Cairo University
Faculty of Engineering
Public Works Department

Traffic Engineering

Intersection Control and Signal Design

Dr. Dalia Said,
Assistant Professor, Highway and Traffic Engineering
Civil Engineering Department,
Cairo University,
dalia_said@yahoo.com

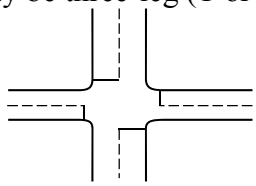
- An intersection is an area shared by two or more roads
- Main function is to allow the change of route directions
- It is an area of decision for all drivers and thus requires additional effort and is a more complicated area for drivers
- Intersections normally perform at levels below those of the rest of the street or highway and thus control the quality of traffic flow , and is a source of congestion in urban areans

Types of Intersections

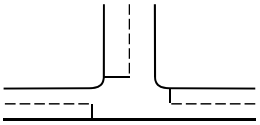
- Intersections can be classified as:
  - At-grade: all roads intersect at the same level:
    - Conventional
    - Roundabouts
  - Grade-separated without ramps: uninterrupted cross-flow of traffic at different levels (over or underpass with no access)
  - Grade-separated with ramps (freeway interchanges)

At-Grade Intersections

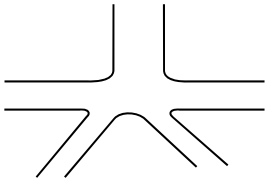
- May be three-leg (T or Y), four-leg, or multi-leg



Four-leg intersection



T-intersection

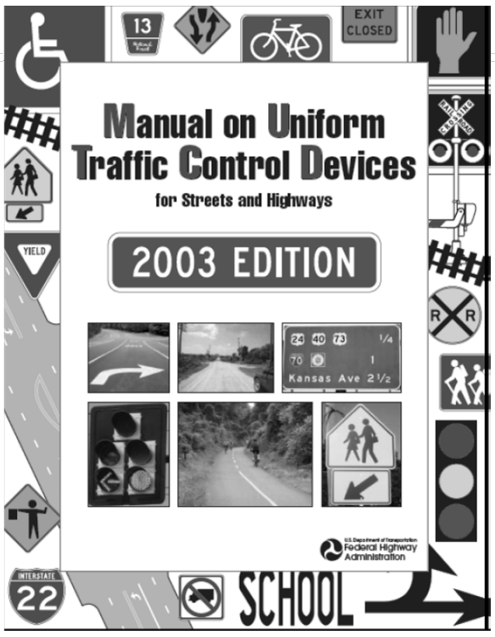


Multi-leg intersection

General Concepts of Traffic Control

- The purpose of traffic control is to assign the right of way to drivers, and thus to facilitate highway safety by ensuring the orderly and predictable movement of all traffic on highways
- Control can be achieved by using traffic signals, signs, or markings that regulate, guide, warn, and/or channel traffic
- A traffic control device must:
  - Fulfill a need
  - Command attention
  - Convey a clear simple meaning
  - Command the respect of road users
  - Give adequate time for proper response

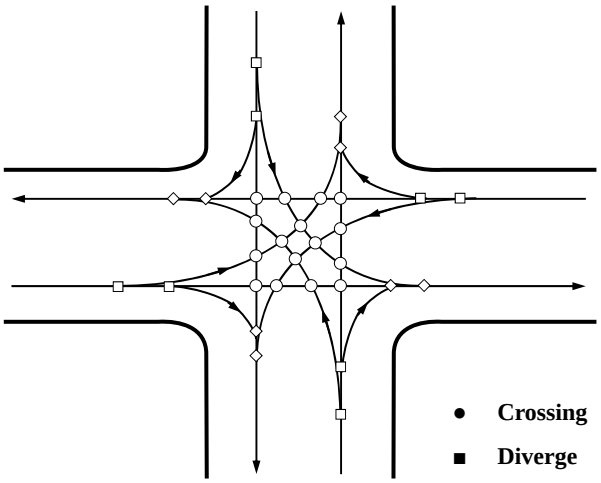
- For the traffic control device to have these five properties, five factors should be considered:
  - Design:
    - Size, colour, shape, …
  - Placement:
    - Within the cone of vision with adequate response time
  - Operation:
    - Used in a manner that ensures the fulfillment of traffic requirements
  - Maintenance:
    - Regularly maintained to sustain legibility
  - Uniformity:
    - To ensure recognition and understanding of these devices
- Guidelines for the different types of traffic control devices are provided in the *Manual on Uniform Traffic Control Devices* (MUTCD)
  - Check the FHWA Millenium Edition of the MUTCD at http://mutcd.fhwa.dot.gov/kno-millennium.htm



