CHAPTER 5
Traffic Controls

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Traffic Controls

Traffic control devices are the media by which traffic engineers communicate with drivers. Virtually every traffic law, regulation, or operating instruction must be communicated through the use of devices that fall into three broad categories:

- Traffic markings
- Traffic signs
- Traffic signals

The effective communication between traffic engineer and driver is a critical link if safe and efficient traffic operations are to prevail. Traffic engineers have no direct control over any individual driver or group of drivers. If a motorman violated a RED signal while conducting a subway train, an automated braking system would force the train to stop anyway. If a driver violates a RED signal, only the hazards of conflicting vehicular and/or pedestrian flows would impede the maneuver. Thus, it is imperative that traffic engineers design traffic control devices that communicate uncomplicated messages clearly, in a way that encourages proper observance.

The driver is accustomed to receiving a certain message in a clear and standard fashion, often with redundancy. A number of mechanisms are used to convey messages. These mechanisms make use of recognized human limitations, particularly with respect to eyesight. Messages are conveyed through the use of:

- ***Color.*** Color is the most easily visible characteristic of a device. Color is recognizable long before a general shape may be perceived and considerably before a specific legend can be read and understood. The principal colors used in traffic control devices are red, yellow, green, orange, black, blue, and brown. These are used to code certain types of devices and to reinforce specific messages whenever possible.

- ***Shape***. After color, the shape of the device is the next element to be discerned by the driver. Particularly in signing, shape is an important element of the message, either identifying a particular type of information that the sign is conveying or conveying a unique message of its own.

- ***Pattern.*** Pattern is used in the application of traffic markings. In general, double solid, solid, dashed, and broken lines are used. Each conveys a type of meaning with which drivers become familiar. The frequent and consistent use of similar patterns in similar applications contributes greatly to their effectiveness and to the instant recognition of their meaning.

- ***Legend.*** The last element of a device that the driver comprehends is its specific legend. Signals and markings, for example, convey their entire message through use of color, shape, and pattern. Signs, however, often use specific leg- end to transmit the details of the message being transmitted. Legend must be kept simple and short, so that drivers do not divert their attention from the driving task, yet are able to see and understand the specific message being given.

This chapter introduces some of the basic principles involved in the design and placement of traffic controls with reference of MUTCD [Manual on Uniform Traffic Control Devices] standards.

5.1 Traffic Markings

Traffic markings are the most plentiful traffic devices in use. They serve a variety of purposes and functions and fall into three broad categories:

- Longitudinal markings
- Transverse markings
- Object markers and delineators

Longitudinal and transverse markings are applied to the roadway surface using a variety of materials, the most common of which are paint and thermoplastic. Reflectorization for better night vision is achieved by mixing tiny glass beads in the paint or by applying a thin layer of glass beads over the wet pavement marking as it is placed. The latter provides high initial reflectorization, but the top layer of glass beads is more quickly worn. When glass beads are mixed into the paint before application, some level of reflectorization is preserved as the marking wears.

5.1.1 Longitudinal Markings

Longitudinal markings are those markings placed parallel to the direction of travel. The vast majority of longitudinal markings involve centerlines, lane lines, and pavement edge lines. Longitudinal markings provide guidance for the placement of vehicles on the traveled way cross-section and basic trajectory guidance for vehicles traveling along the facility. The best example of the importance of longitudinal markings is the difficulty in traversing a newly paved highway segment on which lane markings have not yet been repainted. Drivers do not automatically form neat lanes without the guidance of longitudinal markings; rather, they tend to place themselves somewhat randomly on the cross-section, encountering many difficulties. Longitudinal markings provide for organized flow and optimal use of the pavement width.

- **Centerlines**

Centre line separates the opposing streams of traffic and facilitates their movements. Usually no centre line is provided for roads having width less than 5 m and for roads having more than four lanes. The centre line may be marked with either single broken line, single solid line, double broken line, or double solid line depending upon the road and traffic requirements. On urban roads with less than four lanes, the centre line may be single broken line segments of 3 m long and 150 mm wide. The broken lines are placed with 4.5 m gaps (figure 5.1).

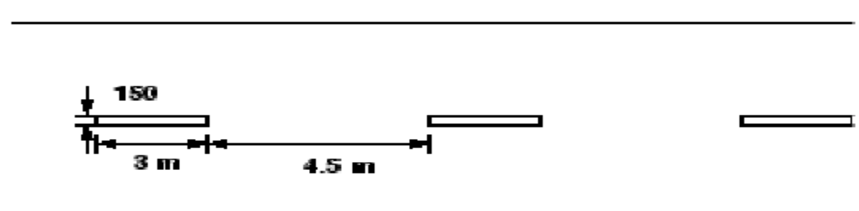


Figure 5.1: Centre line marking for a two lane road

On two-lane, two-way rural highways, centerline markings supplemented by signs are used to regulate passing maneuvers. A double-solid yellow center marking indicates that passing is not permitted in either direction. A solid yellow line with a dashed yellow line indicates that passing is permitted from the dashed side only. Where: passing is permissible in both directions, a single dashed yellow centerline is used.

- **Lane Markings**

The typical lane marking is a single white dashed line separating lanes of traffic in the same direction. MUTCD standards require the use of lane markings on all free- ways and Interstate highways and recommend their use on all highways with two or more adjacent traffic lanes in a single direction. The dashed lane line indicates that lane changing is permitted. A single solid white lane line is used to indicate that lane-changing is discouraged but not illegal. Where lane-changing is to be prohibited, a double-white solid lane line is used.

