Chapter 42

Traffic signal design-II

42.1 Overview

In the previous chapter, a simple design of cycle time was discussed. Here we will discuss how the cycle time is divided in a phase. The performance evaluation of a signal is also discussed.

42.2 Green splitting

Green splitting or apportioning of green time is the proportioning of effective green time in each of the signal phase. The green splitting is given by,

$$g_i = \left[\frac{V_c i}{\sum_{i=1}^{n} V_{ci}} \right] \times t_g \tag{42.1}$$

where $V_c i$ is the critical lane volume and t_g is the total effective green time available in a cycle. This will be cycle time minus the total lost time for all the phases. Therefore,

$$T_g = C - n.t_L \tag{42.2}$$

where C is the cycle time in seconds, n is the number of phases, and t_L is the lost time per phase. If lost time is different for different phases, then cycle time can be computed as follows.

$$T_g = C - \sum_{i=1}^{n} t_{Li} \tag{42.3}$$

where t_{Li} is the lost time for phase i, n is the number of phases and C is the lost time in seconds. Actual greentime can be now found out as,

$$G_i = g_i - y_i + t_{Li} \tag{42.4}$$

where G_i is the actual green time, g_i is the effective green time available, y_i is the amber time, and L_i is the lost time for phase i.

Problem

The phase diagram with flow values of an intersection with two phases is shown in figure 42:1. The lost time and yellow time for the first phase is 2.5 and 3 seconds respectively. For the second phase the lost time and yellow time are 3.5 and 4 seconds respectively. If the cycle time is 120 seconds, find the green time allocated for the two phases.
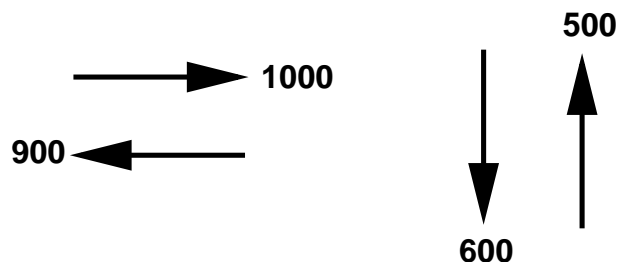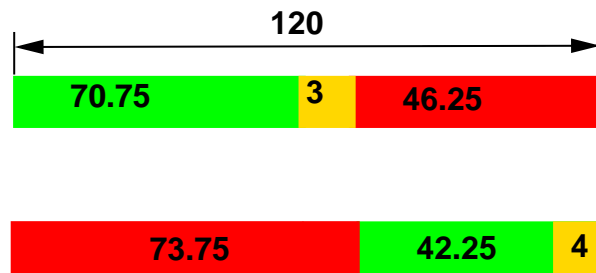
Figure 42:1: Phase diagram for an intersection

Figure 42:2: Timing diagram

Solution

- Critical lane volume for the first phase, $V_{C1} = 1000$ vph.

- Critical lane volume for the second phase, $V_{C2} = 600$ vph.

- The sum of the critical lane volumes, $V_C = V_{C1} + V_{C2} = 1000+600 = 1600$ vph.

- Effective green time can be found out from equationas T_g=120-(2.5-3.5)= 114 seconds.

- Green time for the first phase, g_1 can be found out from equationas $g_1 = \frac{1000}{1600} \times 114 = 71.25$ seconds.

- Green time for the second phase, g_2 can be found out from equationas $g_2 = \frac{600}{1600} \times 114$= 42.75 seconds.

- Actual green time can be found out from equationThus actual green time for the first phase, $G_1 = $ 71.25-3+2.5 = 70.75 seconds.

- Actual green time for the second phase, $G_2 = $ 42.75-3+2.5 = 42.25 seconds.

- The phase diagram is as shown in figure 42:2.

