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 principle. 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 considerations. 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 Definitions and notations

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

- **Cycle**: A signal cycle is one complete rotation through all of the indications provided.
- **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 denoted by C.
- **Interval**: Thus it indicates the change from one stage to another. There are two types of intervals - change interval and clearance interval. *Change interval* is also called the yellow time indicates the interval between the green and red signal indications for an approach. *Clearance interval* 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 intersection.
- **Green interval**: It is the green indication for a particular movement or set of movements and is denoted by G_i. This is the actual duration the green light of a traffic signal is turned on.
- **Red interval**: It is the red indication for a particular movement or set of movements and is denoted by R_i. This is the actual duration the red light of a traffic signal is turned on.
- **Phase**: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.
- **Lost time**: It indicates the time during which the intersection is not effectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is

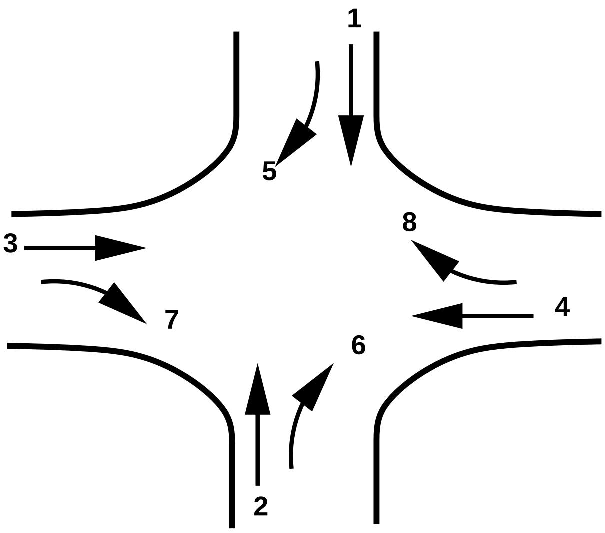

Figure 41:1: Four legged intersection

in the front of the queue, will take some time to perceive the signal (usually called as reaction time) and some time will be lost here before he moves.

41.3 Phase design

The signal design procedure involves six major steps. They include the (1) phase design, (2) determination of amber time and clearance time, (3) determination of cycle length, (4)apportioning of green time, (5) pedestrian crossing requirements, and (6) 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 the drivers. 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 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

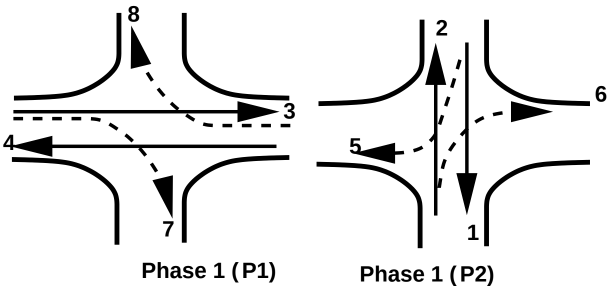

Figure 41:2: Two phase signal

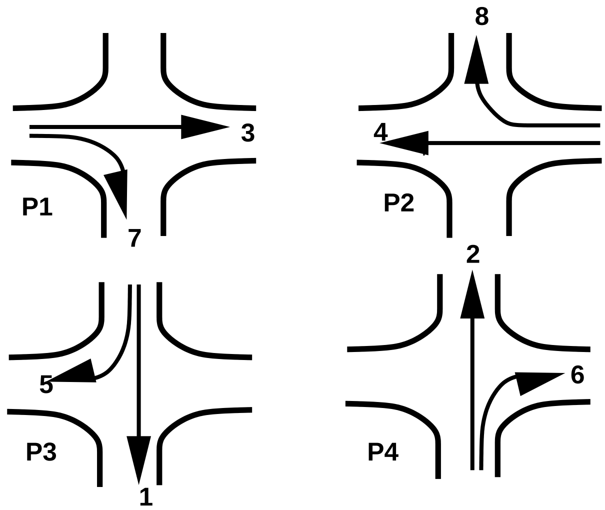

Figure 41:3: One way of providing four phase signals

movements 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 at least three possible phasing options. For example, figure 41:3 shows the most simple and trivial phase plan. where, 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 at least one lane for each movement, and the through traffic volume is significantly high. Figure 41:5 shows yet another phase plan. However, this is rarely used in practice.

