G PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

Department of Civil Engineering

Transportation Engineering – I

Lecture notes on

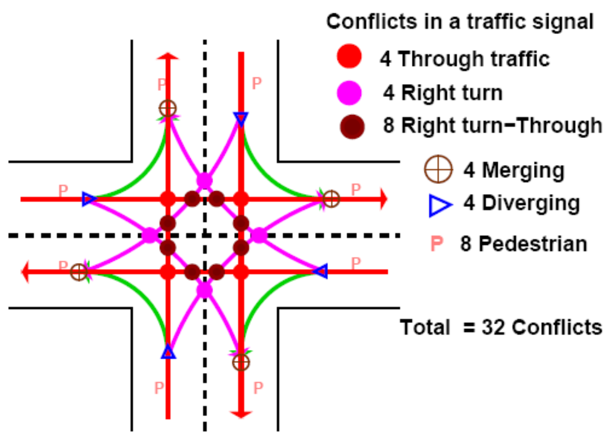
Intersection Design

Traffic intersections

Intersection is an area shared by two or more roads. This area is designated for the vehicles to turn to different directions to reach their desired destinations. Its main function is to guide vehicles to their respective directions. Traffic intersections are complex locations on any highway. This is because vehicles moving in different direction wan to occupy same space at the same time. In addition, the pedestrians also seek same space for crossing. Drivers have to make split second decision at an intersection by considering his route, intersection geometry, speed and direction of other vehicles etc. A small error in judgment can cause severe accidents. It also causes delay and it depends on type, geometry, and type of control. Overall traffic flow depends on the performance of the intersections. It also affects the capacity of the road. Therefore, both from the accident perspective and the capacity perspective, the study of intersections very important for the traffic engineers especially in the case of urban scenario.

Conflicts at an intersection:

Conflicts at an intersection are different for different types of intersection. Consider a typical four-legged intersection as shown in figure. The number of conflicts for competing through movements are 4, while competing right turn and through movements are 8. The conflicts between right turn traffics are 4, and between left turn and merging traffic is 4. The conflicts created by pedestrians will be 8 taking into account all the four approaches. Diverging traffic also produces about 4 conflicts. Therefore, a typical four legged intersection has about 32 different types of conflicts. This is shown in figure



Conflicts at an intersection

The essence of the intersection control is to resolve these conflicts at the intersection for the safe and efficient movement of both vehicular traffic and pedestrians. Two methods of intersection controls are there: time sharing and space sharing. The type of intersection control that has to be adopted depends on the traffic volume, road geometry, cost involved, importance of the road etc.

Levels of intersection control

The control of an intersection can be exercised at different levels. They can be either passive control, semi control, or active control. In passive control, there is no explicit control on the driver . In semi control, some amount of control on the driver is there from the traffic agency. Active control means the movement of the traffic is fully controlled by the traffic agency and the drivers cannot simply maneuver the intersection according to his choice.

Passive control

When the volume of traffic is less, no explicit control is required. Here the road users are required to obey the basic rules of the road. Passive control like traffic signs, road markings etc. are used to complement the intersection control. Some of the intersection control that is classified under passive control are as follows:

1. No control if the traffic coming to an intersection is low, then by applying the basic rules of the road like driver on the left side of the road must yield and that through movements will have priority than turning movements. The driver is expected to obey these basic rules of the road
2. Traffic signs: With the help of warning signs, guide signs etc. it is able to provide some level of control at an intersection. Give way control, two-way stop control, and all-way stop control are some examples. The GIVE WAY control requires the driver in the minor road to slow down to a minimum speed and allow the vehicle on the major road to proceed. Two way stop control requires the vehicle drivers on the minor streets should see that the conflicts are avoided. Finally an all-way stop control is usually used when it is difficult to differentiate between the major and minor roads in an intersection. In such a case, STOP sign is placed on all the approaches to the intersection and the driver on all the approaches are required to stop the vehicle. The vehicle at the right side will get priority over the left approach. The traffic control at 'at-grade' intersection may be uncontrolled in cases of low traffic. Here the road users are required to obey the basic rules of the road. Passive control like traffic signs, road markings etc. are used to complement the intersection control.
3. Traffic signs plus marking: In addition to the traffic signs, road markings also complement the traffic control at intersections. Some of the examples include stop line marking, yield lines, arrow marking etc.

Semi control

In semi control or partial control, the drivers are gently guided to avoid conflicts. Channelization and traffic rotaries are two examples of this.

1. **Channelization:** The traffic is separated to flow through definite paths by raising a portion of the road in the middle usually called as islands distinguished by road markings. The conflicts in traffic movements are reduced to a great extent in such a case. In channelized intersections, as the name suggests, the traffic is directed to flow through different channels and this physical separation is made possible with the help of some barriers in the road like traffic islands, road markings etc.
2. **Traffic rotaries:** It is a form of intersection control in which the traffic is made to flow along one direction around a traffic island. The essential principle of this control is to convert all the severe conflicts like through and right turn conflicts into milder conflicts like merging, weaving and diverging. It is a form of `at-grade' intersection laid out for the movement of traffic such that no through conflicts are there. Free-left turn is permitted where as through traffic and right-turn traffic is forced to move around the central island in a clock-wise direction in an orderly manner. Merging, weaving and diverging operations reduces the conflicting movements at the rotary.

Active control

Active control implies that the road user will be forced to follow the path suggested by the traffic control agencies. He cannot maneuver according to his wish. Traffic signals and grade separated intersections come under this classification.