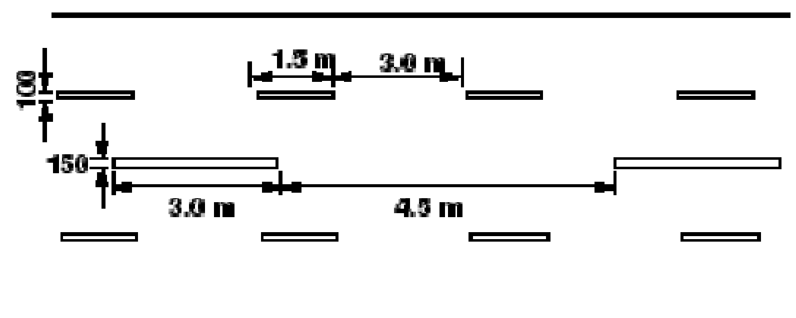


Figure 5.2: Centre line and lane marking for a four lane road

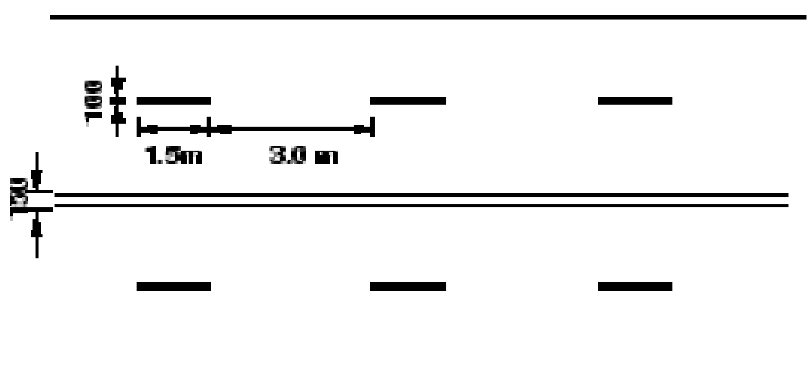


Figure 5.3: Double solid line for a two lane road

- **Edge Markings**

Edge lines indicate edges of rural roads which have no curbs to delineate the limits up to which the driver can safely venture. They should be at least 150 mm from the actual edge of the pavement. They are painted in yellow or white.

All the lines should be preferably light reflective, so that they will be visible during night also. Improved night visibility may also be obtained by the use of minute glass beads embedded in the pavement marking materials to produce a retroreflective surface.

- **Warning lines**

Warning lines warn the drivers about the obstruction approaches. They are marked on horizontal and vertical curves where the visibility is greater than prohibitory criteria specified for no overtaking zones. They are broken lines with 6 m length and 3 m gap. A minimum of seven line segments should be provided. A typical example is shown in figure 5.4.

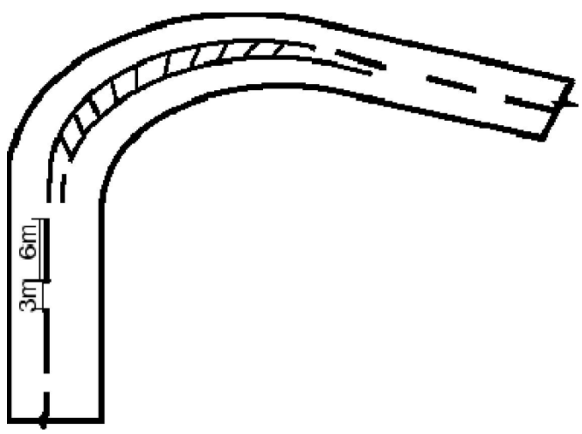


Figure 5.4: Warning line marking for a two lane road

5.1.2 Transverse Markings

Transverse markings, as their name implies, include any and all markings with a component that cuts across a portion or all of the traveled way. When used, all transverse markings are white. may be added to provide greater focus in areas with heavy pedestrian flows. The use of parallel transverse markings to identify the crosswalk is another option used at locations with heavy pedestrian flows.

- **Crosswalk Markings**

While not mandated by the MUTCD, it is recommend that crosswalks be marked at all intersections with "substantial" conflict between vehicles and pedestrian exists. They should also be used at points of pedestrian may be added to provide greater focus in areas with heavy pedestrian flows. The use of parallel transverse markings to identify the crosswalk is another option used at locations with heavy pedestrian flows. The manual also contains a special pedestrian crosswalk marking for signalized intersections where a full pedestrian phase is included.

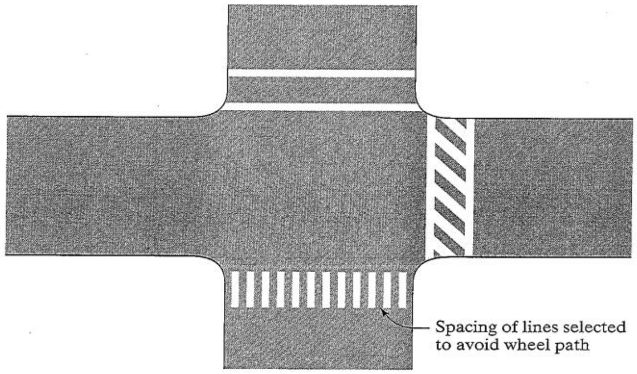


Figure 5.5: Pedestrian marking near an intersection

- **Parking Space Markings**

Parking space markings are not purely transverse, as they contain both longitudinal and transverse elements. They are officially categorized as transverse markings, however, in the MUTCD. They are always optional and are used to encourage efficient use of parking spaces. Such markings can also help prevent encroachment of parked vehicles into fire hydrant zones, loading zones, taxi stands and bus stops, and other specific locations at which parking is prohibited. They are also useful on arterials with curb parking, as they also clearly demark the parking lane, separating it from travel lanes. Figure 5.6 illustrates typical parking lane markings.

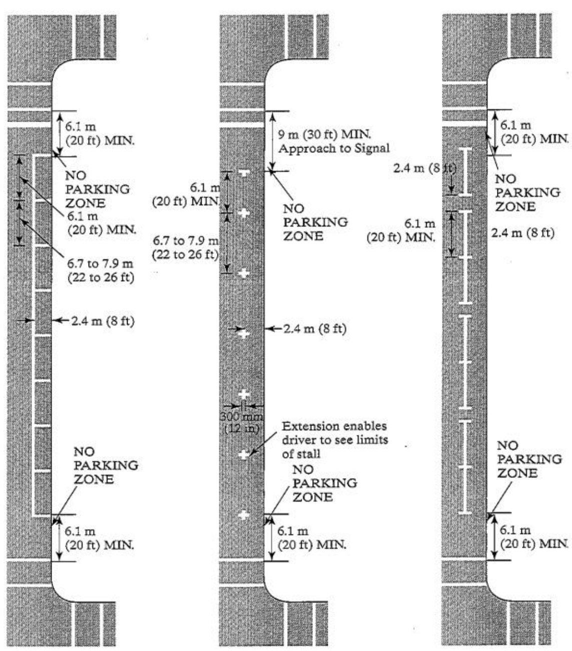


Figure **5.6:** Typical Parking Space Markings

- **Directional arrows**

In addition to the warning lines on approaching lanes, directional arrows should be used to guide the drivers in advance over the correct lane to be taken while approaching busy intersections. Because of the low angle at which the markings are viewed by the drivers, the arrows should be elongated in the direction of traffic for adequate visibility. The dimensions of these arrows are also very important.