There are five phase signals, six phase signals etc. They are normally provided if the intersection control is adaptive, that is, the signal phases and timing adapt to the real time traffic conditions.

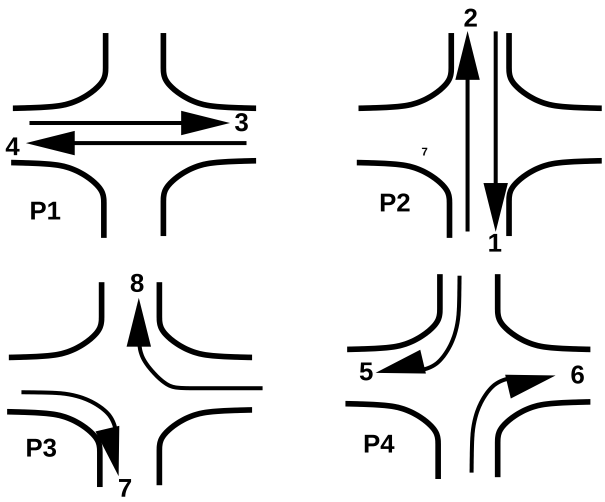

Figure 41:4: Second possible way of providing a four phase signal

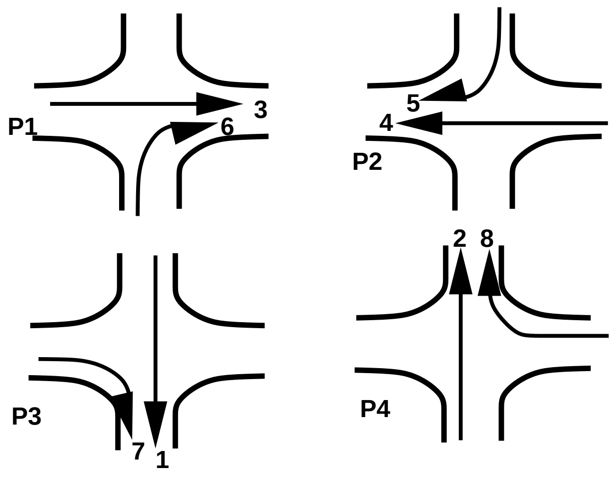

Figure 41:5: Third possible way of providing a four-phase signal

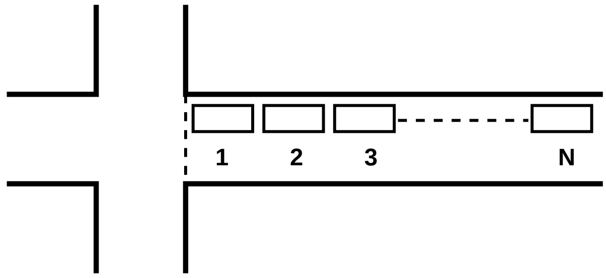

Figure 41:6: Group of vehicles at a signalized intersection waiting for green signal

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.

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. Institute of transportation engineers (ITE) has recommended a methodology for computing the appropriate length of change interval which 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 deceleration 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 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 signalized 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 instant vehicle crossing the curb line. 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 comparatively lower because the second driver can overlap his/her reaction time with that of the first driver's. After few vehicles, the headway will become constant. This constant headway which characterizes all headways beginning with the fourth or fifth vehicle, is defined as the saturation headway, and is denoted as h. This is the headway that can be achieved by a stable