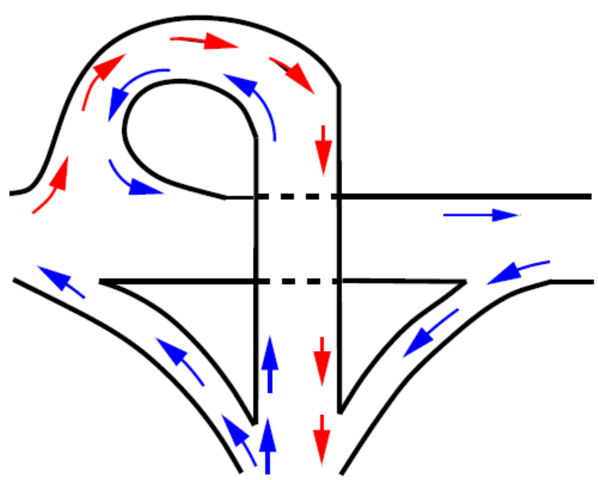
Traffic signals: Control using traffic signal is based on time sharing approach. At a given time, with the help of appropriate signals, certain traffic movements are restricted where as certain other movements are permitted to pass through the intersection. Two or more phases may be provided depending upon the traffic conditions of the intersection. When the vehicles traversing the intersection are very large, then the control is done with the help of signals. The phases provided for the signal may be two or more. If more than two phases are provided, then it is called multiphase signal. The signals can operate in several modes. Most common are fixed time signals and vehicle actuated signals. In fixed time signals, the cycle time, phases and interval of each signal is fixed. Each cycle of the signal will be exactly like another. But they cannot cater to the needs of the fluctuating traffic. On the other hand, vehicle actuated signals can respond to dynamic traffic situations. Vehicle detectors will be placed on the streets approaching the intersection and the detector will sense the presence of the vehicle and pass the information to a controller. The controller then sets the cycle time and adjusts the phase lengths according to the prevailing traffic conditions.

Grade separated intersections: The intersections are of two types. They are at-grade intersections and grade-separated intersections. In at-grade intersections, all roadways join or cross at the same vertical level. Grade separated intersections allows the traffic to cross at different vertical levels. Sometimes the topography itself may be helpful in constructing such intersections. Otherwise, the initial construction cost required will be very high. Therefore, they are usually constructed on high speed facilities like expressways, freeways etc. This type of intersection increases the road capacity because vehicles can flow with high speed and accident potential is also reduced due to vertical separation of traffic.

Grade separated intersections

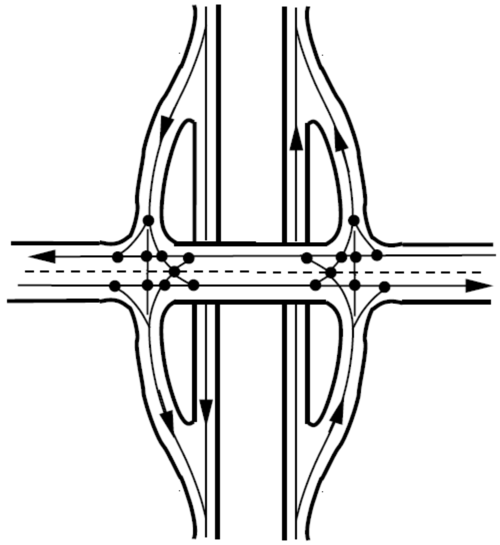
As we discussed earlier, grade-separated intersections are provided to separate the traffic in the vertical grade. But the traffic need not be those pertaining to road only. When a railway line crosses a road, then also grade separators are used. Different types of grade-separators are flyovers and interchange. Flyovers itself are subdivided into overpass and underpass. When two roads cross at a point, if the road having major traffic is elevated to a higher grade for further movement of traffic, then such structures are called overpass. Otherwise, if the major road is depressed to a lower level to cross another by means of an under bridge or tunnel, it is called under-pass. Interchange is a system where traffic between two or more roadways flows at different levels in the grade separated junctions. Common types of interchange include trumpet interchange, diamond interchange, and cloverleaf interchange.

1. Trumpet interchange: Trumpet interchange is a popular form of three leg interchange. If one of the legs of the interchange meets a highway at some angle but does not cross it, then the interchange is called trumpet interchange. A typical layout of trumpet interchange is shown in figure



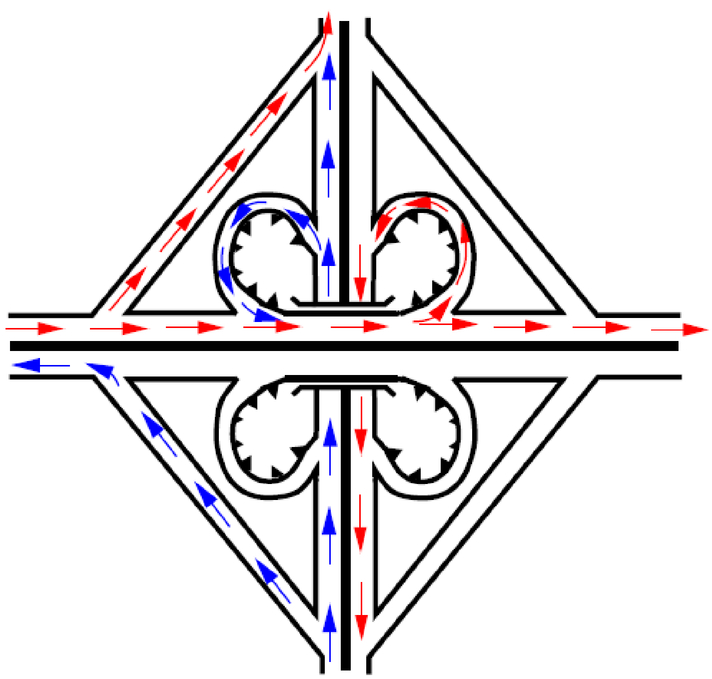
Trumpet interchange

2. Diamond interchange: Diamond interchange is a popular form of four-leg interchange found in the urban locations where major and minor roads crosses. The important feature of this interchange is that it can be designed even if the major road is relatively narrow. A typical layout of diamond interchange is shown in figure.



