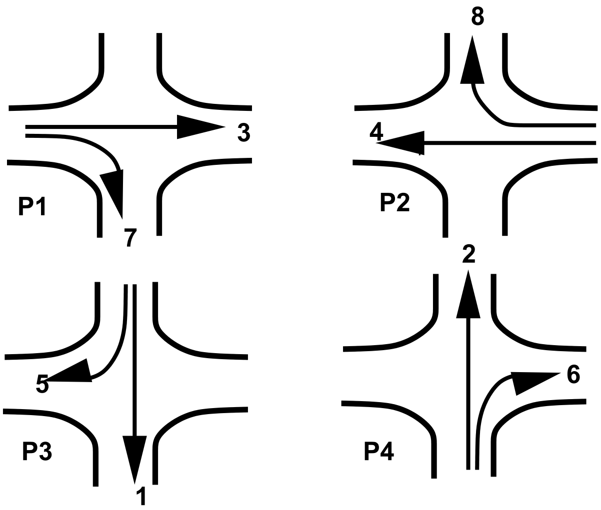

Figure 41:3: One way of providing four phase signals

through traffic 1 and 2 are grouped in the second phase. However, in the first phase flow 7 and 8 offer some conflicts and are called permitted right turns. Needless to say that such phasing is possible only if the turning mmovements are relatively low. On the other hand, if the turning movements are significant ,then a four phase system is usually adopted.

41.3.2 Four phase signals

There are atleast three possible phasing options. For example, figure 41:3 shows the most simple and trivial phase plan.

Here, flow from each approach is put into a single phase avoiding all conflicts. This type of phase plan is ideally suited in urban areas where the turning movements are comparable with through movements and when through traffic and turning traffic need to share same lane. This phase plan could be very inefficient when turning movements are relatively low.

Figure 41:4 shows a second possible phase plan option where opposing through traffic are put into same phase.

The non-conflicting right turn flows 7 and 8 are grouped into a third phase. Similarly flows 5 and 6 are grouped into fourth phase. This type of phasing is very efficient when the intersection geometry permits to have

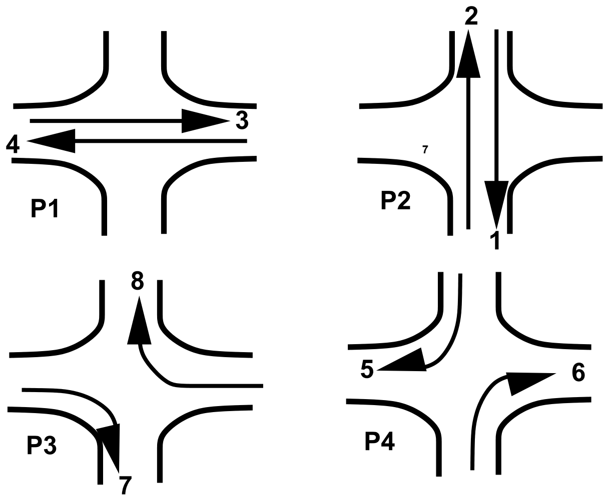

Figure 41:4: Second possible way of providing a four phase signal

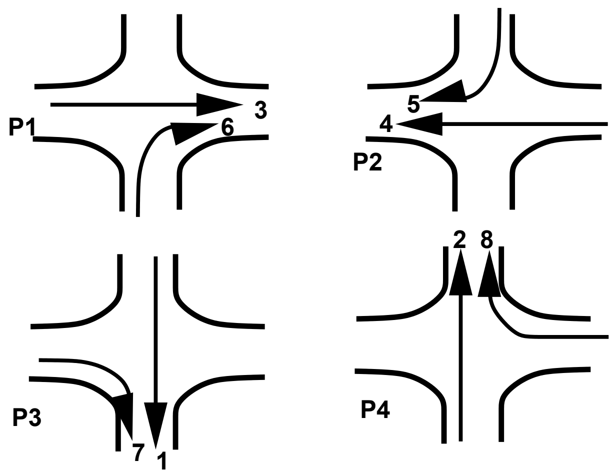

Figure 41:5: Third possible way of providing a four-phase signal

atleast one lane for each movement, and the through traffic volume is significantly high. Figure 41:5 shows yet another phase plan.

There are five phase signals, six phase signals etc. But they are used in the case of adaptive siganls, that is the signals which are highly responsive to the real time traffic. They include the combination of basic four phases.