Conflict Points at Intersections

- Conflicts occur when traffic streams moving in different directions interfere with each other
- Three types of conflicts:
  - Merging
  - Diverging
  - Crossing
- The number of possible conflict points at any intersection depends on:
  - Number of approaches
  - Turning movements
  - Type of traffic control

– Example: conflict points at a four-leg intersection



●	**Crossing**	**= 16**
■	**Diverge**	**= 8**
♦	**Merge**	**= 8**
	Total	**= 32**

Types of Intersection Control

– The primary objective of a traffic control system at an intersection is to reduce the number of conflict points

– The choice of one method for traffic control at the intersection depends on many factors:

- Vehicle volume
- Turning movements
- Pedestrian volume
- School crossing
- Accident experience
- Delay (Interruptions of Traffic Flow)
- Other considerations

– Warrants for the different types of traffic control devices are given in the MUTCD

Types of Intersection Control

1. Yield Signs:
   - Drivers on approaches with yield signs are required to slow down and yield the right of way to all conflicting vehicles at the intersection
   - Stopping is not mandatory unless it interferes with a traffic stream that has the right of way
2. Stop Signs:
   - Approaching vehicles are required to stop before entering the intersection
   - Use of stop signs results in considerable inconvenience to motorists and thus must be used only when warranted
   - Stop signs may be warranted at intersection with restricted view
3. Multiway Stop Signs:
   - All vehicles approaching the intersection stop before entering it
   - Used as a safety measure at some intersections with traffic volumes on all approaches are approximately equal
4. Intersection Channelization:
   - Used to separate turn lanes from through lanes
   - Solid lines or raised barriers guide traffic within a lane so that vehicles can safely negotiate a complex intersection
   - Raised islands can also provide a refuge for pedestrians
5. Traffic Signals:
   - Traffic signals are used to assign the use of the intersection to different traffic streams at different times, and thus eliminate many conflicts
   - Efficient operation of a traffic signal requires proper timing of the different colour indications

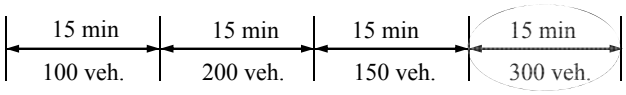
Signal Timing at Isolated Intersections

- An isolated intersection is one in which the signal time is not coordinated with that of any other intersection and therefore operates independently
- **Definitions**:
  - **Cycle (cycle length):** the time in seconds required for one complete colour sequence of signal indication (G+Y+R)
  - **Phase (signal phase):** that part of a cycle allocated to a stream of traffic, or a combination of two or more streams of traffic, having the right of way simultaneously during one or more intervals
  - **Interval:** any part of the cycle length during which signal indications do not change
  - **Change and clearance interval:** total length of time in seconds of the yellow and all-red signal indications (allows vehicles to clear the intersection before conflicting movements are released)
  - **All-red interval:** the display time of a red indication for all approaches

Signal Timing at Isolated Intersections

– **Definitions (cont'd)**:

- **Peak-hour factor (PHF):** a measure of variability of demand during the peak hour, and is equal to the ratio of the volume during the peak hour to the maximum rate of flow during a given period within the peak hour (smallest time period is 15 min.)