Diamond interchange

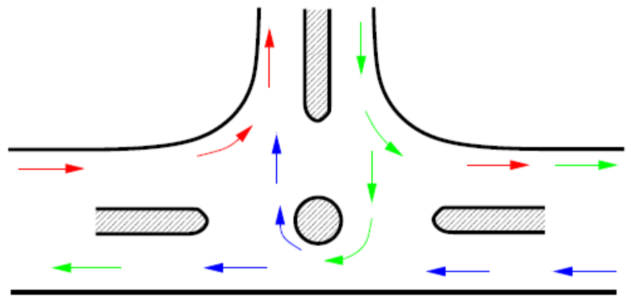
3. Clover leaf interchange: It is also a four leg interchange and is used when two highways of high volume and speed intersect each other with considerable turning movements. The main advantage of cloverleaf intersection is that it provides complete separation of traffic. In addition, high speed at intersections can be achieved. However, the disadvantage is that large area of land is required. Therefore, cloverleaf interchanges are provided mainly in rural areas. A typical layout of this type of interchange is shown in figure



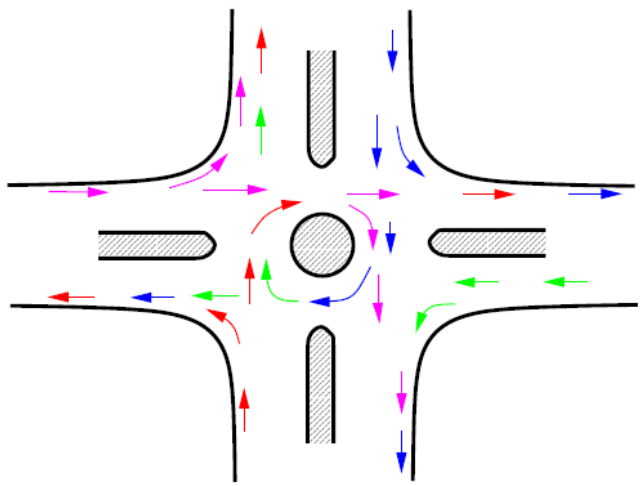
Cloverleaf interchange

Channelized intersection

Vehicles approaching an intersection are directed to definite paths by islands, marking etc. and this method of control is called channelization. Channelized intersection provides more safety and efficiency. It reduces the number of possible conflicts by reducing the area of conflicts available in the carriageway. If no channelizing is provided the driver will have less tendency to reduce the speed while entering the intersection from the carriageway. The presence of traffic islands, markings etc. forces the driver to reduce the speed and becomes more cautious while maneuvering the intersection. A channelizing island also serves as a refuge for pedestrians and makes pedestrian crossing safer. Channelization of traffic through a three-legged intersection (refer figure) and a four-legged intersection (refer figure) is shown in the figure.



Channelization of traffic through a three-legged intersection



Channelization of traffic through a four-legged intersection

Traffic intersections are problem spots on any highway, which contribute to a large share of accidents. For safe operation, these locations should be kept under some level of control depending upon the traffic quantity and behavior. Based on this, intersections and interchanges are constructed, the different types of which were discussed in the chapter.

Traffic rotaries:

Rotary intersections or round about are special form of at-grade intersections laid out for the movement of traffic in one direction around a central traffic island. Essentially all the major conflicts at an intersection namely the collision between through and right-turn movements are converted into milder conflicts namely merging and diverging. The vehicles entering the rotary are gently forced to move in a clockwise direction in orderly fashion. They then weave out of the rotary to the desired direction. The benefits, design principles, capacity of rotary etc. will be discussed in this chapter.

Advantages and disadvantages of rotary

The key advantages of a rotary intersection are listed below:

1. Traffic flow is regulated to only one direction of movement, thus eliminating severe conflicts between crossing movements.
2. All the vehicles entering the rotary are gently forced to reduce the speed and continue to move at slower speed. Thus, none of the vehicles need to be stopped, unlike in a signalized intersection.
3. Because of lower speed of negotiation and elimination of severe conflicts, accidents and their severity are much less in rotaries.
4. Rotaries are self governing and do not need practically any control by police or traffic signals.
5. They are ideally suited for moderate traffic, especially with irregular geometry, or intersections with more than three or four approaches.

Although rotaries over some distinct advantages, there are few specific limitations for rotaries which are listed below.

1. All the vehicles are forced to slow down and negotiate the intersection. Therefore, the cumulative delay will be much higher than channelized intersection.
2. Even when there is relatively low tra_c, the vehicles are forced to reduce their speed.
3. Rotaries require large area of relatively at land making them costly at urban areas.
4. The vehicles do not usually stop at a rotary. They accelerate and exit the rotary at relatively high speed.
5. Therefore, they are not suitable when there are high pedestrian movements.

Guidelines for the selection of rotaries

Because of the above limitation, rotaries are not suitable for every location. There are few guidelines that help in deciding the suitability of a rotary. They are listed below.