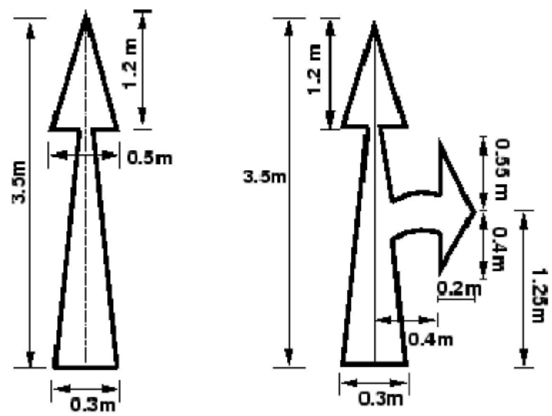


Figure 5.7 A typical example of a directional arrow

- **Word and Symbol Markings**

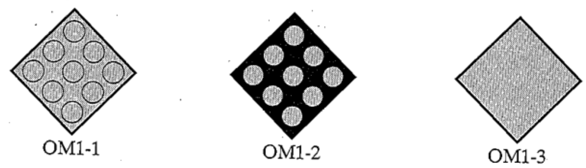
The MUTCD prescribes a number of word and symbol markings that may be used, often in conjunction with signs and/or signals. These include arrow markings indicating lane-use restrictions. Such arrows (with accompanying signs) are mandatory where a through lane becomes a left- or right-turn-only lane approaching an intersection.

Word markings include "ONLY" used in conjunction with lane use arrows, and "STOP" which can be used only in conjunction with a STOP line and a STOP sign. "SCHOOL" markings are often used in conjunction with signs to demark school and school-crossing zones. The MUTCD contains a listing of all authorized word markings and allows for discretionary use of unique messages where needed.

5.1.3 Object Markers

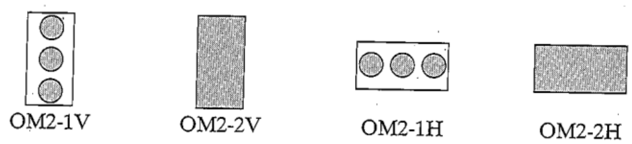
Object markers are used to denote obstructions either or adjacent to the traveled way. There are three types of object markers used, as illustrated in Figure below. Obstructions within the roadway *must* be marked using a Type 1 or Type 3 marker. The Type 3 marker, when used, must have the alternating yellow and black stripes sloped downward at a 45° angle towards the side on which traffic is to pass the obstruction. When used to mark a roadside obstruction, the inside edge. of the marker must be in line with the inner edge of the obstruction.

Typical Type 1 Object Markers



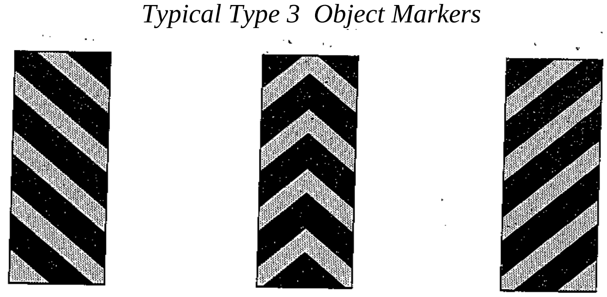
Nine yellow retroreflectors with 3-in minimum diameter on a yellow or black diamond panel of 18 in or more on a side; or an all-yellow retro reflective diamond panel of the same size.

Typical Type 2 Object Markers



Three yellow retroreflectors with 3-in minimum diameter arranged horizontally or vertically on white panel of at least 6 X 12 in; or an all- yellow retroreflective panel of the same size.

Typical Type 3 Object Markers



A striped marker measuring 12 X 36 in with alternating black and yellow stripes sloping downward at an angle of 45° toward the side of the obstruction on which traffic is to pass.

5.2 Traffic Signs

In general, traffic signs fall into one of three major categories:

- **Regulatory *signs.***
- ***Warning signs.***
- ***Guide signs*.**

5.2.1. Regulatory Signs

Regulatory signs shall be used to inform road users of selected traffic laws or regulations and indicate the applicability of the legal requirements. Regulatory signs convey information concerning specific traffic regulations. Regulations may relate to right-of-way, speed limits, lane usage, parking, or a variety of other functions.

Regulatory signs shall be installed at or near where the regulations apply. The signs shall clearly indicate the requirements imposed by the regulations and shall be designed and installed to provide adequate visibility and legibility in order to obtain compliance.

Drivers are expected to be aware of many general traffic regulations, such as the basic right-of-way rule at intersections and the state speed limit. Signs, however, should be used in all cases where the driver cannot be expected to know the applicable regulation.

Except for some special signs, such as the STOP and YIELD sign, most regulatory signs are rectangular, with the long dimension vertical. Some regulatory signs are square. These are primarily signs using symbols instead of legend to impart information. The background color of regulatory signs, with a few exceptions, is white, while legend or symbols are black. In symbol signs, a red circle with a bar through it signifies a prohibition of the movement indicated by the symbol.

Right of way series: These include two unique signs that assign the right of way to the selected approaches of an intersection. They are the STOP sign and GIVE WAY sign For example, when one minor road and major road meets at an intersection, preference should be given to the vehicles passing through the major road. Hence the give way sign board will be placed on the minor road to inform the driver on the minor road that he should give way for the vehicles on the major road. In case two major roads are meeting, then the traffic engineer decides based on the traffic on which approach the sign board has to be placed. Stop sign is another example of regulatory signs that comes in right of way series which requires the driver to stop the vehicle at the stop line.

Speed series: Number of speed signs may be used to limit the speed of the vehicle on the road. They include typical speed limit signs, truck speed, minimum speed signs etc. Speed limit signs are placed to limit the speed of the vehicle to a particular speed for many reasons. Separate truck speed limits are applied on high speed roadways where heavy commercial vehicles must be limited to slower speeds than passenger cars for safety reasons. Minimum speed limits are applied on high speed roads like expressways, freeways etc. where safety is again a predominant reason. Very slow vehicles may present hazard to themselves and other vehicles also.

Movement series: They contain a number of signs that affect specific vehicle maneuvers. These include turn signs, alignment signs, exclusion signs, one way signs etc. Turn signs include turn prohibitions and lane use control signs. Lane use signs make use of arrows to specify the movements which all vehicles in the lane must take. Turn signs are used to safely accommodate turns in unsignalized intersections.

Parking series: They include parking signs which indicate not only parking prohibitions or restrictions, but also indicate places where parking is permitted, the type of vehicle to be parked, duration for parking etc.

Pedestrian series: They include both legend and symbol signs. These signs are meant for the safety of pedestrians and include signs indicating pedestrian only roads, pedestrian crossing sites etc.