41.4 Interval design

There are two intervals, namely the change interval and clearance interval normally provided in a traffic signal. The change interval or yellow time is provided after green time for movement. The purpose is to warn a driver approaching the intersection during the end of a green time about the coming of a red signal. They normally have a value of 3 to 6 seconds.

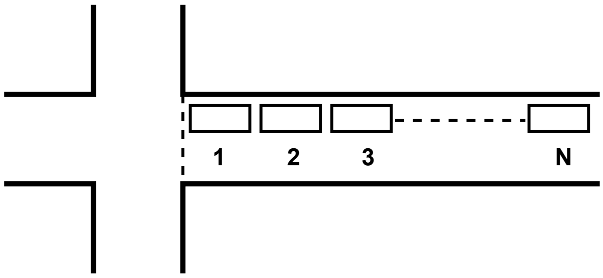

Figure 41:6: Group of vehicles at a signalised intersection waiting for green signal

The design consideration is that a driver approaching the intersection with design speed should be able to stop at the stop line of the intersection before the start of red time. ITE's recommended methodology for computing the appropriate length of change interval is as follows:

$$y = t + \frac{v_{85}}{2a + 19.6g} \tag{41.1}$$

where y is the length of yellow interval in seconds, t is the reaction time of the driver, v_{85} is the 85^{th} percentile speed of approaching vehicles in m/s, a is the decceleration rate of vehicles in m/s^2, g is the grade of approach expressed as a decimal. Change interval can also be approximately computed as $y = \frac{SSD}{v}$, where SSD is the stopping sight distance and v is the speed of the vehicle. The clearance interval is provided after yellow interval and as mentioned earlier, it is used to clear off the vehicles in the intersection. Clearance interval is optional in a signal design. It depends on the geometry of the intersection. If the intersection is small, then there is no need of clearance interval whereas for very large intersections, it may be provided.

41.5 Cycle time

Cycle time is the time taken by a signal to complete one full cycle of iterations. i.e. one complete rotation through all signal indications. It is denoted by the letter C. The way in which the vehicles depart from an intersection when the green signal is initiated will be discussed now. Figure 41:6 illustrates a group of N vehicles at a signalised intersection, waiting for the green signal. As the signal is initiated, the time interval between two vehicles, referred as headway crossing the curb line is noted. The first headway is the time interval between the initiation of the green signal and the vehicle crossing the curb line whereas the second headway is the time interval between the first and the second vehicle crossing the curb line. Successive headways are then plotted as in figure 41:7.

The first headway will be relatively longer since it includes the reaction time of the driver and the time necessary to accelerate. The second headway will be comparitively lower because the second driver ca overlap his/her reaction time with that of the first driver's. Finally we can see that the headways level out. The level headway which characterises all headways begining with the fourth or fifth vehicle, is defined as the saturation headway, and is denoted as h in the figure. This is the headway that can be achieved by a stable moving platoon of vehicles passing through a green indication. If every vehicles require h seconds of green time, and if the signal were always green, then s vehicles/per hour would enter the intersection. This s is called saturation flow rate. Thus,

$$s = \frac{3600}{h} \tag{41.2}$$

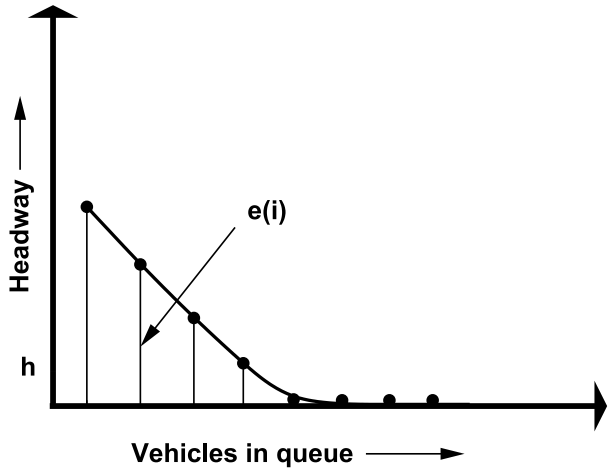

Figure 41:7: Headways departing signal

where s is the saturation flow rate in vphgl, h is the saturation headway in seconds. The unit of saturation flow rate is vehicles per hour of green time per lane. But we know that the signal wont be green always. Also the headway will be more than h paricularly for the first 4 or 5 vehicles. This difference between the actual headway and h is denoted as e(i) as shown in figure 41:7. These differences can be added for the first few vehicles,

$$l_1 = \sum_{i=1}^{n} e(i) \tag{41.3}$$

The green time required to clear N vehicles can be found out as,

$$T = l_1 + h(N) \tag{41.4}$$

where T is the time required to clear N vehicles through signal, l_1 is the start-up lost time, h is the saturation headway in seconds.