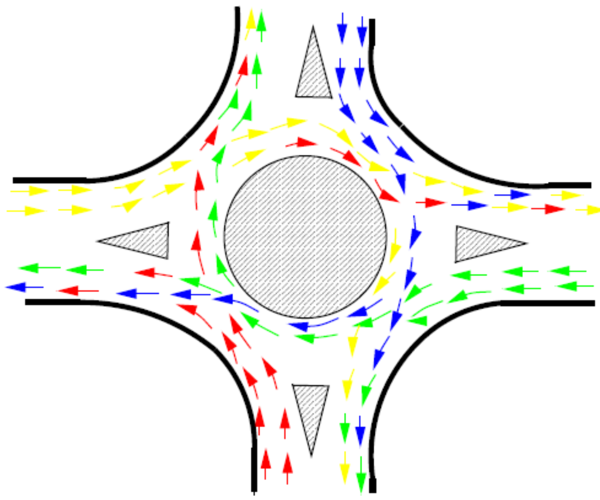
1. Rotaries are suitable when the traffic entering from all the four approaches are relatively equal.
2. A total volume of about 3000 vehicles per hour can be considered as the upper limiting case and a volume of 500 vehicles per hour is the lower limit.
3. A rotary is very beneficial when the proportion of the right-turn traffic is very high; typically if it is more than 30 percent.
4. Rotaries are suitable when there are more than four approaches or if there is no separate lanes available for right-turn traffic. Rotaries are ideally suited if the intersection geometry is complex.

Traffic operations in a rotary

As noted earlier, the traffic operations at a rotary are three; diverging, merging and weaving. All the other conflicts are converted into these three less severe conflicts.

1. Diverging: It is a traffic operation when the vehicles moving in one direction is separated into different streams according to their destinations.
2. Merging: Merging is the opposite of diverging. Merging is referred to as the process of joining the traffic coming from different approaches and going to a common destination into a single stream.
3. Weaving: Weaving is the combined movement of both merging and diverging movements in the same direction.

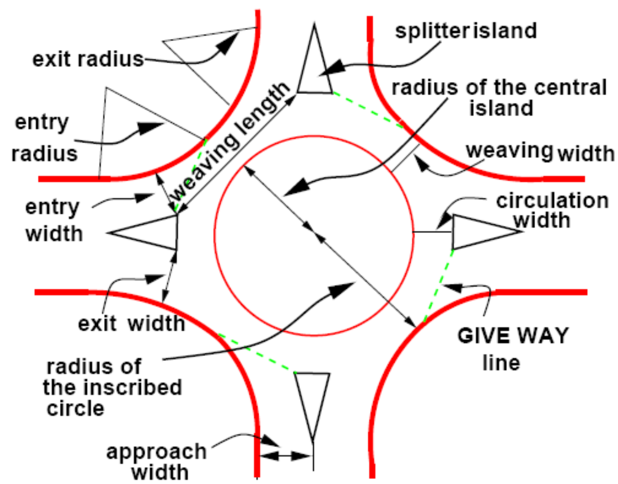
These movements are shown in figure it can be observed that movements from each direction split into three; left, straight, and right turn.



Traffic operations in a rotary

Design elements

The design elements include design speed, radius at entry, exit and the central island, weaving length and width, entry and exit widths. In addition the capacity of the rotary can also be determined by using some empirical formula. A typical rotary and the important design elements are shown in figure.



Design of a rotary

Design speed

All the vehicles are required to reduce their speed at a rotary. Therefore, the design speed of a rotary will be much lower than the roads leading to it. Although it is possible to design roundabout without much speed reduction, the geometry may lead to very large size incurring huge cost of construction. The normal practice is to keep the design speed as 30 and 40 kmph for urban and rural areas respectively.

Entry, exit and island radius

The radius at the entry depends on various factors like design speed, super-elevation, and coe_cient of friction. The entry to the rotary is not straight, but a small curvature is introduced. This will force the driver to reduce the speed. The entry radius of about 20 and 25 metres is ideal for an urban and rural design respectively. The exit radius should be higher than the entry radius and the radius of the rotary island so that the vehicles will discharge from the rotary at a higher rate. A general practice is to keep the exit radius as 1.5 to 2 times the entry radius. However, if pedestrian movement is higher at the exit approach, then the exit radius could be set as same as that of the entry radius. The radius of the central island is governed by the design speed, and the radius of the entry curve. The radius of the central island, in practice, is given a slightly higher radius so that the movement of the traffic already in the rotary will have priority. The radius of the central island which is about 1.3 times that of the entry curve is adequate for all practical purposes.

Width of the rotary

The entry width and exit width of the rotary is governed by the tra_c entering and leaving the intersection and the width of the approaching road. The width of the carriageway at entry and exit will be lower than the width of the carriageway at the approaches to enable reduction of speed. IRC suggests that a two lane road of 7 m width should be kept as 7 m for urban roads and 6.5 m for rural roads. Further, a three lane road of 10.5 m is to be reduced to 7 m and 7.5 m respectively for urban and rural roads.

The width of the weaving section should be higher than the width at entry and exit. Normally this will be one lane more than the average entry and exit width. Thus weaving width is given as,

$$\mathrm{w_{weaving}} = \left(\frac{\mathrm{e_1 + e_2}}{2}\right) + 3.5\mathrm{m}$$

Where e1 is the width of the carriageway at the entry and e2 is the carriageway width at exit.

