Chapter 36

Special Requirement in Traffic Signal

36.1 Overview

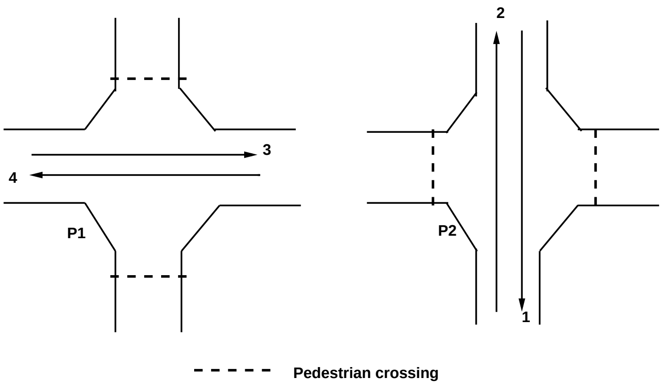
Traffic signals are designed to ensure safe and orderly flow of traffic, Protect pedestrians and vehicles at busy intersections and reduce the severity and frequency of accidents between vehicles entering intersections. Previous chapters discussed some important design principles such as: (i) Phase Design (ii) Cycle Time Determination (iii) Green Splitting (iv) Performance Evaluation This chapter we will discuss some special requirements in the signal design such as: (i) Pedestrian crossing requirement (ii) Interval design, (iii) Effect of tuning vehicles, and (iv) Lane utilization.

36.2 Pedestrian crossing

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 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,

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

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 meters, 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.



36.3 Interval design

There are two intervals, namely the change interval and clearance interval, normally provided in a traffic signal.

36.3.1 Change interval

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:

$$Y = t + \frac{v}{2(gn + a))} \tag{36.1}$$

where t is the reaction time (about 1.0 sec), v is the velocity of the approaching vehicles, g is the acceleration due to gravity (9.8 m/sec2), n is the grade of the approach in decimals and a is the deceleration of Change interval can also be approximately computed as y = 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.

36.3.2 Clearance interval

The clearance interval or all-red will facilitate a vehicle just crossed the stop line at the turn of red to clear the intersection without being collided by a vehicle from the next phase. ITE recommends the following policy for the design of all read time, given as

$$R_{AR} == \begin{cases} \frac{w+L}{v} & \text{if no pedestrians} \\ \max\left(\frac{w+L}{v}, \frac{P}{v}\right) & \text{if pedestrian crossing} \\ \frac{P+L}{v} & \text{if protected} \end{cases} \tag{36.2}$$

where w is the width of the intersection from stop line to the farthest conflicting traffic, L is the length of the vehicle (about 6 m), v is the speed of the vehicle, and P is the width of the intersection from STOP line to the farthest conflicting pedestrian cross-walk.

36.4 Effect of turning vehicles

36.4.1 Right turning vehicles

Right-turn signal phases facilitate right-turning traffic and may improve the safety of the intersection for right-turning vehicles. However, this is done at the expense of the amount of green time available for through traffic and will usually reduce the capacity of the intersection. Right-turn arrows also result in longer cycle lengths, which in turn have a detrimental effect by increasing stops and delays. While phases for protected right-turning vehicles are popular and commonly requested, other methods of handling right-turn conflicts also need to be considered. Potential solutions may include prohibiting right-turns and geometric improvements. The three criteria for right -turn phase is presented below:

1. Traffic Volumes

2. Delay: Separate right -turn phasing may be considered if the average delay for all right-turning vehicles on the approach is at least 35 seconds during that same peak hour.

3. Collision Experience: Separate right -turn phasing may be considered if the critical number of reportable right -turn collisions has occurred. These are: (i) For one approach to the intersection, the critical number is five l right -turn collisions in one year, or seven in two years. (ii) For both approaches to an intersection, the critical number is seven right -turn collisions in one year, or eleven in two years.

So the right turning vehicles affected saturation flow based on adjusted saturation headway. Finally actual values of right turning are calculated from right turn adjustment factor. The adjustments factor is calculated by following equations. Adjusted saturation headway,

$$h_{adj} = h_{ideal} \times (P_{RT} \times e_{RT} + (1 - P_{RT}) \times 1)$$

Adjusted saturation flow,

$$S_{adj} = \frac{3600}{h_{adj}}$$

Multiplicative right turn adjustment factor,

$$f_{RT} = \frac{1}{1 + P_{RT}(e_{RT} - 1)}$$

$$S_{adj} = S_{ideal} \times f_{RT}$$

Numerical example

If there is 15 percent right turning movement, eRT (through-car equivalent for permitted left turns) is 3, saturation headway is 2 sec; Find the value of Adjusted Saturation flow.