$V = 100 + 200 + 150 + 300 = 750$ veh/h
$q = 300 \times 4 = 1200$ veh/h
PHF = 750/1200 = 0.625

Signal Timing at Isolated Intersections

– **Definitions (cont'd)**:

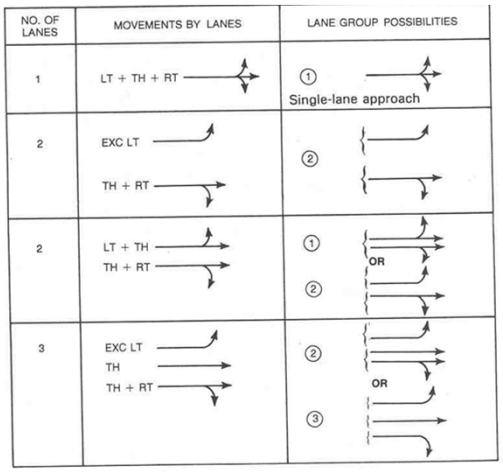
Signal design is based on through[1] traffic movements and passenger cars[2]. Therefore, we need **conversion factors** for vehicles other than passenger cars and movements other than through vehicles.

- **Passenger car equivalent (PCE):** a factor to convert straight-through volumes of buses and trucks to straight-through volumes of passenger cars (1.6–2.5 for intersections)
- **Turning movement factors:** factors to convert turning vehicles to equivalent straight-through vehicles (1.4–1.6 for left-turning vehicles and 1.0–1.4 for right-turning vehicles)

Signal Timing at Isolated Intersections

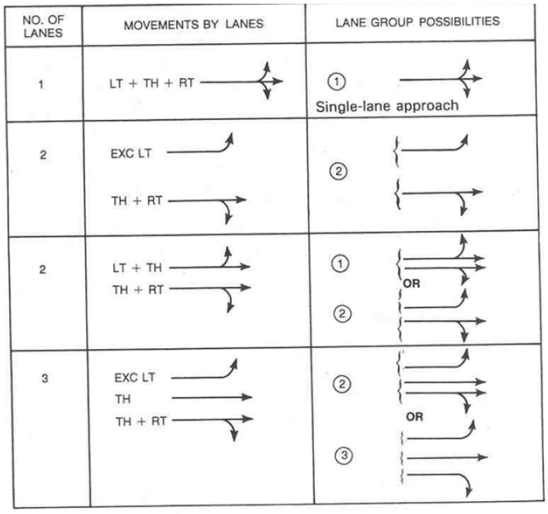
– Definitions (cont'd):

- **Lane Group:** consists of one or more lanes on an intersection approach having the same green phase
- **Critical lane group:** the lane group that requires the longest green time in a phase. The critical lane group determines the green time that is allocated to that phase.
- **Critical lane volume:** maximum lane volume in a phase (veh/h)
- **Saturation flow rate:** the flow rate in veh/hr that the lane group can carry if it has the green indication continuously