Miscellaneous: Wide variety of signs that are included in this category are: a "KEEP OF MEDIAN" sign, signs indicating road closures, signs restricting vehicles carrying hazardous cargo or substances, signs indicating vehicle weight limitations etc.

Figure 5.7: Examples of regulatory signs (stop sign, give way sign, signs for no entry, sign indicating prohibition for right turn, vehicle width limit sign, speed limit sign)

5.2.2. Warning Signs

Warning signs call attention to unexpected conditions on or adjacent to a highway or street and to situations that might not be readily apparent to road users. Warning signs alert road users to conditions that might call for a reduction of speed or an action in the interest of safety and efficient traffic operations.

Most warning signs are diamond-shaped, with black lettering or symbols on a yellow background. A pennant shape is used for the "No Passing Zone" sign, used in conjunction with passing restrictions on two- lane, two-way rural highways. A rectangular shape is used for some arrow indications. A circular shape is used for railroad crossing warnings.

The MUTCD indicates that warning signs shall be used only in conjunction with an engineering study or based on engineering judgment. While this is a fairly loose requirement, it emphasizes the need to avoid over- use of such signs. A warning sign should be used only to alert drivers of conditions that they could not be normally expected to discern on their own. Overuse of warning signs encourages drivers to ignore them, which could lead to dangerous situations.

When used, warning signs must be placed far enough in advance of the hazard to allow drivers adequate time to perform the required adjustments. Warning signs may be used with supplementary panels indicating either the distance to the hazard or an advisory speed. The advisory speed is the recommended safe speed through the hazardous area and is determined by an engineering study of the location. Warning signs are used to inform drivers of a variety of potentially hazardous circumstances, including:

- Changes in horizontal alignment
- Intersections
- Advance warning of control devices
- Converging traffic lanes
- Narrow roadways
- Changes in highway design
- Grades
- Roadway surface conditions
- Railroad crossings

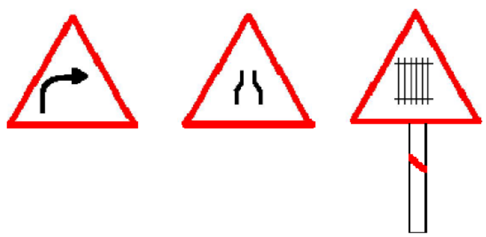


Figure 5.8: Examples of cautionary signs (right hand curve sign board, signs for narrow road, sign indicating railway track ahead)

5.2.3. Guide/Informative/ Signs

Guide signs provide information to road users concerning destinations, available services, and historical/recreational facilities. They serve a unique purpose in that drivers who are familiar or regular users of a route will generally not need to use them; they provide critical information, however, to unfamiliar road users. The background varies by the type of information contained on the sign. Directional or destination information is provided by signs with a green background; information on services is provided by signs with a blue background; cultural, historical, and/or recreational in- formation is provided by signs with a brown back- ground. Route markers, included in this category, have varying shapes and colors depending on the type and jurisdiction of the route.

The MUTCD provides guide-signing information for three types of facilities: conventional roads, free- ways, and expressways. Guide signing is somewhat different from other types in that overuse is generally not a serious issue, unless it leads to confusion. Clarity and consistency of message is the most important aspect of guide signing. Several general principles may be applied:

1. If a route services a number of destinations, the most important of these should be listed.
2. No guide sign should list more than three (four may be acceptable in some circumstances) destinations on a single sign. This, in conjunction with the first principle, makes the selection of priority destinations a critical part of effective guide signing.
3. Where roadways have both a name and a route number, both should be indicated on the sign if space permits. In cases where only one may be listed, the route number takes precedence. Road maps show route numbers prominently, while not all facility names are included. Unfamiliar drivers are, therefore, more likely to know the route number than the facility name.
4. Wherever possible, advance signing of important junctions should be given. This is more difficult on conventional highways, where junctions may be frequent and closely spaced. On free- ways and expressways, this is critical, as high approach speeds make advance knowledge of upcoming junctions a significant safety issue.
5. Wherever possible, advance signing of important junctions should be given. This is more difficult on conventional highways, where junctions may be frequent and closely spaced. On freeways and expressways, this is critical, as high approach speeds make advance knowledge of upcoming junctions a significant safety issue.
6. Confusion on the part of the driver must be avoided at all cost. Sign sequencing should be logical and should naturally lead the driver to the desired route selections. Overlapping sequences should be avoided wherever possible. Left-hand exits and other unusual junction features should be signed extremely carefully.
7. The size, placement, and lettering of guide signs vary considerably, and the manual gives information on numerous options. A number of site-specific

conditions affect these design features, and there is more latitude and choice involved than for other types of highway signs. The MUTCD should be consulted directly for this information.

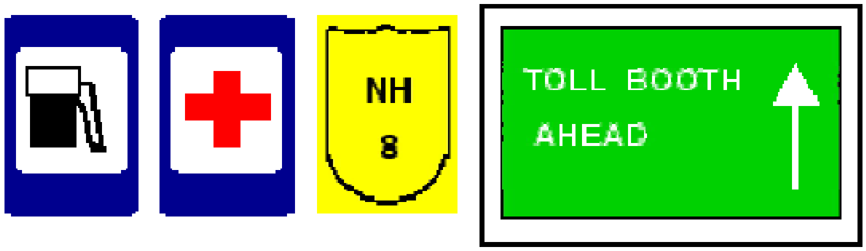


Figure 5.9: Examples of informative signs (route markers, destination signs, mile posts, service centre information etc)

5.3 Traffic signal

The operation of signalized intersections is often complex, involving competing vehicular and pedestrian movements. Appropriate methodologies for design and timing of signals and for the operational analysis of signalized intersections require that the behavior of drivers and pedestrians at a signalized intersection be modeled in a form that can be easily manipulated and optimized.

- **Objectives of Signal Timing**

The main objectives of signal timing at an intersection are to reduce the average delay of all vehicles and the probability of accidents. These objectives are achieved by minimizing the possible conflict points when assigning the right of way to different traffic streams at different times. The objective of reducing delay, however, sometimes conflicts with that of accident reduction. This is because the number of distinct phases should be kept to a minimum to reduce average delay, whereas many more distinct phases may be required to separate all traffic streams from each other. When this situation exists, it is essential that engineering judgment be used to determine a compromise solution. In general, however, it is usual to adapt a two-phase system whenever possible, using the shortest practical cycle length that is consistent with the demand. At a complex intersection, though, it may be necessary to use a multiphase (three or more phases) system to achieve the main design objectives.

Types of Signal Operation

Traffic signals can operate on a pre-timed basis or may be partially or fully actuated by arriving vehicles sensed by detectors. In networks, or on arterials, signals may be coordinated through computer control.