Solution: Given $h_{ideal} = 2\ sec$, $P_{RT} = 15\%(0.15)$, $S_{ideal} = 1800$, $e_{RT} = 3$

Case 1: Find adjusted saturation headway as:

$$\begin{aligned} h_{adj} &= h_{ideal} \times (P_{RT} \times e_{RT} + (1 - P_{RT}) \times 1) \\ &= 2 \times (0.15 \times 3 + (1 - 0.15) \times 1) \\ &= 2.6 sec/veh \end{aligned}$$

Now, find adjusted saturation flow as: $S_{adj} = \frac{3600}{h_{adj}} = \frac{3600}{2.6} = 1385$. The adjusted saturation flow is 1385 vph.

Case 2 Find the adjustment factor to calculate adjusted saturation flow based on ideal saturation flow (1800)

$$\begin{aligned} f_{RT} &= \frac{1}{1 + P_{RT}(e_{RT} - 1)} \\ &= \frac{1}{1 + 0.15(3 - 1)} = 0.77 \\ s_{adj} &= S_{ideal} \times f_{RT} = 1800 \times 0.77 = 1386 \end{aligned}$$

The adjusted saturation flow is 1386 vph. The result is same from both cases.

36.4.2 Left turning vehicles

Lft turn adjustment factor for saturation flow rate is as follows: For exclusive lane f_{LT} is 0.85 and for shared lane $f_{LT} = 1.0 - 0.15\ P_{LT}$, where pLT is the proportions of left turns in lane group. Normally in left turn, separate signal phase are not provided at intersection as per Indian standard.

36.4.3 Effect of Lane Distribution

Congestion and Delay at intersection particularly formed by to too many vehicles are moving same lane. So reduce that problem, we need to provide lane distribution. The lane distribution at intersection normally followed two categories.

First one is the total volume of given approach are distributed by providing separate lane for left, right and through movement. For that individual movement, we need to fix some percentage of total flow at that particular approach. This type clearly defined in Figure 5 and following example.

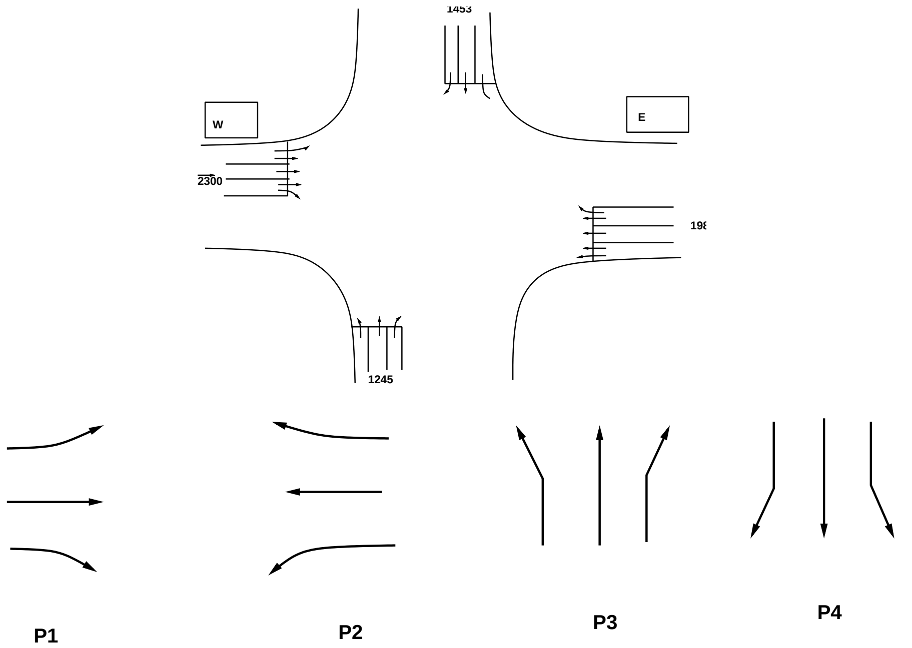
In second type, the given approach total volumes are separated by individual lane for left, right and straight. And straight moving vehicles also distributed into left and right turn lanes for unavoidable condition. If through movement vehicles are high, we need to follow second type distribution. Second type is explained in Figure 6 and example. Normally high straight cases we followed second method. In that second type divided into two distribution methods. First one is, through movement distributed into left, right and straight lanes. Second is, extra separate lane provide for through movement. So each cases some lane distribution factors are followed. That importance points are shown in following examples.