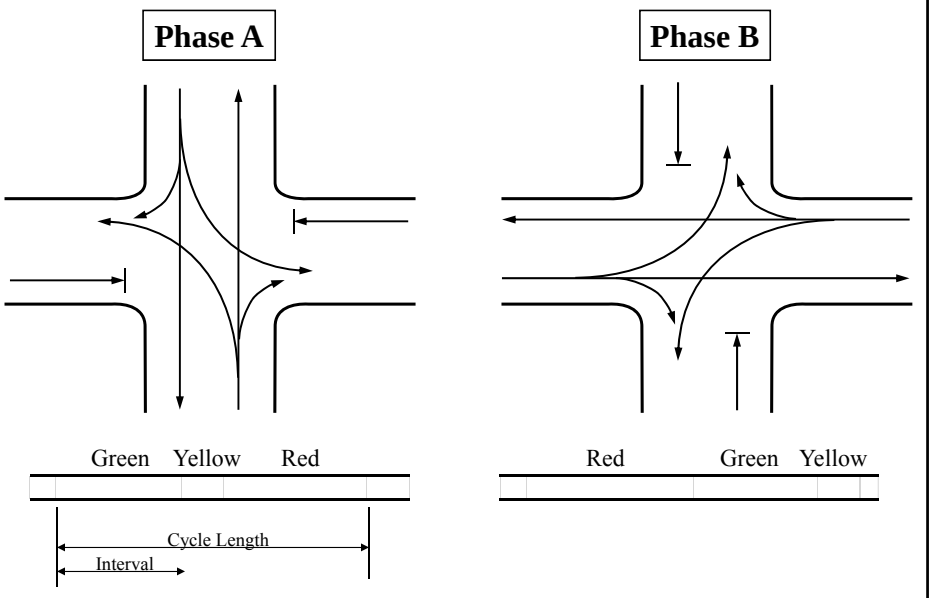


Signal Timing at Isolated Intersections

– Typical Lane Groups for Analysis

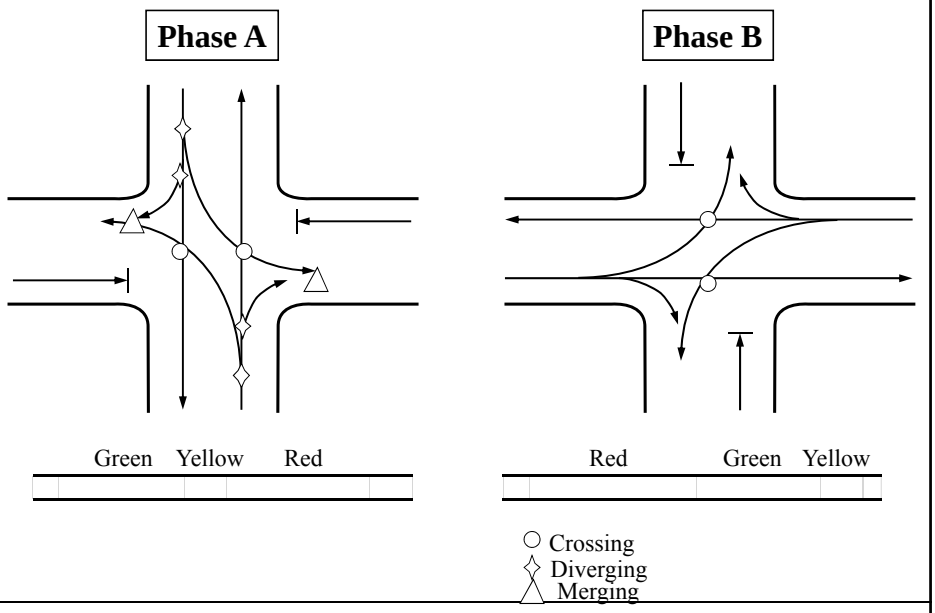


Source: Highway Capacity Manual



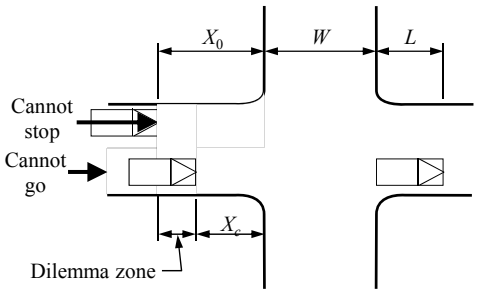
– The main objectives of signal timing are:
  • To reduce the average delay of all vehicles
  • To reduce the probability of accidents

– The two objectives may conflict with each other:
  • Increasing the number of phases will:
    – ***reduce*** the probability of accidents (by reducing conflict points of traffic) and
    – ***increase*** average delay



Yellow Interval

- The objectives of the yellow indication after the green are:
  - To alert motorists to the fact that the green time is about to change to red
  - 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 in which vehicles can neither stop safely before the intersection nor clear it without speeding before the red signal comes on
- Therefore, the yellow interval must guarantee that an approaching vehicle can either:
  - Stop safely, or
  - Proceed through the intersection without speeding



Yellow Interval

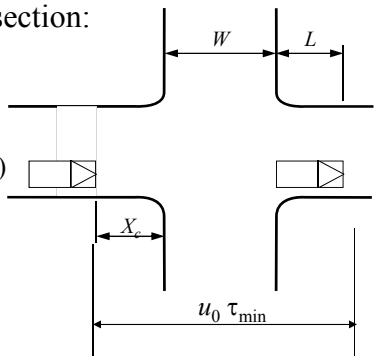
– At the minimum yellow interval required to eliminate the dilemma zone (τ_{min}):

$$\boldsymbol{X_0 = X_c}$$

• For vehicles to just clear the intersection:

$$X_c = u_0\,\tau_{min} - (W + L)$$

– u_0 = speed limit on the approach (m/s)
– W = width of intersection (m)
– L = length of vehicle (m)