1. *Pre-timed operation.* In pre-timed operation, the cycle length, phase sequence, and timing of each interval are constant. Each cycle of the signal follows the same predetermined plan. "Multi-dial" controllers will allow different pre- timed settings to be established. An internal clock is used to activate the appropriate timing. In such cases, it is typical to have at least an AM peak, a PM peak, and an off-peak signal timing.

2. ***Semi-actuated operation.*** In semi-actuated operation, detectors are placed on the minor approach (es) to the intersection; there are no detectors on the major street. The light is green for the major street at all times except when a "call" or actuation is noted on one of the minor approaches. Then, subject to limitations such as a minimum major-street green, the green is transferred to the minor street. The green returns to the major street when the maximum minor- street green is reached or when the detector senses that there is no further demand on the minor street.

3. ***Full actuated operation.*** In full actuated operation, every lane of every approach must be monitored by a detector. Green time is allocated in for capturing and retaining the green. In full actuated operation, the cycle length, sequence of phases, and green time split may vary from cycle to cycle.

4. ***Computer control.*** Computer control is a system term. No individual signal is "computer controlled," unless the signal controller is considered to be a computer. In a computer-controlled system, the computer acts as a master controller, coordinating the timings of a large number (hundreds) of signals. The computer selects or calculates an optimal coordination plan based on input from detectors placed through out the system. In general, such selections are made only once in advance of an AM or PM peak period. The nature of a system transition from one timing plan to another is sufficiently disruptive to be avoided during peak-demand periods. Individual signals in a computer-controlled system generally operate in the pretimed mode. For coordination to be effective, all signals in the network must use the same cycle length (or an even multiple thereof), and it is therefore difficult to maintain a progressive pat tern where cycle length or phase splits are allowed to vary.

Components of a Signal Cycle

The following terms describe portions and sub portions of a signal cycle. The most fundamental unit in signal design and timing is the cycle, as defined below.

1. ***Cycle.*** A signal cycle is one complete rotation through all of the indications provided. In general, every legal vehicular movement receives a "green" indication during each cycle, although there are some exceptions to this rule.
2. ***Cycle length.*** The cycle length is the time (in seconds) that it takes to complete one full cycle of indications. It is given the symbol "C."
3. ***Interval.*** The interval is a period of time during which no signal indication changes. It is the smallest unit of time described within a signal cycle. There are several types of intervals with- in a signal cycle:

   (a) ***Change interval***. The change interval is the "yellow" indication for a given movement. It is part of the transition from "green" to "red," in which movements about to lose "green" are given a "yellow" signal, while all other movements have a "red" signal. It is timed to allow a vehicle that cannot safely stop when the "green" is withdrawn to enter the intersection legally. The change interval is given the symbol "τ_i" *for* movement(s) *i*.

   (b) ***Clearance interval.*** The clearance interval is also part of the transition from "green" to "red" for a given set of movements. During the clearance interval, all movements have a "red" signal. It is timed to allow a vehicle that legally enters the intersection on "yellow" to safely cross the intersection before conflicting flows are released. The clearance interval is given the symbol "ar_i" (for "all red") for movement(s) *i*.

   (c) ***Green interval.*** Each movement has one green interval during the signal cycle. During
   a green interval, the movements permitted have a "green" light, while all other movements have a "red" light. The green interval is given the symbol "G_i" for movement(s) *i*.

(d) *Red interval.* Each movement has a red interval during the signal cycle. All movements not permitted have a "red" light, while those permitted to move have a "green" light. In general, the red interval overlaps the green intervals for all other movements in the inter- section. The red interval is given the symbol *"R_i"* for movement(s) ***i***.

4. *Phase.* A signal phase consists of a green interval, plus the change and clearance intervals that follow it. It is a set of intervals that allows a designated movement or set of movements to flow and to be safely halted before release of a conflicting set of movements.

Lane groups.

A lane group consists of one or more lanes on an intersection approach and having the

same green phase. Lane groups for each approach are established using the following guidelines:

- Separate lane groups should be established for exclusive left-turn lane(s), unless the approach also contains a shared left-turn and through lane. In such a case, consideration also should be given to the distribution of traffic volume between the movements. These same guidelines apply for exclusive right-turn lanes.
- When exclusive left-turn lane(s) and/or exclusive right-turn lane(s) are provided on an approach, all other lanes are generally established as a single lane group.
- When an approach with more than one lane also has a shared left-turn lane, the operation of the shared left-turn lane should be evaluated to determine whether it is effectively operating as an exclusive left-turn lane because of the high volume of left-turn vehicles on it.