42.3 Pedestrian crossing requirements

Pedestrian crossing requirements can be taken care by two ways; by suitable phase design or by providing an exclusive pedestrian phase. It is possible in some cases to allocate time for the pedestrians without providing an exclusive phase for them. For example, consider an intersection in which the traffic moves from north to south and also from east to west. If we are providing a phase which allows the traffic to flow only in north-south direction, then the pedestrians can cross in east-west direction and vice-versa. However in some cases, it may

$D_1 = $ **Stopped time delay**
$D_2 = $ **Approach delay**
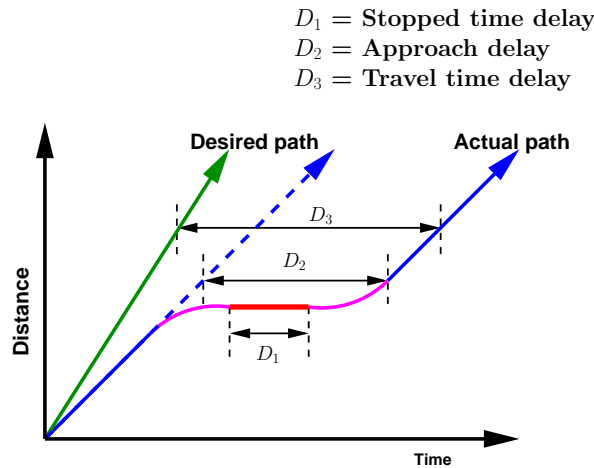$D_3 = $ **Travel time delay**

Figure 42:3: Illustration of delay measures

be necessary to provide an exclusive pedestrian phase. In such cases, the procedure involves computation of time duration of allocation of pedestrian phase. Green time for pedestrian crossing G_p can be found out by,

$$G_p = t_s + \frac{dx}{u_P} \tag{42.5}$$

where G_p is the minimum safe time required for the pedestrians to cross, often referred to as the "pedestrian green time", t_s is the start-up lost time, dx is the crossing distance in metres, and u_p is the walking speed of pedestrians which is about 15th percentile speed. The start-up lost time t_s can be assumed as 4.7 seconds and the walking speed can be assumed to be 1.2 m/s.

42.4 Performance measures

Performance measures are parameters used to evaluate the effectiveness of the design. There are many parameters involved to evaluate the effectiveness of the design and most common of these include delay, queuing, and stops. Delay is a measure that most directly relates the driver's experience. It describes the amount of time that is consumed while traversing the intersection. The figure 42:3 shows a plot of distance versus time for the progress of one vehicle. The desired path of the vehicle as well as the actual progress of the vehicle is shown. There are three types of delay as shown in the figure. They are stopped delay, approach delay and control delay. *Stopped time delay* includes only the time at which the vehicle is actually stopped waiting at the red signal. It starts when the vehicle reaches a full stop, and ends when the vehicle begins to accelerate. *Approach delay* includes the stopped time as well as the time lost due to acceleration and deceleration. It is measured as the time differential between the actual path of the vehicle, and path had there been green signal. *Control delay* is measured as the difference between the time taken for crossing the intersection and time taken to traverse the same section, had been no intersection. For a signalized intersection, it is measured at the stop-line as the vehicle enters the intersection. Among various types of delays, stopped delay is easy to derive and often used as a performance indicator and will be discussed.

Vehicles are not uniformly coming to an intersection. i.e., they are not approaching the intersection at constant time intervals. They come in a random manner. This makes the modeling of signalized intersection delay complex. Most simple of the delay models is Webster's delay model. It assumes that the vehicles are
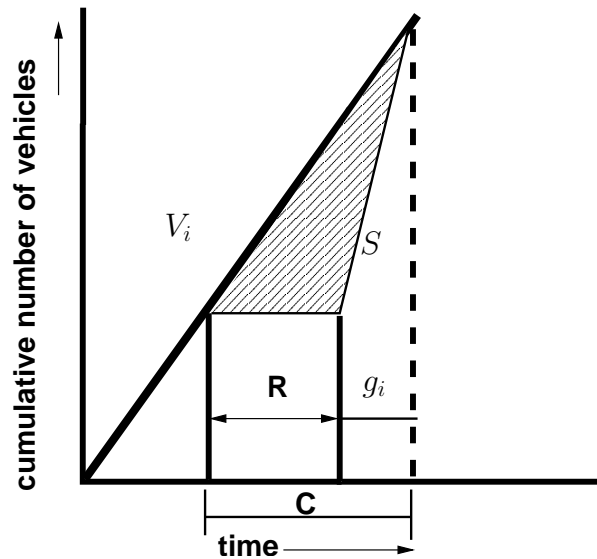
Figure 42:4: Graph between time and cumulative number of vehicles at an intersection

arriving at a uniform rate. Plotting a graph with time along the x-axis and cumulative vehicles along the y-axis we get a graph as shown in figure 42:4. The delay per cycle is shown as the area of the hatched portion in the figure. Webster derived an expression for delay per cycle based on this, which is as follows.

$$d_i = \frac{\frac{C}{2}[1 - \frac{g_i}{C}]^2}{1 - \frac{V_i}{S}} \tag{42.6}$$

where g_i is the effective green time, C is the cycle length, V_i is the critical flow for that phase, and S is the saturation flow.