Numerical example

Find Critical Volume (Vi) for a Given 4 arm Intersection. Traffic flow Proportion of Left and Right turn are 10% and 20% respectively (For all approach). Left and Right turn Lane utilization factors are 0.2 and 0.3 respectively. Use following Phase Plan:

Solution: From West to East,

- Left turn Traffic movement from total directional movement = 10%
- Right turn Traffic from total directional movement = 20%
- Through Traffic from total directional movement = 70%



- Left turning Vehicles = $2300 \times 0.1 = 230\ veh/hr$
- Right turning Vehicles = $2300 \times 0.2 = 460\ veh/hr$
- Through Movement Vehicles = $2300 \times 0.7 = 1610\ veh/hr$

Lane Distribution

- Left turn utilization factor = 0.2
- Right turn utilization factor = 0.3
- Through traffic in Left turn Lane = $(2300 \times 0.7) \times 0.2 = 322\ veh/hr$
- Through traffic in Right turn Lane = $(2300 \times 0.7) \times 0.3 = 483\ veh/hr$
- Through traffic in Median Lane = $(2300 \times 0.7) \times 0.5 = 805\ veh/hr$

From East to west,

- Left turn Traffic movement from total directional movement = 10%
- Right turn Traffic from total directional movement = 20%
- Through Traffic from total directional movement = 70%
- Left turning Vehicles = $1985 \times 0.1 = 198\ veh/hr$

- Right turning Vehicles = $1985 \times 0.2 = 397$ veh/hr
- Through Movement Vehicles = $1985 \times 0.7 = 1390$ veh/hr

Lane Distribution

- Left turn utilization factor = 0.2
- Right turn utilization factor = 0.3
- Through traffic in Left turn Lane = $(1985 \times 0.7) \times 0.2 = 278$ veh/hr
- Through traffic in Right turn Lane = $(1985 \times 0.7) \times 0.3 = 417$ veh/hr
- Through traffic in Median Lane = $(1985 \times 0.7) \times 0.5 = 695$ veh/hr

From North to south,

- Left turn Traffic movement from total directional movement = 10%
- Right turn Traffic from total directional movement = 20%
- Through Traffic from total directional movement = 70%
- Left turning Vehicles = $1453 \times 0.1 = 145$ veh/hr
- Right turning Vehicles = $1453 \times 0.2 = 291$ veh/hr
- Through Movement Vehicles =$1453 \times 0.7 = 1017$ veh/hr

From south to North,

- Left turn Traffic movement from total directional movement = 10%
- Right turn Traffic from total directional movement = 20%
- Through Traffic from total directional movement = 70%
- Left turning Vehicles =$1245 \times 0.1 = 124$ veh/hr
- Right turning Vehicles =$1245 \times 0.2 = 250$ veh/hr
- Through Movement Vehicles =$1245 \times 0.7 = 871$ veh/hr