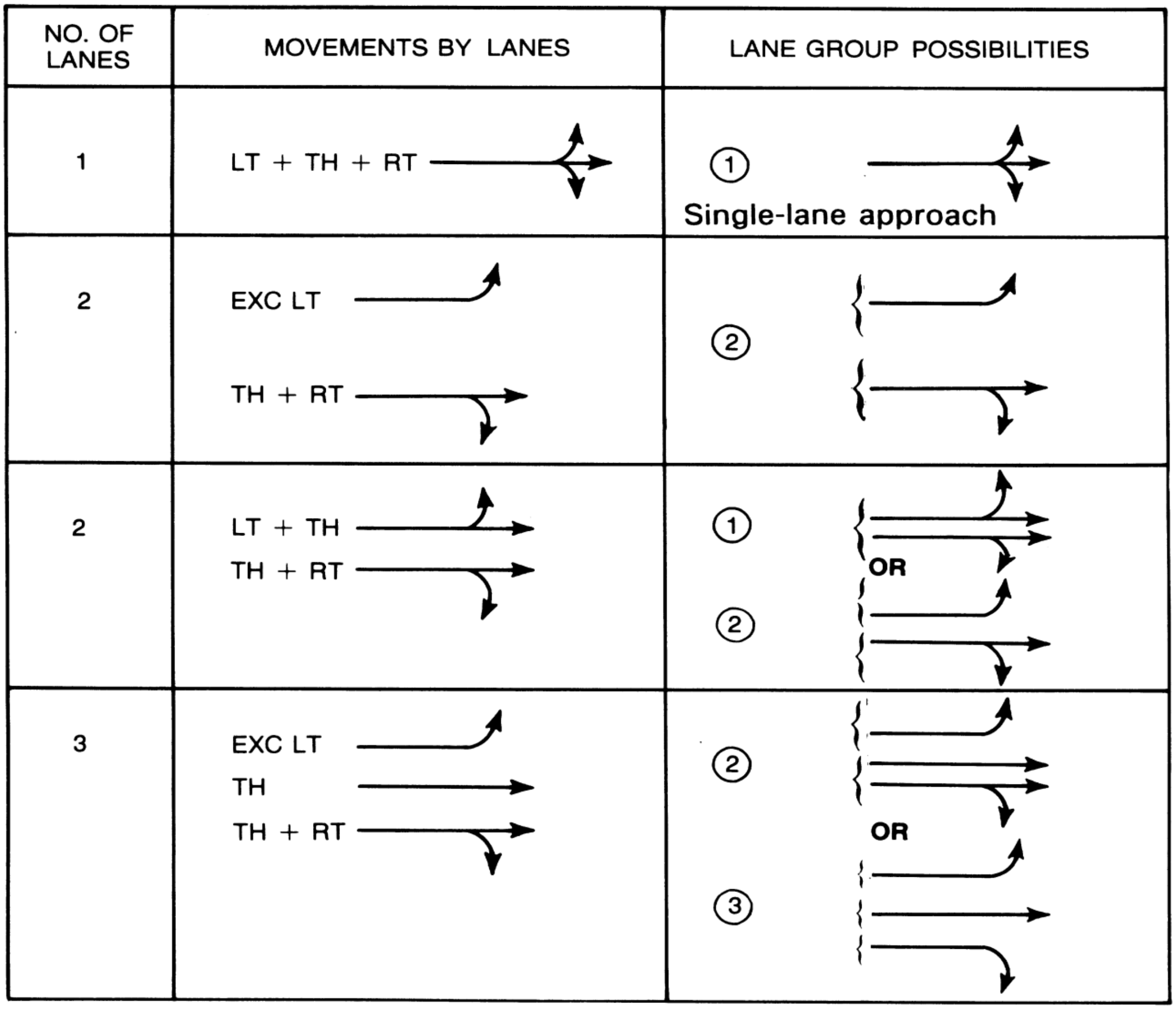


Figure .shows typical lane groups used for analysis.

Signal Timing at Isolated Intersections

An isolated intersection is one in which the signal time is not coordinated with that of any other intersection and therefore operates independently. The cycle length for an intersection of this type should be short, preferably between 35 and 60 sec, although it may be necessary to use longer cycles when approach volumes are very high. However, cycle lengths should be kept below 120 sec, since very long cycle lengths will result in excessive delay. Several methods have been developed for determining the optimal cycle length at an intersection and, in most cases, the yellow interval is considered as a component of the green time. Before discussing two of these methods, we will discuss the basis for selecting the yellow interval at an intersection.

Yellow Interval

The main purpose of the yellow indication after the green is to alert motorists to the fact that the green light is about to change to red and to allow vehicles already in the intersection to cross it. A bad choice of yellow interval may lead to the creation of a dilemma zone, an area close to an intersection in which a vehicle can neither stop safely before the intersection nor clear the intersection without speeding before the red signal comes on. The required yellow interval is the time period that guarantees that an approaching vehicle can either stop safely or proceed through the intersection without speeding.

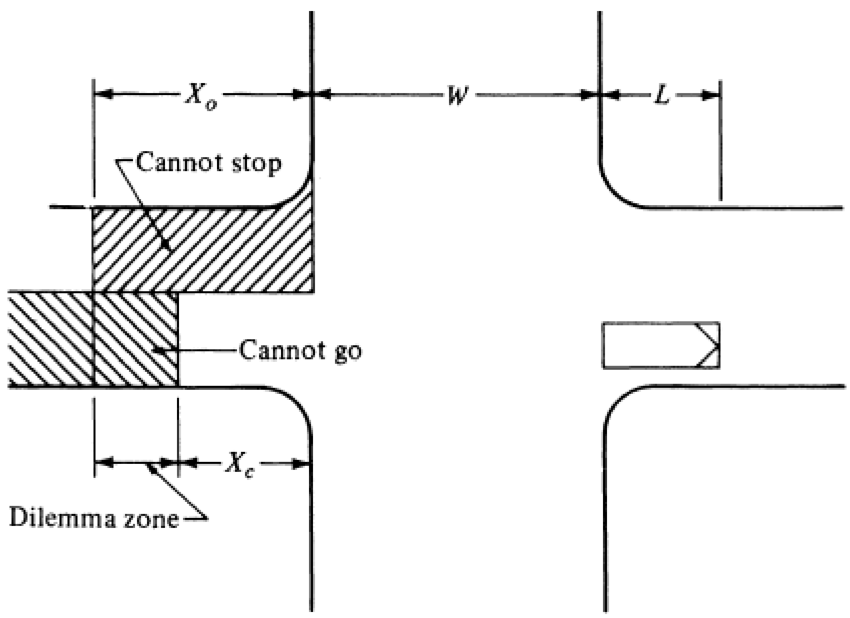


Figure 5.10 schematic of a dilemma zone.

For the dilemma zone to be eliminated the distance X_o should be equal to the distance X_c. Let τ_{min} be the yellow interval (sec) and let the distance traveled during the change interval without accelerating be u_o (τ_{min}), with u_o = speed limit on approach (m/sec). If the vehicle just clears the intersection, then

$$X_c = u_o(\tau_{min}) - (W + L)$$

Where: X_c is the distance within which a vehicle traveling at the speed limit (u_o) during the yellow interval time cannot stop before encroaching on the intersection. Vehicles within this distance at the start of the yellow interval will therefore have to go through the intersection; W =width of intersection (m); L = length of vehicle (m)

For vehicles to be able to stop, however,

$$X_o = u_o \delta + \frac{u_o^2}{2a}$$

Where: X_o = the minimum distance from the intersection for which a vehicle traveling at the speed limit u_o during the clearance interval Y_o cannot go through the intersection without accelerating; any vehicle at this distance or at a distance greater than this has to stop; δ= perception-reaction time; a = constant rate of braking deceleration (m/sec2)

For the dilemma zones to be eliminated, X_o must be equal to X_c. Accordingly,

$$u_o (\tau_{min}) - (W + L) = u_o \delta + \frac{u_o^2}{2a}$$

$$\tau_{min} = \delta + \frac{u_o}{2a} + \frac{(W+L)}{u_o}$$

If the effect of grade is added,

$$\tau_{min} = \delta + \frac{u_o}{2(a+Gg)} + \frac{(W+L)}{u_o}$$

Where, τ_{min} = *the minimum yellow interval, (sec)*

δ = perception-reaction time (sec)

W = width of intersection, (m)

L = length of vehicle, (m)

u_o = *speed (m/sec)*

a = deceleration, (m/sec^2)

G = grade of the approach road, and

g = acceleration due to gravity

Yellow intervals of 3 to 5 sec are normally used. When longer yellow intervals than 5 see are computed from the above equations, an all-red phase can be inserted to follow the yellow indication, but the change interval, yellow plus all-red, must be at least the value computer from the equations.