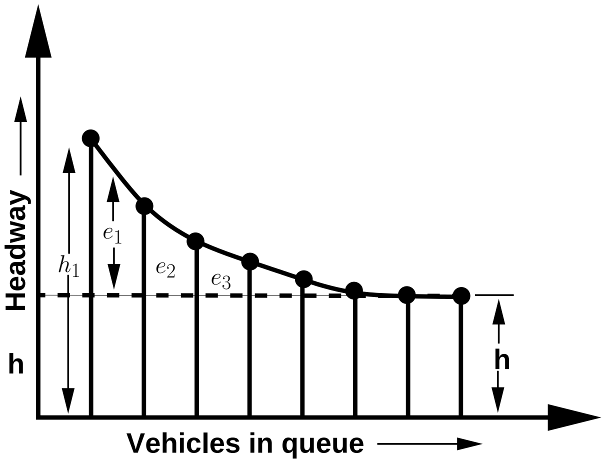

Figure 41:7: Headways departing signal

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 pass the intersection. Therefore,

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

where s is the saturation flow rate in vehicles per hour of green time per lane, h is the saturation headway in seconds. vehicles per hour of green time per lane. As noted earlier, the headway will be more than h particularly for the first few vehicles. The difference between the actual headway and h for the i^{th} vehicle and is denoted as e_i shown in figure 41:7. These differences for the first few vehicles can be added to get start up lost time, l_1 which is given by,

$$l_1 = \sum_{i=1}^{n} e_i \tag{41.3}$$

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, and h is the saturation headway in seconds.

41.5.1 Effective green time

Effective green time is the actual time available for the vehicles to cross the intersection. It is the sum of actual green time (G_i) plus the yellow minus the applicable lost times. This lost time is the sum of start-up lost time (l_1) and clearance lost time (l_2) denoted as t_L. 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 a 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

Let the cycle time of an intersection is 60 seconds, the green time for a phase is 27 seconds, and the corresponding yellow time is 4 seconds. If the saturation 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 Total lost time, t_L = 2+1 = 3 seconds. From equation effective green time, g_i = 27+4-3 = 28 seconds. From equationsaturation flow rate, $s_i = \frac{3600}{h} = \frac{3600}{2.4} = 1500$ veh/hr. Capacity of the given phase can be found out from equation,$C_i = 1500 \times \frac{28}{60} = 700$ 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 $L = Nt_L$. If C is the cycle length in seconds, then the number of cycles per hour = $\frac{3600}{C}$ The total lost time per hour is the number of cycles per hour times the lost time per cycle and is = $\frac{3600}{C}.L$ 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 T_g available for the movement in a hour will be one hour minus the total lost time in an hour. Therefore,

$$T_g = 3600 - \frac{3600.N.t_L}{C} \tag{41.7}$$

$$= 3600 \left[1 - \frac{N.t_L}{C}\right] \tag{41.8}$$

(41.9)

Let the total number of critical lane volume that can be accommodated per hour is given by V_c, then $V_c = \frac{T_g}{h}$ Substituting for T_g, from equation 41.9 and s_i from the maximum sum of critical lane volumes that can be accommodated within the hour is given by,

$$= \frac{T_g}{h} \tag{41.10}$$

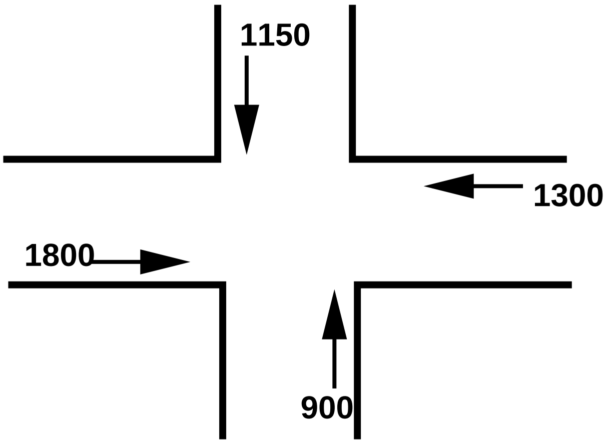

Figure 41:8: Traffic flow in the intersection

$$V_c = \frac{3600}{h}\left[1-\frac{N.t_L}{C}\right] \quad (41.11)$$

$$= s_i\left[1-\frac{N.t_L}{C}\right] \quad (41.12)$$

$$Therefore\ C = \frac{N.t_L}{1-\frac{V_c}{s}} \quad (41.13)$$

$$(41.14)$$

The expression for C can be obtained by rewriting the above equation. The above equation is based on the assumption 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, (PHF) 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. Incorporating these two factors in the equation for cycle length, the final expression will be,

$$C = \frac{N.t_L}{1-\frac{V_c}{s_i \times PHF \times \frac{v}{c}}} \quad (41.15)$$