$V_i = V_1 + V_2 + V_3 + V_4 = 804 + 695 + 871 + 1071 = 3442$ veh/hr

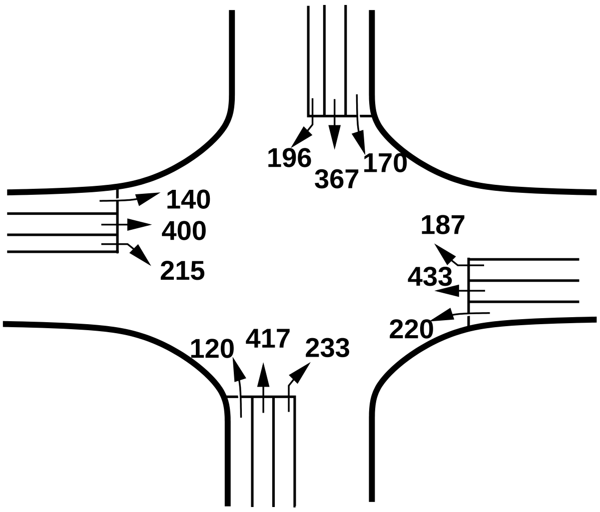


Figure 36:1: Traffic flow for a typical four-legged intersection

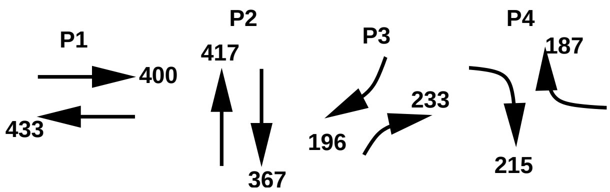


Figure 36:2: Phase plan

Numerical example

The traffic flow for a four-legged intersection is as shown in figure 36:1. 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

1. The phase plan is as shown in figure 36:2. Sum of critical lane volumes is the sum of maximum lane volumes in each phase, ΣV_{Ci} = 433+417+233+215 = 1298 vph.

2. 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.

3. Cycle length can be found out from the equation C=$\frac{4\times2.4\times0.9}{0.9-\frac{1298}{1637}}$ = 80.68 seconds $\approx$ 80 seconds.

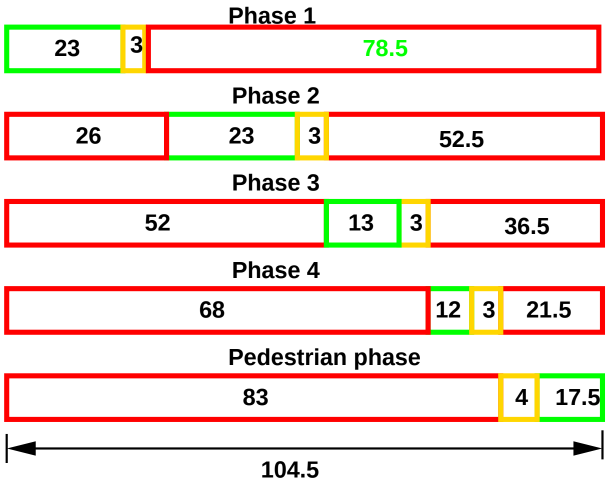


Figure 36:3: Timing diagram

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

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

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

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

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

9. The actual green time for phase 1 from equationG_1= 22.88-3+2.4 ≈ 23 seconds.

10. Similarly actual green time for phase 2, G_2 = 22.02-3+2.4 ≈ 23 seconds.

11. Similarly actual green time for phase 3, G_3 = 12.04-3+2.4 ≈ 13 seconds.

12. Similarly actual green time for phase 4, G_4 = 11.66-3+2.4 ≈ 12 seconds.

13. 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 36:3. 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.

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

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

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

$$d_{WE} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{400}{1637}} = 41.44 sec/cycle. \tag{36.3}$$

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

$$d_{NS} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{367}{1637}} = 40.36 sec/cycle. \tag{36.4}$$

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

$$d_{SN} = \frac{\frac{104.5}{2}[1 - \frac{23-2.4+3}{104.5}]^2}{1 - \frac{417}{1637}} = 42.018 sec/cycle. \tag{36.5}$$

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

$$d_{SE} = \frac{\frac{104.5}{2}[1 - \frac{13-2.4+3}{104.5}]^2}{1 - \frac{233}{1637}} = 46.096 sec/cycle. \tag{36.6}$$

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

$$d_{NW} = \frac{\frac{104.5}{2}[1 - \frac{13-2.4+3}{104.5}]^2}{1 - \frac{196}{1637}} = 44.912 sec/cycle. \tag{36.7}$$

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

$$d_{WS} = \frac{\frac{104.5}{2}[1 - \frac{12-2.4+3}{104.5}]^2}{1 - \frac{215}{1637}} = 46.52 sec/cycle. \tag{36.8}$$

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

$$d_{EN} = \frac{\frac{104.5}{2}[1 - \frac{12-2.4+3}{104.5}]^2}{1 - \frac{187}{1637}} = 45.62 sec/cycle. \tag{36.9}$$

36.5 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.

36.6 References

1. L. R Kadiyali. *Traffic Engineering and Transportation Planning.* Khanna Publishers, New Delhi, 1987.

2. William R McShane, Roger P Roesss, and Elena S Prassas. *Traffic Engineering.* Prentice-Hall, Inc, Upper Saddle River, New Jesery, 1998.