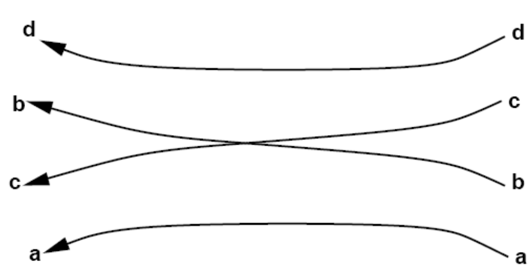
Weaving length determines how smoothly the traffic can merge and diverge. It is decided based on many factors such as weaving width, proportion of weaving traffic to the non-weaving traffic etc. This can be best achieved by making the ratio of weaving length to the weaving width very high. A ratio of 4 is the minimum value suggested by IRC. Very large weaving length is also dangerous, as it may encourage over-speeding.

Capacity:

The capacity of rotary is determined by the capacity of each weaving section. Transportation road research lab (TRL) proposed the following empirical formula to find the capacity of the weaving section.

$$Q_w = \frac{280w[1+\frac{e}{w}][1-\frac{p}{3}]}{1+\frac{w}{l}}$$

where e is the average entry and exit width, i.e, (e_1+e_2) / 2 , w is the weaving width, l is the length of weaving, and p is the proportion of weaving traffic to the non-weaving traffic. Figure shows four types of movements at a weaving section, a and d are the non-weaving traffic and b and c are the weaving traffic. Therefore,



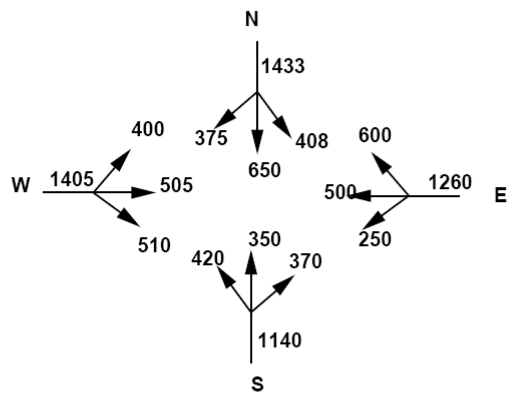
$$p = \frac{b+c}{a+b+c+d}$$

This capacity formula is valid only if the following conditions are satisfied.

1. Weaving width at the rotary is in between 6 and 18 metres.
2. The ratio of average width of the carriage way at entry and exit to the weaving width is in the range of 0.4 to 1.
3. The ratio of weaving width to weaving length of the roundabout is in between 0.12 and 0.4.
4. The proportion of weaving traffic to non-weaving traffic in the rotary is in the range of 0.4 and 1.
5. The weaving length available at the intersection is in between 18 and 90 m.

Example

The width of a carriage way approaching an intersection is given as 15 m. The entry and exit width at the rotary is 10 m. The traffic approaching the intersection from the four sides is shown in the figure below. Find the capacity of the rotary using the given data.

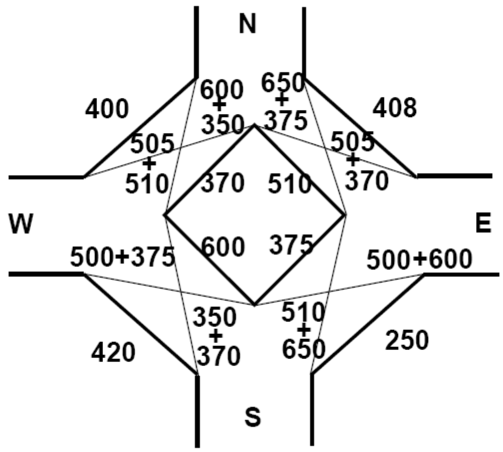


Solution

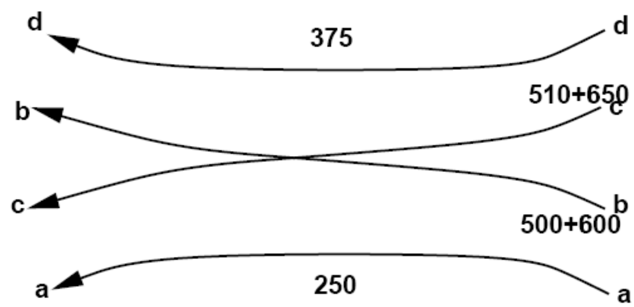
- The traffic from the four approaches negotiating through the roundabout is illustrated in figure.
- Weaving width is calculated as, w = [(e_1+e_2) / 2] + 3:5 = 13.5 m
- Weaving length, l is calculated as = 4 X w = 54 m
- The proportion of weaving traffic to the non-weaving traffic in all the four approaches is found out first.
- It is clear from equation, that the highest proportion of weaving traffic to non-weaving traffic will give the minimum capacity. Let the proportion of weaving traffic to the non-weaving traffic in West-North direction be denoted as p_{WN}, in North-East direction as p_{NE}, in the East-South direction as p_{ES}, and finally in the South-West direction as p_{SW}.
- The weaving traffic movements in the East-South direction are shown in figure. Then using equation, p_{ES}

$$= \frac{510+650+500+600}{510+650+500+600+250+375} = \frac{2260}{2885} = 0.783$$

$$p_{WN} = \frac{505+510+350+600}{505+510+350+600+400+370} = \frac{1965}{2735} = 0.718$$



Traffic negotiating a rotary



Traffic weaving in East-South direction

$$p_{NE} = \frac{650+375+505+370}{650+375+505+370+510+408} = \frac{1900}{2818} = 0.674$$

$$p_{SW} = \frac{350+370+500+375}{350+370+500+375+420+600} = \frac{1595}{2615} = 0.6099$$

- Thus the proportion of weaving traffic to non-weaving traffic is highest in the East-South direction.
- Therefore, the capacity of the rotary will be capacity of this weaving section. From equation,

$$Q_{ES} = \frac{280 \times 13.5[1 + \frac{10}{13.5}][1 - \frac{0.783}{3}]}{1 + \frac{13.5}{54}} = 2161.164 veh/hr.$$

Traffic rotaries reduce the complexity of crossing traffic by forcing them into weaving operations. The shape and size of the rotary are determined by the traffic volume and share of turning movements. Capacity assessment of a rotary is done by analyzing the section having the greatest proportion of weaving traffic. The analysis is done by using the formula given by TRL.