41.5.1 Effective green time

There is another concept to find the amount of green time available. This is called effective green time. It is the sum of actual green time (G_i) plus the yellow and all red times (Y_i) minus the applicable lost times. This lost time is the sum of start-up lost time (l_1) and clearance lost time (l_2). Thus effective green time can be written as,

$$g_i = G_i + Y_i - t_L \tag{41.5}$$

41.5.2 Lane capacity

The ratio of effective green time to the cycle length ($\frac{g_i)}{C}$)is defined as green ratio. We know that saturation flow rate is the number of vehicles that can be moved in one lane in one hour assuming the signal to be green always. Then the capacity of the lane can be computed as,

$$c_i = s_i \frac{g_i}{C} \tag{41.6}$$

where c_i is the capacity of lane in vehicle per hour, s_i is the saturation flow rate in vehicle per hour per lane, C is the cycle time in seconds.

Problem

For a movement at a signalised intersection green time is given as 27 seconds, 3 seconds for yellow plus all red out of a 60 seconds cycle. If the satutration headway is 2.4 seconds/vehicle, the start-up lost time is 2 seconds/phase and the clearance lost time is 1 second/phase, find the capacity of the movement per lane?

Solution

Lost time, t_L = 2+1 = 3 From equation 41.5 effective green time, g_i = 27+3-3 = 27 seconds

From equation 41.2 saturation flow rate, $s_i = \frac{3600}{h} = \frac{3600}{2.4} = 1500$ veh/hr.

Capacity of the movement per lane can be found out from equation 41.6 as $C_i = 1500 \times \frac{27}{60} = 675$ veh/hr/lane.

41.5.3 Critical lane

During any green signal phase, several lanes on one or more approaches are permitted to move. One of these will have the most intense traffic. Thus it requires more time than any other lane moving at the same time. If sufficient time is allocated for this lane, then all other lanes will also be well accommodated. There will be one and only one critical lane in each signal phase. The volume of this critical lane is called critical lane volume.

41.6 Determination of cycle length

The cycle length or cycle time is the time taken for complete indication of signals in a cycle. Fixing the cycle length is one of the crucial steps involved in signal design.

If t_{Li} is the start-up lost time for a phase i, then the total start-up lost time per cycle, $L = \sum_{i=1}^{N} t_L$, where N is the number of phases.

If start-up lost time is same for all phases, then the total start-up lost time is $L = Nt_L$.

Number of cycles per hour = $\frac{3600}{C}$

The total lost time per hour = $\frac{3600}{C}.L$

Substituting as $L = Nt_L$, total lost time per hour can be written as = $\frac{3600.N.t_l}{C}$

The total effective green time available for the movement in a hour will be one hour minus the total lost time in an hour. It is given by, $T_g = 3600 - \frac{3600.N.t_L}{C}$

Total number of critical lane volume that can be accommodated per hour is given by V_c as, $V_c = \frac{T_g}{h}$

Substituting for T_g, the maximum sum of critical lane volumes that can be accommodated within the hour is,

$$V_c = \frac{3600}{h}[1 - \frac{N.t_L}{C}] \quad (41.7)$$

$$= S_i[1 - \frac{N.t_L}{C}] \quad (41.8)$$

$$C = \frac{N.t_L}{1 - \frac{V_c}{S}} \quad (41.9)$$

(41.10)

It is assumed that there will be uniform flow of traffic in an hour. To account for the variation of volume in an hour, a factor called peak hour factor which is the ratio of hourly volume to the maximum flow rate is introduced. Another ratio called v/c ratio indicating the quality of service is also included in the equation.