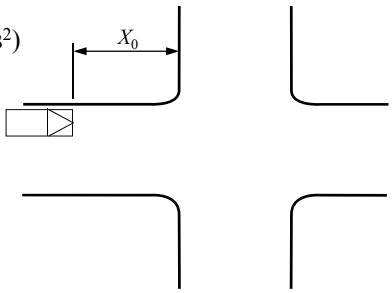


Yellow Interval

• For vehicles to stop before the intersection:

$$X_0 = u_0\delta + \frac{u_0^2}{2a}$$

– δ = perception-reaction time (s)
– a = rate of braking deceleration (m/s^2)



• Therefore,

$$u_0\tau_{min} - (W + L) = u_0\delta + \frac{u_0^2}{2a}$$

• and

$$\tau_{min} = \delta + \frac{(W + L)}{u_0} + \frac{u_0}{2a}$$

• If the effect of grade is added:

$$\tau_{min} = \delta + \frac{(W + L)}{u_0} + \frac{u_0}{2(a + Gg)}$$

– G = grade of the approach
– g = acceleration due to gravity (m/s^2)

– Note:
  - For safety considerations, the yellow interval should not be less than 3 s
  - To encourage motorists' respect for the yellow interval, it should not be greater than 5 s
  - If a longer yellow interval is required, use the maximum yellow interval and add an all-red interval

•Example:

Determine the minimum yellow interval at a flat intersection whose width is 12 m if the maximum allowable speed on the approach roads is 50 km/h. Assume average length of vehicle is 6.0 m, comfortable deceleration rate is 0.27*g*, and perception-reaction time is 1.0 sec

Cycle Length

– We will only discuss pre-timed (fixed) signals
  - Each signal has a preset cycle length that remains fixed for a specific period of the day or for the whole day

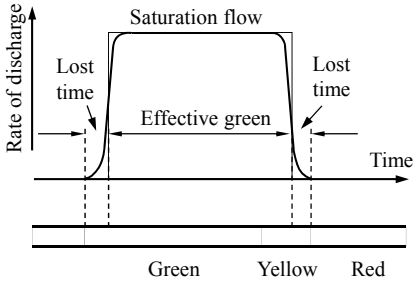
– Other types of signals are:
  - Semi-actuated
  - Fully actuated

– Several methods exist for determining the cycle length
  - We will study only Webster method

– Rate of discharge of vehicles at an intersection:

Rate of discharge of vehicles at an intersection:

- At the beginning of the green interval, some time is lost before the vehicles start moving
- The rate of discharge then increases to a maximum (saturation flow, *S*)
- If there are sufficient vehicles in the queue to use the available green time, the saturation flow will be sustained until the yellow interval occurs
- The rate of discharge then falls to zero when the yellow signal changes to red
- The number of vehicles discharged through the intersection is represented by the area under the curve
- Dividing the number of vehicles by the saturation flow will give the effective green time
- The effective green is less than the sum of the green and yellow; the difference is considered lost time



Webster Method

– For a wide range of practical conditions, minimum intersection delay is obtained when the cycle length is obtained by:

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

- C_o = optimum cycle length (s)
- L = total lost time per cycle (s)
- $Y_i = q_{ij}/S_j$ = maximum value of the ratios of approach flows to saturation flows for all traffic streams using phase *i*
- ϕ = number of phases
- q_{ij} = flow on lane *j* having the right of way during phase *i*
- S_j = saturation flow on lane *j*

– Lost time for each phase can be estimated as:

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

- ℓ_i = lost time for phase *i*
- G_{ai} = actual green time for phase *i*
- τ_i = yellow time for phase *i*
- G_{ei} = effective green time for phase *i*

– Total lost time is given as:

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

  - R = total all-red time during the cycle

– Total effective green time per cycle is:

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

  - C = actual cycle length (the value of C_o rounded to the nearest 5 s)