Traffic signal design-I

The conflicts arising from movements of traffic in different directions is solved by time sharing of the principle. The advantages of traffic signal include an orderly movement of tra_c, an increased capacity of the intersection and require 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.

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 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 for 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 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.

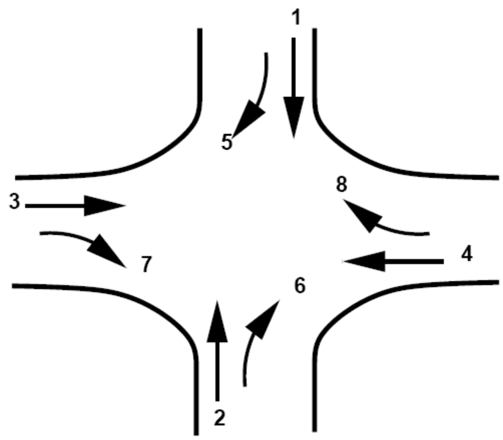
Phase design

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.

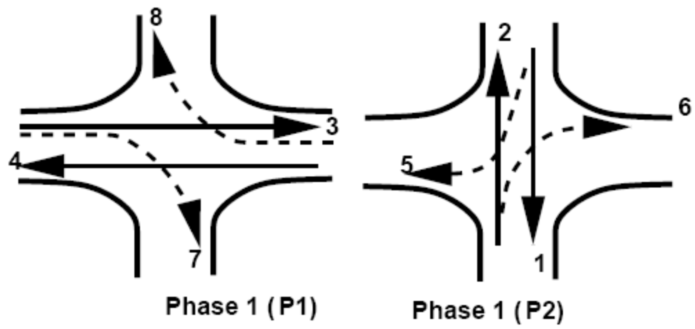
There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, flow pattern especially the turning movements, the relative magnitudes of flow. Therefore, a trial and error procedure is often adopted. However, phase design is very important because 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. 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.



Four legged intersection

Two phase signals

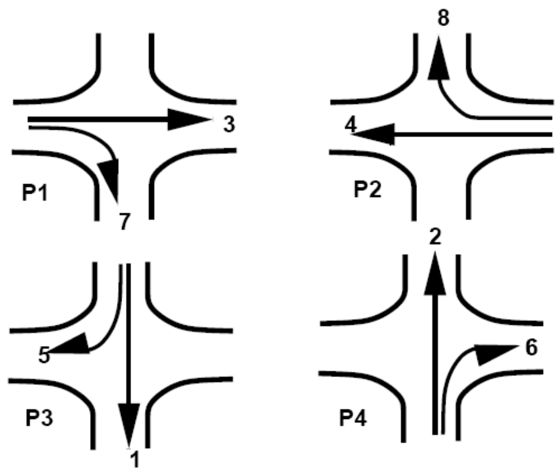
Two phase system is usually adopted if through traffic is significant compared to the turning movements. For example in figure 41:2, non-conflicting through traffic 3 and 4 are grouped in a single phase and non-conflicting through traffic 1 and 2 are grouped in the second phase. However, in the first 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 movements are relatively low. On the other hand, if the turning movements are significant , then a four phase system is usually adopted.



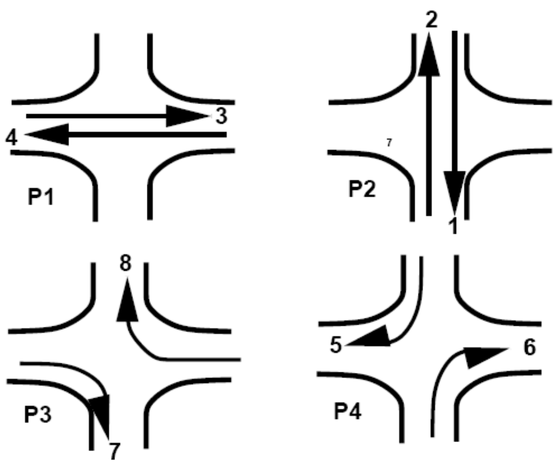
Two phase signal

Four phase signals

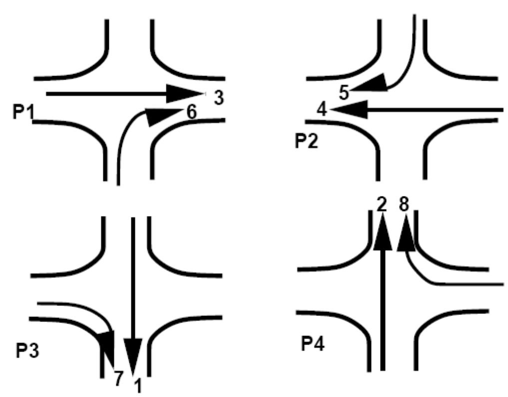
There are at least three possible phasing options. For example, figure shows the most simple and trivial phase plan. Where, flow from each approach is put into a single phase avoiding all conflicts. This type of phase plan is ideally suited in urban areas where the turning movements are comparable with 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 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 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.