Highway capacity manual (HCM) has given an equation for determining the cycle length which is a slight modification of the above equation. Accordingly, cycle time C is given by,

$$C = \frac{N.L.X_C}{X_C - \Sigma(\frac{V}{s})_i} \quad (41.16)$$

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

Solution

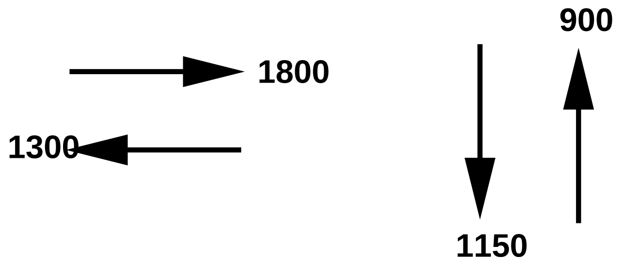

Figure 41:9: One way of providing phases

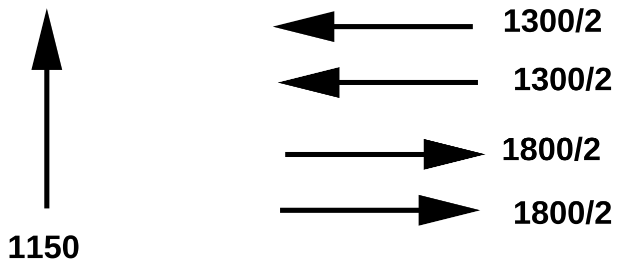

Figure 41:10: second way of providing phases

- If we assign two phases as shown below figure 41:9, then 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. Therefore, 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 as $s_i = \frac{3600}{2.3} = 1565.2$ vph. This means, that the intersection can handle only 1565.2 vph. However, the critical volume is 2950 vph . Hence the critical lane volume should be reduced and one simple option is to split the major traffic into two lanes. So the resulting phase plan is as shown in figure (41:10).
- Here we are dividing the lanes in East-West direction into two, the critical volume in the first phase is 1150 vph and in the second phase it is 900 vph. 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 critical 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 of the second phase is 600 vph, so that the 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,$C = \frac{2\times 3}{1-\frac{1175}{1565.2}} = 24$ 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 multivalued. The design procedure discussed in this chapter

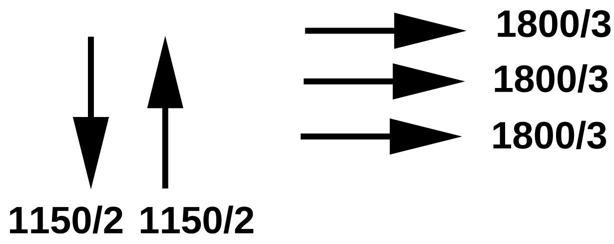

Figure 41:11: Third way of providing phases

include interval design, determination of cycle time, and computation of saturation flow making use of HCM guidelines.

41.8 Problems

1. Saturation flow rate can be computed as,
   (a) $\frac{3600}{h}$
   (b) $\frac{h}{3600}$
   (c) 3600×h
   (d) none of these
2. Lane capacity is
   (a) $c_i = s_i \times \frac{g_i}{C}$
   (b) $c_i = s_i \times g_i$
   (c) $c_i = \frac{s_i}{C}$
   (d) none of these

41.9 Solutions

1. Saturation flow rate can be computed as,
   (a) $\frac{3600}{h}\surd$
   (b) $\frac{h}{3600}$
   (c) 3600×h
   (d) none of these
2. Lane capacity is
   (a) $c_i = s_i \times \frac{g_i}{C}\surd$
   (b) $c_i = s_i \times g_i$
   (c) $c_i = \frac{s_i}{C}$
   (d) none of these