Delay is the most frequently used parameter of effectiveness for intersections. Other measures like length of queue at any given time (Q_T) and number of stops are also useful. Length of queue is used to determine when a given intersection will impede the discharge from an adjacent upstream intersection. The number of stops made is an important input parameter in air quality models.

Problem

The traffic flow for a four-legged intersection is as shown in figure 42:5. Given that the lost time per phase is 2.4 seconds, saturation headway is 2.2 seconds, amber time is 3 seconds per phase, find the cycle length, green time and performance measure(delay per cycle). Assume critical v/c ratio as 0.9.

Solution

- The phase plan is as shown in figure 42:6. Sum of critical lane volumes is the sum of maximum lane volumes in each phase, $\Sigma V_{Ci} = 433+417+233+215 = 1298$ vph.

- Saturation flow rate, S_i from equation$=\frac{3600}{2.2} = 1637$ vph. $\frac{V_c}{S_i} = \frac{433}{1637} + \frac{417}{1637} + \frac{233}{1637} + \frac{1298}{1637} = 0.793$.

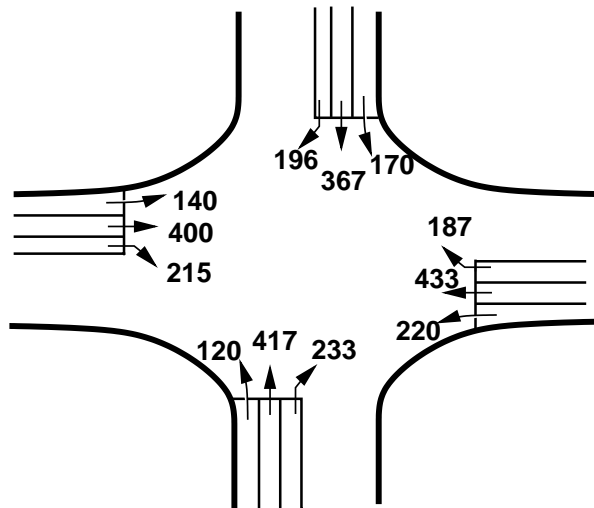- Cycle length can be found out from the equation as C$=\frac{4 \times 2.4 \times 0.9}{0.9 - \frac{1298}{1637}} = 80.68$ seconds ≈ 80 seconds.

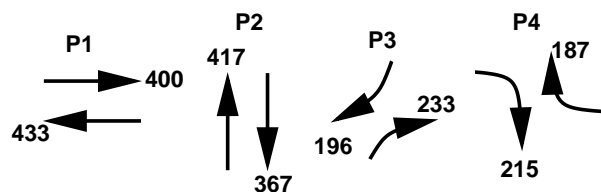Figure 42:5: Traffic flow for a typical four-legged intersection

Figure 42:6: Phase plan

Phase 1

| 23 | 3 | 78.5 |

Phase 2

| 26 | 23 | 3 | 52.5 |

Phase 3

| 52 | 13 | 3 | 36.5 |

Phase 4

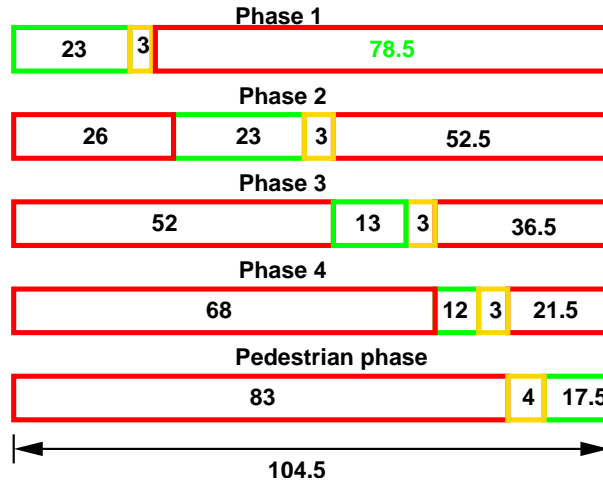| 68 | 12 | 3 | 21.5 |

Pedestrian phase

| 83 | 4 | 17.5 |

104.5

Figure 42:7: Timing diagram

- The effective green time can be found out as $G_i = \frac{V_{Ci}}{V_C} \times (C - L) = 80\text{-}(4\times 2.4) = 70.4$ seconds, where L is the lost time for that phase = 4×2.4.