One way of providing four phase signals



Second possible way of providing a four phase signal



Third possible way of providing a four-phase signal

Interval design

There are two intervals, namely the change interval and clearance interval, normally provided in a tra_c 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:

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

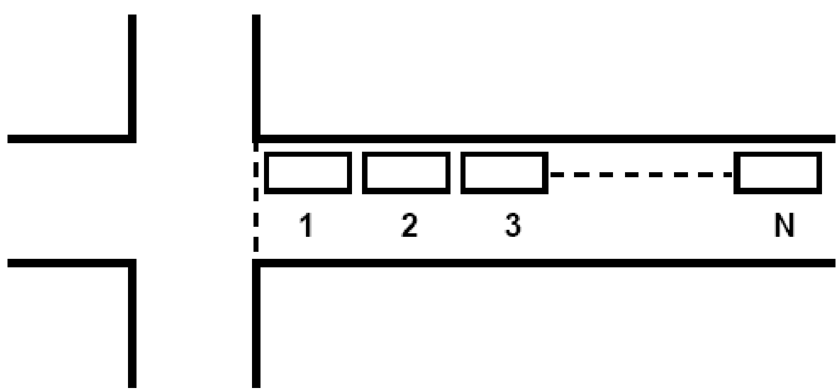
where y is the length of yellow interval in seconds, t is the reaction time of the driver, v_{85} is the 85th percentile speed of approaching vehicles in m/s, a is the deceleration rate of vehicles in m = s_2, g is the grade of approach expressed as a decimal. Change interval can also be approximately computed as

$$y = SSD / v ,$$

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 o_ 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

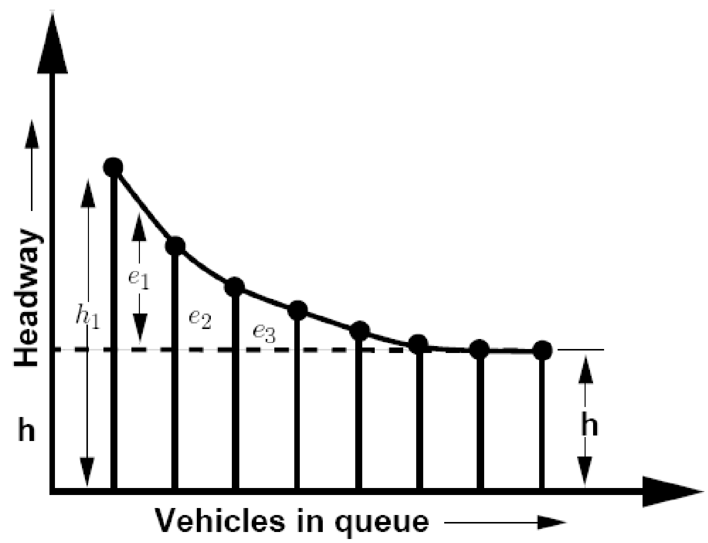
Cycle time is the time taken by a signal to complete one full cycle of iterations. i.e. one complete rotation through all signal indications. It is denoted by C. The way in which the vehicles depart from an intersection when the green signal is initiated will be discussed now. Figure 41:6 illustrates 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. 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.



Group of vehicles at a signalized intersection waiting for green 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,

$$s = 3600/h$$



Headways departing signal

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

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

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

$$T = l_1 + h.N$$

where T is the time required to clear N vehicles through signal, l1 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,

$$g_i = G_i + Y_i - t_L$$

Lane capacity

The ratio of effective green time to the cycle length (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,

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

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, _nd 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.

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.

Determination of cycle length

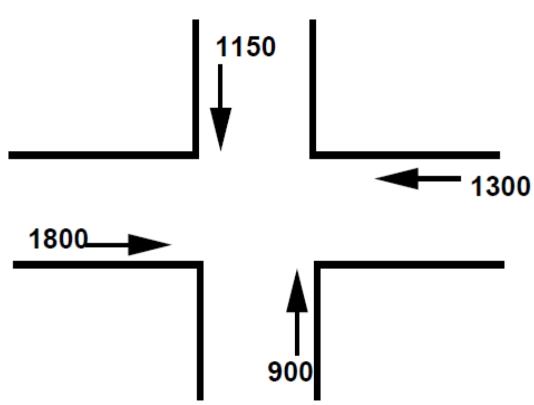
The cycle length or cycle time is the time taken for complete indication of signals in a cycle. Fixing the cycle length is one of the crucial steps involved in signal design.