– The total effective green time is distributed among the different phases in proportion to their Y values:

$$G_{ei} = \frac{Y_i}{\sum_{i=1}^{\phi} Y_i} G_{te}$$

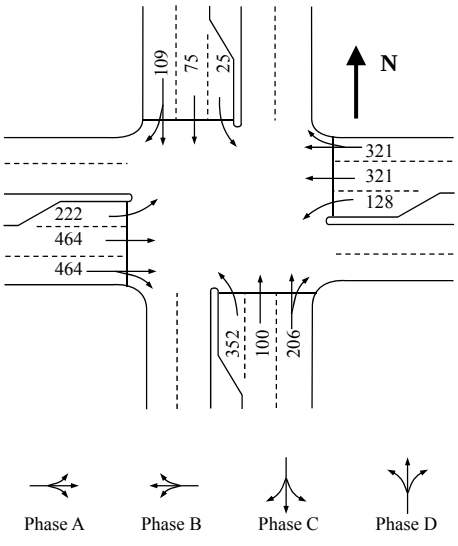
– The actual green time is obtained as:

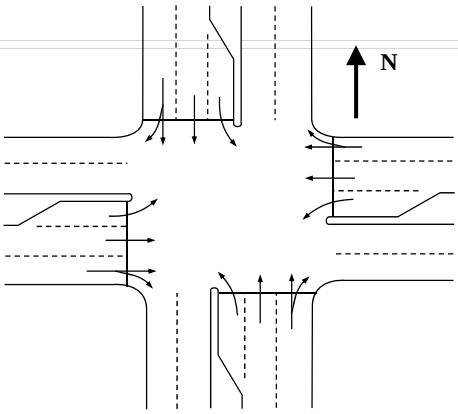
$$G_{ai} = G_{ei} + \ell_i - \tau_i$$

•Example

The following figure shows peak-hour volumes for a major intersection on an expressway. 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 s and assume the total lost time is 3.5 s per phase. Additional information:

– PHF = 0.95
– Left-turn factor = 1.4
– PCE for buses and trucks = 1.6
– Truck percentages:
  - 4% for the west approach
  - 0% for the other approaches
– Saturation flow rate = 2000 pc/h for all lanes
– Assume the given phasing system





Phase, ϕ	Critical Lane Volume
A B C D	
Total	

– Determine Y_i and $\sum Y_i$:

	Phase A (EB)			Phase B (WB)			Phase C (SB)			Phase D (NB)		
Lane	1	2	3	1	2	3	1	2	3	1	2	3
q_{ij}	335	499	499	189	338	338	115	79	37	519	105	217
S_j	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
q_{ij}/S_j	0.17	0.25	0.25	0.09	0.17	0.17	0.06	0.04	0.02	0.26	0.05	0.11
Y_i	0.25			0.17			0.06			0.26		
$\sum Y_i$	0.74											

– Optimum cycle length:

- Total lost time $L = 3.5 \times$ number of phases $= 3.5 \times 4 = 14$ s

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{\phi} Y_i} = \frac{1.5 \times 14 + 5}{1 - 0.74} = 100\,\text{s}$$

– Total effective green time:
G_{te} =

– Effective and actual green times for each phase:

$G_{ai} = G_{ei} + \ell_i - \tau_i$ =
- G_{aA} =
- G_{aB} =
- G_{aC} =
- G_{aD} =

– Check:

•Determination of LT Treatment

If the adjusted left turn passenger car equivalent volumes is greater than 240 vph, we usually need a left-turn phase, which means that we need a left-turn bay. Up to that value, the yellow interval can provide enough time for LTs.

•Determination of LT Treatment

Permitted Left Turns: LTs are made within gaps of opposing through traffic steam. Suitability of permitted turns depends on the geometric characteristics of the intersection, the turning volume, and the opposing volume.

Protected Left Turns: LTs are made in a separate "protected" phase. It is protected from conflicts with vehicles in an opposing stream.

Protected/Permitted : Combination of both conditions. Vehicles are first allowed to make left turns under protected conditions and then allowed to make LT under permissive conditions.

Determination of LT treatment depends on :
- No. of LT lane approaching (2 or more – protected)
- LT volumes (>240 veh/h – protected)
- Ratio of LT volume to through traffic. (L.E.F >3.5)