Cycle lengths: - Several design methods have been developed to determine the optimum cycle, length, one of which the Webster method is presented here.

Example 1

Webster method

- **Cycle Length**

Webster has shown that for a wide range of practical conditions, minimum intersection delay is obtained when the cycle length is obtained by the equation:

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{n} Y_i}$$

Where, C_o = *optimum cycle length (sec)*

L = *total lost time per cycle (sec)*

Y_i = *maximum value of the ratios of approach flows to saturation flows for all traffic streams using phase i (i.e.,* V_{ii} / S_j*)*

n = *number of phases*

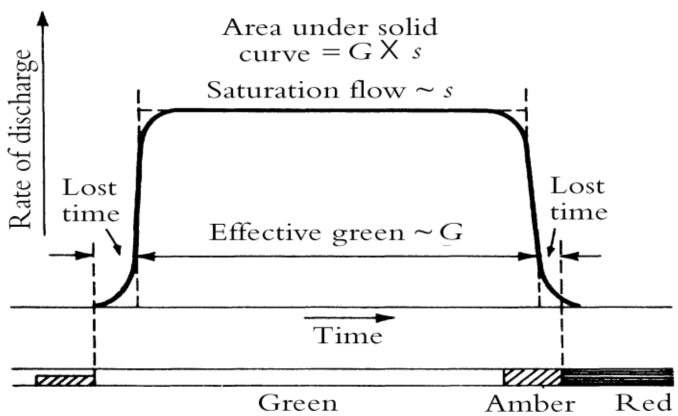
V_{ij} = *flow on lane j having the right of way during phase i*

S_j = *saturation flow on lane i*

- **Total Lost Time.**

Figure shows a graph of rate of discharge of vehicles at various times during a green phase of a signal cycle at an intersection. Initially, some time is lost before the vehicles start moving, and then the rate of discharge increases to a maximum. This maximum rate of discharge is the saturation flow. If there are sufficient vehicles in the queue to use the available green time, the maximum rate of discharge will be sustained until the yellow phase occurs. The rate of discharge will then fall to zero when the yellow signal changes to red. The number of vehicles that go through the intersection is represented by the area under the curve. Dividing the number of vehicles that go through the intersection by the saturation flow will give the effective green time, which is less than the sum of the green and yellow times. This difference is considered lost time, since it is not used by any other phase for the discharge of vehicles; it can be expressed as

$$\ell_i = G_{ai} + \tau_i - G_{ei}$$



Where, l_i *= lost time for phase i*

G_{ai} *= actual greed time for phase i(not including yellow time)*

τ_i *= yellow time for phase i*

G_{ei} *= effective green time for phase i*

Total lost time is given as

$$L = \sum_{i=1}^{\phi} l_i + R$$

Where, R is the total all-red time during the cycle

- **Allocation of Green Times.**

In general, the total effective green time available per cycle is given by

$$G_{te} = C - L = C - (\sum_{i=1}^{\phi} l_i + R)$$

Where, C= actual cycle length used(usually obtained by rounding off C_o *to the nearest five seconds*

G_{te} = *total effective greed time per cycle*

To obtain minimum overall delay, the total effective green time should be distributed among the different phases in proportion to their Y values to obtain the effective green time for each phase.

$$G_{ei} = \frac{Y_i}{Y_1 + Y_2 + ...Y_\phi} G_{te}$$

And the actual green time for each phase is obtained as

$$G_{a1} = G_{e1} + l_1 - \tau_1$$
$$G_{a2} = G_{e2} + l_2 - \tau_2$$
$$G_{ai} = G_{ei} + l_i - \tau_i$$
$$G_{a\phi} = G_{e\phi} + l_\phi - \tau_\phi$$

- **Minimum Green Time**

At an intersection where a significant number of pedestrians cross, it is necessary to provide a minimum green time that will allow the pedestrians to safely cross the intersection.

The length of this minimum green time may be higher than that needed for vehicular traffic to go through the intersection.

The green time allocated to the traffic moving in the north–south direction should, therefore, not be less than the green time required for pedestrians to cross the east–west approaches at the intersection. Similarly, the green time allocated to the traffic moving in the east–west direction cannot be less than that required for pedestrians to cross the north–south approaches.

The minimum green time can be determined by using the HCM expressions given

$$G_p = 3.2 + \frac{L}{S_p} + [2.7\frac{N_{ped}}{W_E}].......W_E > 10\,ft$$

$$G_p = 3.2 + \frac{L}{S_p} + (0.27N_{ped}).......W_E \le 10\,ft$$

Where, Gp = minimum green time (sec)

L = crosswalk length (ft)

S_p = average speed of pedestrians, usually taken as 4ft/sec(assumed to represent 15th percentile pedestrian walking speed0

3.2= pedestrian start-up time

W_E = effective crosswalk width

N_{ped}= number of pedestrians crossing during an interval

Example 2

Figure 5.11a and table showed below shows peak-hour volumes for a major intersection on an arterial highway. Using the Webster method, determine suitable signal timing for the intersection using a four–phase system and the additional data given in the figure. Use a Yellow interval of 3.5sec.

	East Approach (A)			West Approach (B)			South Approach (C)			North Approach (D)		
Lane	L	T	T+R	L	T	T+R	T+R	T	L	T+R	T	L
PHV	222	464	464	128	321	321	109	75	25	206	100	352

% of truck = 4%

Left turn factor= 1.3

Truck factor to PCE= 1.6

Saturation flow= 1960veh/hr for all approach.