- Green splitting for the phase 1 can be found out as $g_1 = 70.4 \times [\frac{483}{1298}] = 22.88$ seconds.

- Similarly green splitting for the phase 2,$g_2 = 70.4 \times [\frac{417}{1298}] = 22.02$ seconds.

- Similarly green splitting for the phase 3,$g_3 = 70.4 \times [\frac{233}{1298}] = 12.04$ seconds.

- Similarly green splitting for the phase 4,$g_4 = 70.4 \times [\frac{215}{1298}] = 11.66$ seconds.

- The actual green time for phase 1 from equationas $G_1 = 22.88\text{-}3+2.4 \approx 23$ seconds.

- Similarly actual green time for phase 2, $G_2 = 22.02\text{-}3+2.4 \approx 23$ seconds.

- Similarly actual green time for phase 3, $G_3 = 12.04\text{-}3+2.4 \approx 13$ seconds.

- Similarly actual green time for phase 4, $G_4 = 11.66\text{-}3+2.4 \approx 12$ seconds.

- Pedestrian time can be found out from as $G_p = 4 + \frac{6\times 3.5}{1.2} = 21.5$ seconds. The phase diagram is shown in figure 42:7. The actual cycle time will be the sum of actual green time plus amber time plus actual red time for any phase. Therefore, for phase 1, actual cycle time = 23+3+78.5 = 104.5 seconds.

- Delay at the intersection in the east-west direction can be found out from equationas

$$d_{EW} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{433}{1637}} = 42.57 sec/cycle. \tag{42.7}$$

- Delay at the intersection in the west-east direction can be found out from equation,as

$$d_{WE} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{400}{1637}} = 41.44 sec/cycle. \tag{42.8}$$

- Delay at the intersection in the north-south direction can be found out from equation,

$$d_{NS} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{367}{1637}} = 40.36 sec/cycle. \tag{42.9}$$

- Delay at the intersection in the south-north direction can be found out from equation,

$$d_{SN} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{417}{1637}} = 42.018 sec/cycle. \tag{42.10}$$

- Delay at the intersection in the south-east direction can be found out from equation,

$$d_{SE} = \frac{\frac{104.5}{2}[1 - \frac{13-2.4+3}{104.5}]^2}{1 - \frac{233}{1637}} = 46.096 sec/cycle. \tag{42.11}$$

- Delay at the intersection in the north-west direction can be found out from equation,

$$d_{NW} = \frac{\frac{104.5}{2}[1 - \frac{13-2.4+3}{104.5}]^2}{1 - \frac{196}{1637}} = 44.912 sec/cycle. \tag{42.12}$$

- Delay at the intersection in the west-south direction can be found out from equation,

$$d_{WS} = \frac{\frac{104.5}{2}[1 - \frac{12-2.4+3}{104.5}]^2}{1 - \frac{215}{1637}} = 46.52 sec/cycle. \tag{42.13}$$

- Delay at the intersection in the east-north direction can be found out from equation,

$$d_{EN} = \frac{\frac{104.5}{2}[1 - \frac{12-2.4+3}{104.5}]^2}{1 - \frac{187}{1637}} = 45.62 sec/cycle. \tag{42.14}$$

42.5 Summary

Green splitting is done by proportioning the green time among various phases according to the critical volume of the phase. Pedestrian phases are provided by considering the walking speed and start-up lost time. Like other facilities, signals are also assessed for performance, delay being th e important parameter used.

42.6 Problems

1. Table shows the traffic flow for a four-legged intersection. The lost time per phase is 2.4 seconds, saturation headway is 2.2 seconds, amber time is 3 seconds per phase. Find the cycle length, green time and performance measure. Assume critical volume to capacity ratio as 0.85. Draw the phasing and timing diagrams.