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,

$$\begin{aligned} T_g &= 3600 - \frac{3600.N.t_L}{C} \\ &= 3600\left[1 - \frac{N.t_L}{C}\right] \end{aligned}$$

Let the total number of critical lane volume that can be accommodated per hour is given by Vc, then Vc = Tg / h Substituting for Tg, from equation 41.9 and si from the maximum sum of critical lane volumes that can be accommodated within the hour is given by,

= Tg / h



Traffic flow in the intersection

$$
\begin{aligned}
V_c &= \frac{3600}{h}\left[1 - \frac{N.t_L}{C}\right] \\
&= s_i\left[1 - \frac{N.t_L}{C}\right] \\
Therefore\ C &= \frac{N.t_L}{1 - \frac{V_c}{s}}
\end{aligned}
$$

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,

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

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,

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

where N is the number of phases, L is the lost time per phase, $(V / s)_i$ is the ratio of volume to saturation flow for phase i, XC is the quality factor called critical 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

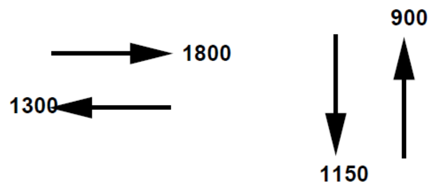
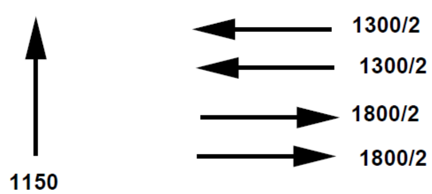


Figure 41:9: One way of providing phases



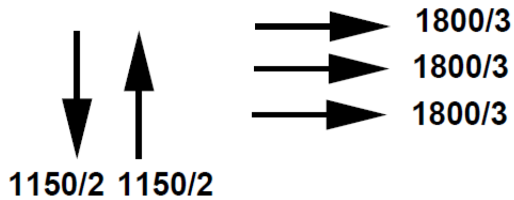
Second way of providing phases

- ✓ If we assign two phases as shown below figure, 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 = 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.
- ✓ 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, 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,

$$C = (2X3) / (1- (1175/1565:2)) = 24 \text{ seconds.}$$



Traffic signal design-II

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.

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,

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

where V_{ci} 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,

$$Tg = C - n.tL$$

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.

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

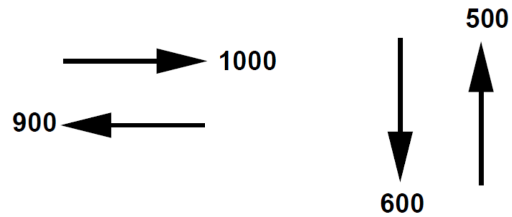
where t_{Li} is the lost time for phase i, n is the number of phases and C is the lost time in seconds. Actual green time can be now found out as,

$$G_i = g_i - y_i + t_{Li}$$

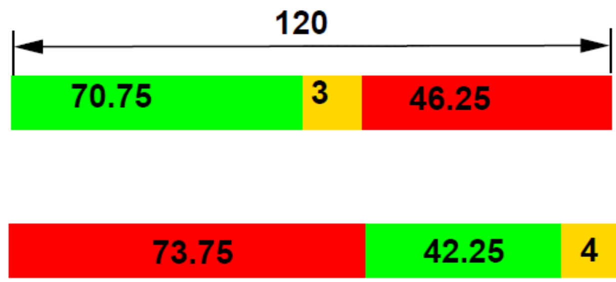
where G_i is the actual green time, g_i is the effective green time available, y_i is the amber time, and L_i is the lost time for phase i.

Problem

The phase diagram with flow values of an intersection with two phases is shown in figure. 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.



Phase diagram for an intersection



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 equations Tg=120-(2.5-3.5)= 114 seconds.
- ✓ Green time for the _rst phase, g1 can be found out from equations g_1 = (1000 /1600) X 114 = 71.25 seconds.
- ✓ Green time for the second phase, g2 can be found out from equations g_2 = (600 /1600) X 114= 42.75 seconds.
- ✓ Actual green time can be found out from equation Thus 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

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

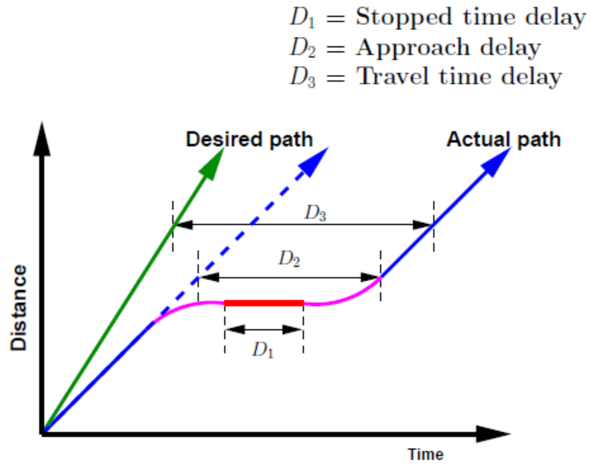


Illustration of delay measures

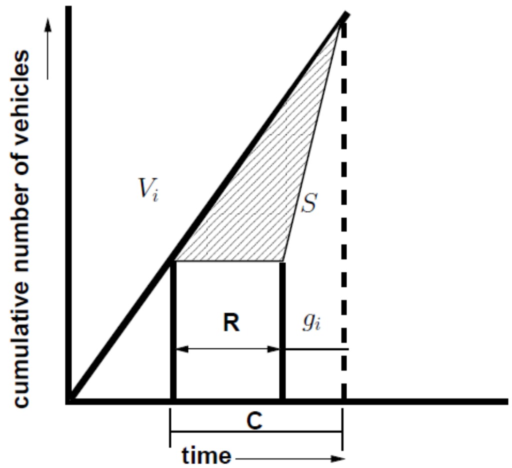
be necessary to provide an exclusive pedestrian phase. In such cases, the procedure involves computation of time duration of allocation of pedestrian phase. Green time for pedestrian crossing Gp can be found out by,

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

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, d_x is the crossing distance in metres, and up 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.

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 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 modelling of signalized intersection delay complex. Most simple of the delay models is Webster's delay model. It assumes that the vehicles are



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. 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.

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

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.