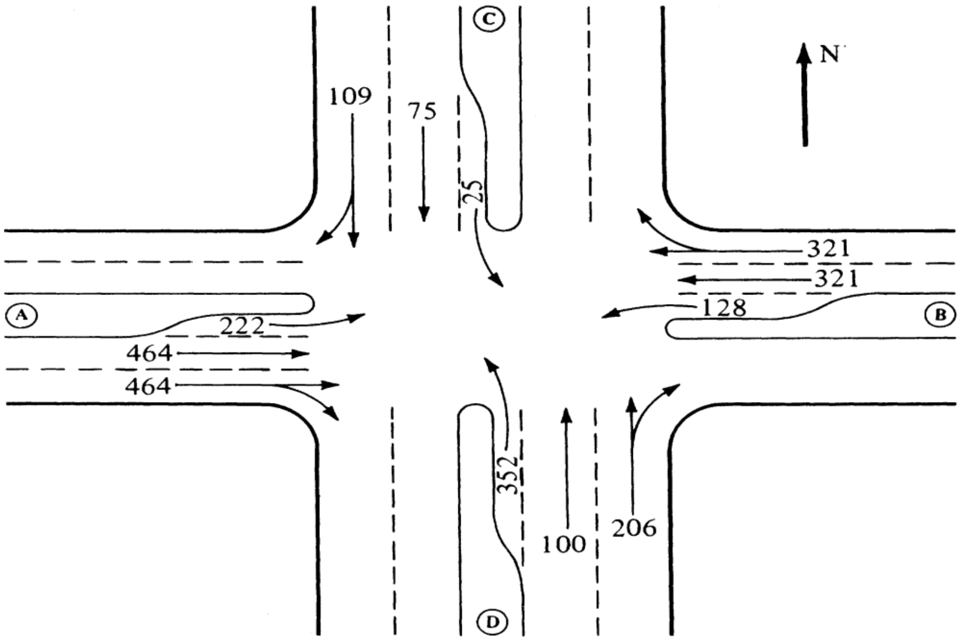
Neglect pedestrian effect.

Solution:

First convert the mixed volumes to equivalent straight-through passenger cars. The equivalent volumes are shown Figure 5-11b. The volumes were obtained by dividing by the PHF, and then by applying the relevant factors for trucks and left–turning vehicles as necessary. No factors for right- turning vehicles were used because those volumes were very low. Assume the following phasing system, where the arrows indicate traffic streams that have the right of way:

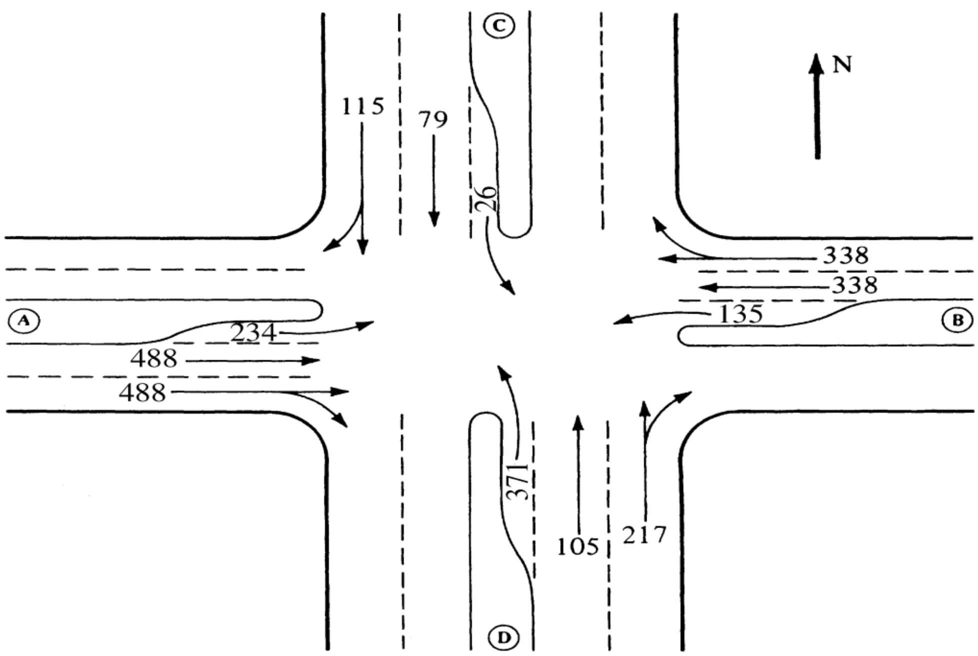
The critical lane volumes are (see Figure 5-11b)

Compute the total time using l_i=*3.5sec*. Since there is not an all-red phase-that is, R=0 and there are four phases,



PHF = 0.95
Pedestrian volume is negligible.

(a) Data for Example 8.5



(b) Equivalent hourly flows

Figure 5.11a & b: Peak hour volume for major intersection on arterial highway

	East Approach (A)			West Approach (B)			South Approach (C)			North Approach (D)		
Lane	L	T	T+R	L	T	T+R	L	T+R	T	L	T+R	T
PHV	222	464	464	128	321	321	25	109	75	352	206	100
DHV	234	488	488	135	338	338	26	115	79	371	217	105
PCE	239	500	500	138	346	346	27	118	81	379	222	108
PCE LT eq.	311	500	500	179	346	346	35	118	81	493	222	108

Phase, n	Critical Lane volume
A	500
B	346
C	118
D	493
	1471

	East Approach (A)			West Approach (B)			South Approach (C)			North Approach (D)		
Lane	1	2	3	1	2	3	1	2	3	1	2	3
Vi	311	500	500	179	346	346	35	118	81	493	222	108
Si	1960	1960	1960	1960	1960	1960	1960	1960	1960	1960	1960	1960
Yi= (Vi/Si)	0.159	0.255	0.255	0.091	0.177	0.177	0.018	0.060	0.041	0.251	0.113	0.055
Max Yi	0.255			0.177			0.060			0.251		
					Σyi=	0.74						

$$L = \sum_{i=1}^{n} l_i = 4\ x\ 3.5 = 14 sec$$

$$\sum Y_i = 0.74$$

Determine the optimum cycle length

$$C_o = \frac{1.5L+5}{1-\sum_{i=1}^{n} Y_i} = \frac{1.5x14+5}{1-0.74} = 100sec$$

Find the total effective green time:

G_{te}= C - L = 100 – 14 = 86 sec

Effective time for phase i is obtained from:

$$G_{ei} = \frac{Y_i}{Y_1 + Y_2 + \ldots + Y_n} G_{te}$$

$$G_{ei} = \frac{Y_i}{0.74} 86$$

Yellow time τ_i =3*sec*; then the actual green time for each phase can be calculated as:

$$G_{ai} = G_{ei} + l_i - \tau_i$$

- Actual green time for phase A: $G_{aA} = \frac{0.25}{0.74}$ x 86 + 3.5 – 3.0 = 30sec
- Actual green time for phase A: $G_{aB} = \frac{0.17}{0.74}$ x 86 + 3.5 – 3.0 = 20sec
- Actual green time for phase A: $G_{aC} = \frac{0.06}{0.74}$ x 86 + 3.5 – 3.0 = 7sec
- Actual green time for phase A: $G_{aD} = \frac{0.26}{0.74}$ x 86 + 3.5 – 3.0 = 31sec

  Therefore because of pedestrian volume is negligible, you can use the above actual green time for allocation as it is.

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