4.4 SIGNALIZED INTERSECTION

Traffic Signal Design

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 .
- 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 . 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 . 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 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.

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 1.

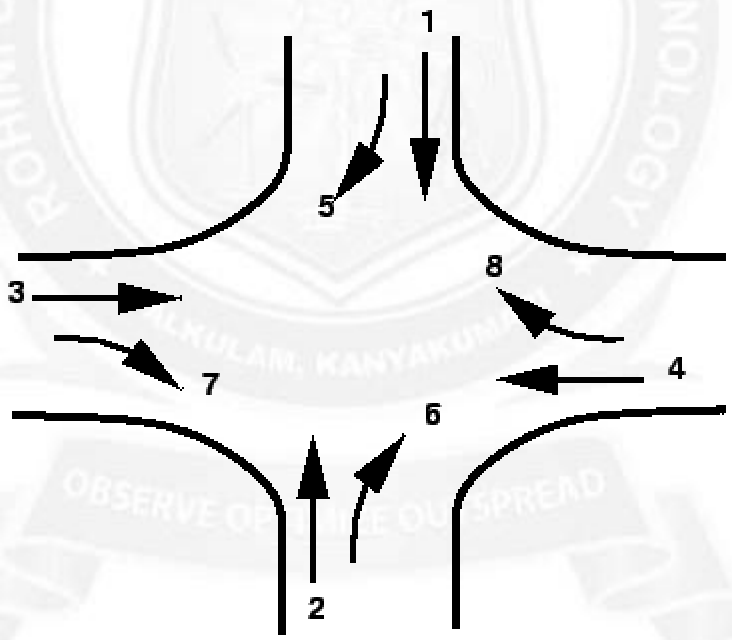

Figure 1: Four legged intersection

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.

Two phase signals

Two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in figure 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.

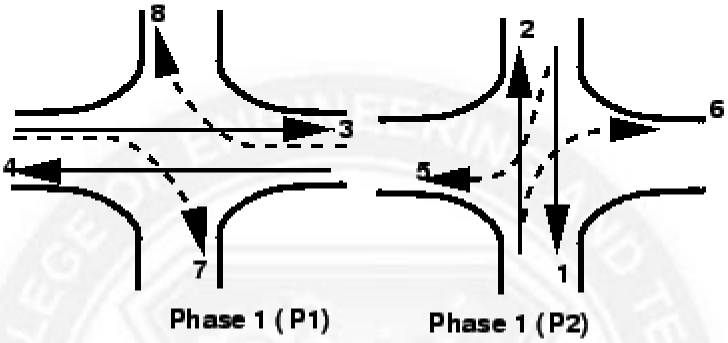

Figure 2: Two phase signal

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 movements are relatively low. On the other hand, if the turning movements are significant ,then a four phase system is usually adopted.

Four phase signals

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

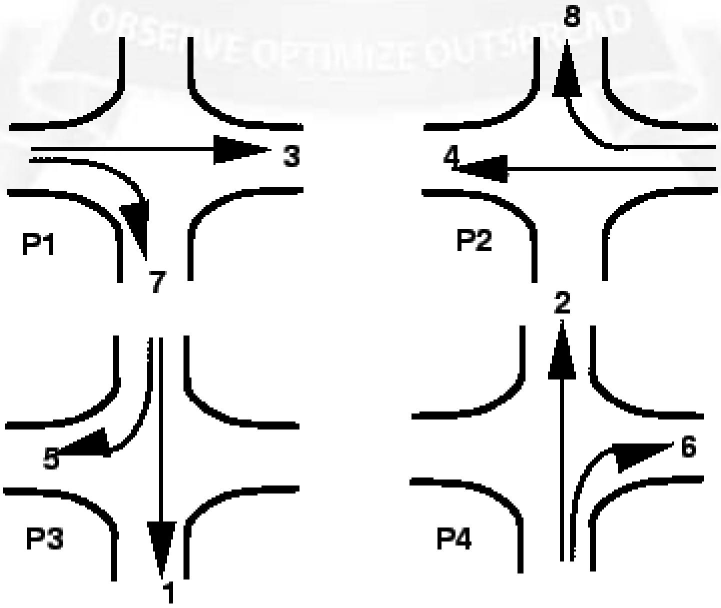

Figure 3: One way of providing four phase signals

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

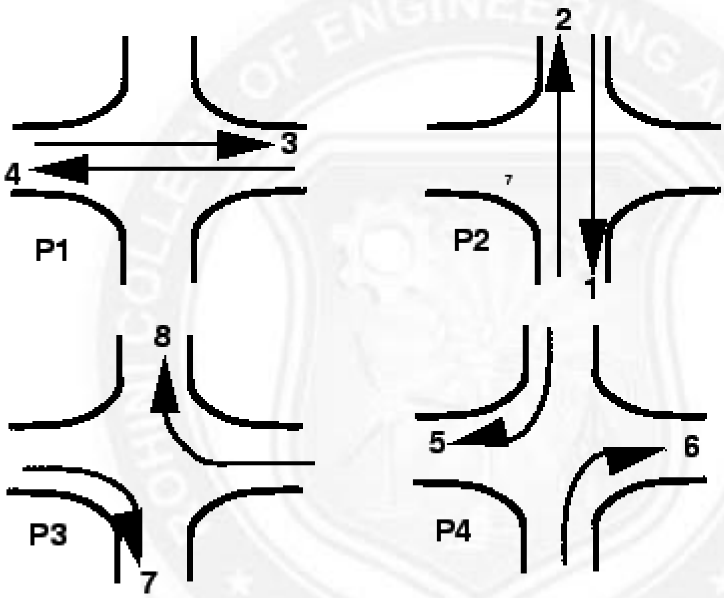

Figure 4: Second possible way of providing a four phase signal

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 5 shows yet another phase plan. However, this is rarely used in practice.