From	To	Flow(veh/hr)
North	South	750
East	West	650
West	East	500

P1

P2

450

500

650

750

Figure 42:8: Phase diagram

P1

P2

450

500

650

750/2 750/2
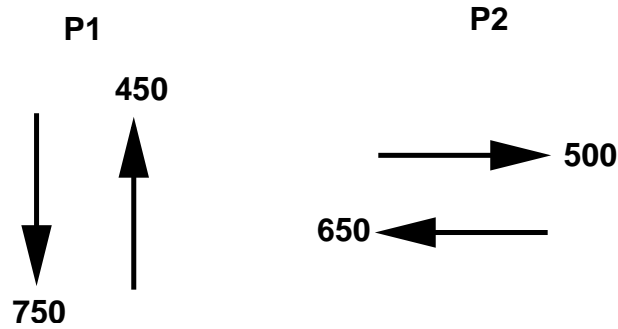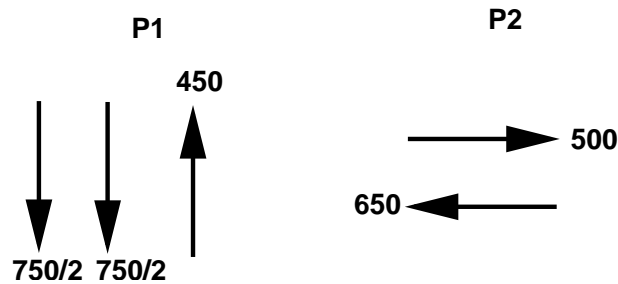
Figure 42:9: Phase diagram

Solution

- Given, saturation headway is 2.2 seconds, total lost time per phase (t_L) is 2.4 seconds, saturation flow = $\frac{3600}{2.2}$ = 1636.36 veh/hr. Phasing diagram can be assumed as in figure 42:9.

- Cycle time C can be found from equation= $\frac{2 \times 2.4 \times 0.85}{0.85 - \frac{750 + 650}{1636.36}}$ as negative.

- Hence the traffic flowing from north to south can be allowed to flow into two lanes.

- Now cycle time can be find out as $\frac{2 \times 2.4 \times 0.85}{0.85 - \frac{450 + 650}{1636.36}}$ = 22.95 or 23 seconds.

- The effective green time , $t_g = C - (N \times t_L) = 23 - (2 \times 2.4) = 18.2$ seconds.

- This green time can be split into two phases as, For phase 1, $g_1 = \frac{450 \times 18.2}{1100}$ = 7.45 seconds. For phase 2, $g_2 = \frac{650 \times 18.2}{1100}$ = 10.75 seconds. Now actual green time ,$G_1 = g_1$ minus amber time plus lost time. Therefore, G_1 = 7.45-3+2.4 = 6.85 seconds. G_2 = 10.75-3+2.4 = 10.15 seconds.

- Timing diagram is as shown in figure 42:10

- Delay at the intersection in the east-west direction can be found out from equationas

$$d_{EW} = \frac{\frac{23}{2}[1 - \frac{10.75 - 2.4 + 3}{23}]^2}{1 - \frac{650}{1636.36}} = 4.892 sec/cycle. \tag{42.15}$$
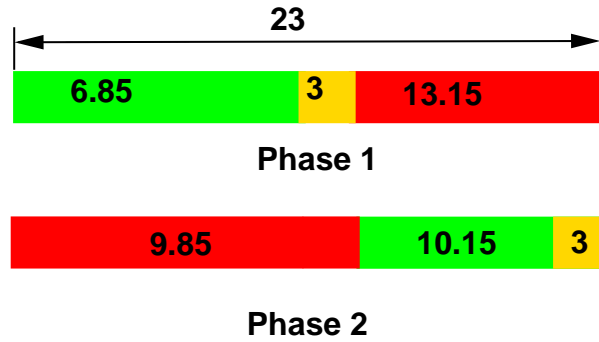
Phase 1

Phase 2

Figure 42:10: Timing diagram

- Delay at the intersection in the west-east direction can be found out from equation,as

$$d_{WE} = \frac{\frac{23}{2}[1 - \frac{10.75-2.4+3}{23}]^2}{1 - \frac{500}{1636.36}} = 4.248 sec/cycle. \tag{42.16}$$

- Delay at the intersection in the north-south direction can be found out from equation,

$$d_{NS} = \frac{\frac{23}{2}[1 - \frac{7.45-2.4+3}{23}]^2}{1 - \frac{750}{1636.36}} = 8.97 sec/cycle. \tag{42.17}$$

- Delay at the intersection in the south-north direction can be found out from equation,

$$d_{SN} = \frac{\frac{23}{2}[1 - \frac{7.45-2.4+3}{23}]^2}{1 - \frac{450}{1636.36}} = 6.703 sec/cycle. \tag{42.18}$$