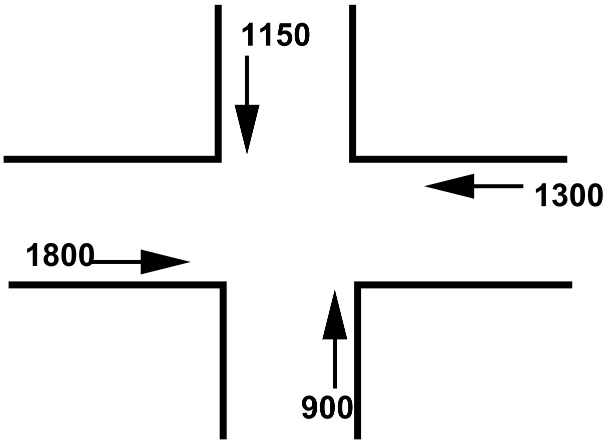

Figure 41:8: Traffic flow in the intersection

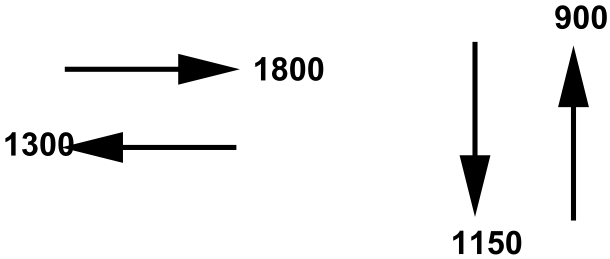

Figure 41:9: One way of providing phases

Incorporating these two factors in the equation for cycle length, the final expression will be,

$$C = \frac{N.t_L}{1 - \frac{V_c}{S_i \times PHF \times \frac{v}{c}}} \tag{41.11}$$

Highway capacity manual (HCM) has given an equation for determining the cycle length which is as follows:

$$C = \frac{N.L.X_C}{X_C - \Sigma(\frac{V}{S})_i} \tag{41.12}$$

where N is the number of phases, L is the lost time per phase, $(\frac{V}{S})_i$ is the ratio of volume to saturation flow for phase i, X_C is the quality factor called critical $\frac{V}{C}$ratio where V is the volume and C is the capacity.

Problem

The traffic flow in an intersection is shown in the figure 41:8 below.

Given start-up lost time is 3 seconds, saturation head way is 2.3 seconds, compute the cycle length for the signal in that intersection.

Solution

If we assign the phases as shown below figure 41:9, the critical volume for the first phase which is the maximum of the flows in that phase = 1150 vph

Similarly critical volume for the second phase = 1800 vph

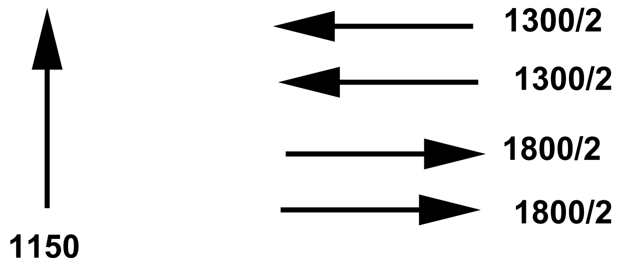

Figure 41:10: second way of providing phases

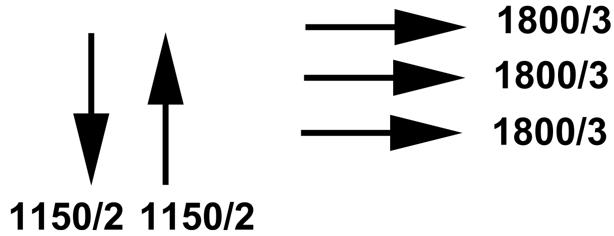

Figure 41:11: Third way of providing phases

Total critical volume for the two signal phases = 1150+1800 = 2950 vph

Saturation flow rate for the intersection can be found out from the equation 41.2 as $S_i = \frac{3600}{2.3} = 1565.2$ vph

The intersection can handle only 1565.2 vph, but the critical volume is 2950 vph .

Therefore the total of the critical lane volumes should be reduced by breaking them as shown below. So assigning the phases as shown below (41:10),

Here we are dividing the lanes in East-West direction into two, the critical volume in the first phase is 1150vph and in the second phase it is 900vph. The total critical volume for the signal phases is 2050 vph which is again greater than the saturation flow rate and hence we have to again reduce the lane volumes.

Assigning three lanes in East-West direction, as shown in figure 41:11, the critical volume in the first phase is 575 vph and that in the second phase is 600 vph, total critical lane volume = 575+600 = 1175 vph which is lesser than 1565.2 vph.

Now the cycle time for the signal phases can be computed from equation 41.10 as,

$C = \frac{2\times3}{1-\frac{1175}{1565.2}} = 24$ seconds

41.7 Summary

Traffic signal is an aid to control traffic at intersections where other control measures fail. The signals operate by providing right of way to a certain set of movements in a cyclic order. Depending on the requirements they can be either fixed or vehicle actuated and two or multiphased. The design procedure discussed in this chapter include interval design, determination of cycle time, and computation of saturation flow making use of HCM guidelines.

41.8 Problems