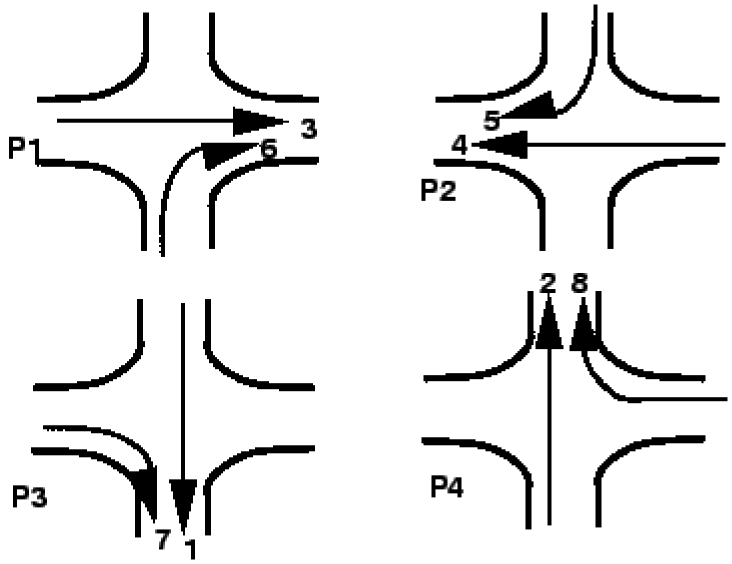

Figure 5: Third possible way of providing a four-phase signal

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.

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:

$$y = t + \frac{v_{85}}{2a + 19.6g} \tag{1}$$

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.

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 6 illustrates a group of N vehicles at a signalized intersection, waiting for the green signal.

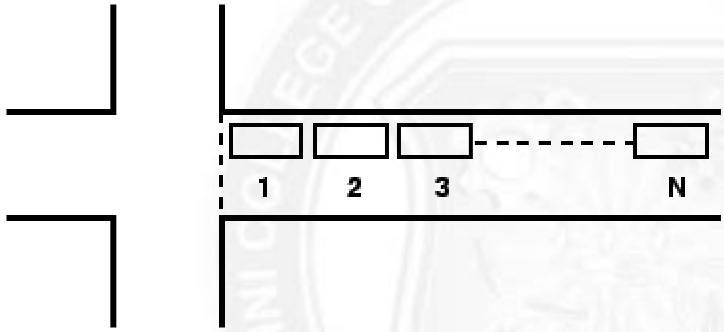

Figure 6: Group of vehicles at a signalized intersection waiting for green signal

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 7.

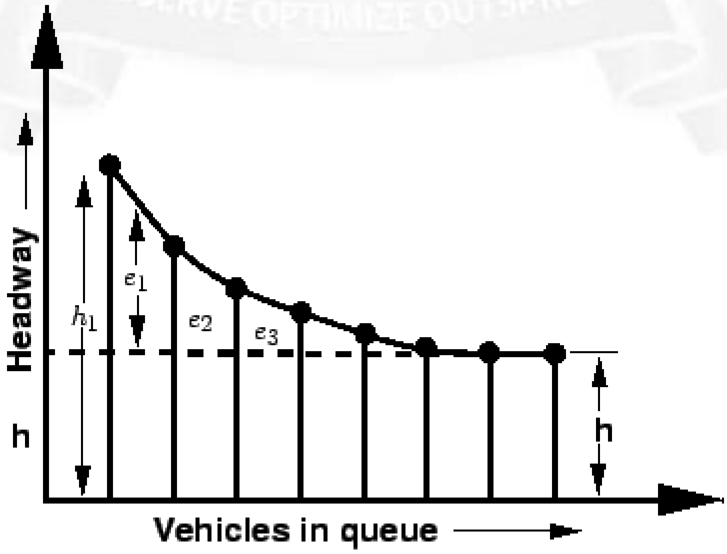

Figure 7: Headways departing signal

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 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,

$$s = \frac{3600}{h} \tag{2}$$

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 7. These differences for the first few vehicles can be added to get start up lost time, l_1 which is given by,

$$l_1 = \sum_{i=1}^{n} e_i \tag{3}$$

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

$$T = l_1 + h.N \tag{4}$$

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.

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,

$$g_i = G_i + Y_i - t_L \tag{5}$$

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,

$$c_i = s_i \frac{g_i}{C} \tag{6}$$

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.