Cairo University
Faculty of Engineering
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Traffic Engineering

Intersection Design and Control

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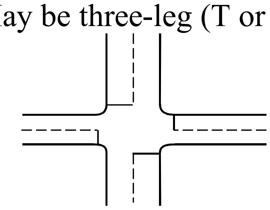
- An intersection is an area shared by two or more roads
- Main function is to allow the change of route directions
- It is an area of decision for all drivers and thus requires additional effort and is a more complicated area for drivers
- Intersections normally perform at levels below those of the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

Types of Intersections

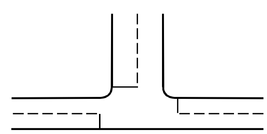
- Intersections can be classified as:
  - – At-grade: all roads intersect at the same level:
    - Conventional
    - Roundabouts
  - – Grade-separated without ramps: uninterrupted cross-flow of traffic at different levels (over or underpass with no access)
  - – Grade-separated with ramps (freeway interchanges)

At-Grade Intersections

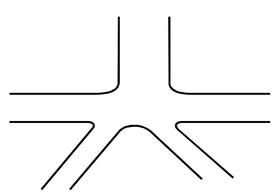
– May be three-leg (T or Y), four-leg, or multi-leg



Four-leg intersection



T-intersection



Multi-leg intersection

Intersection Control and Signal Design

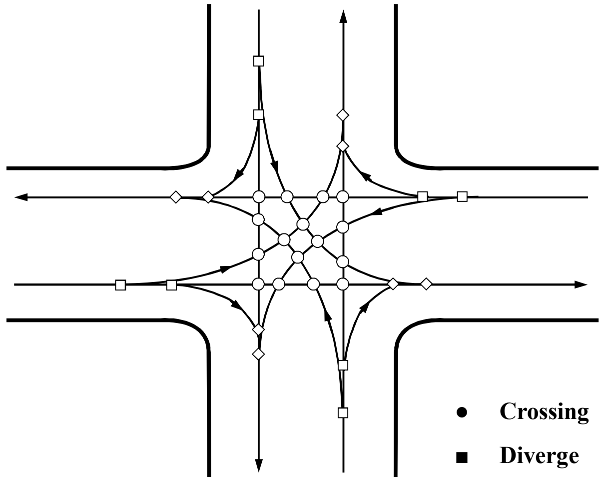
General Concepts of Traffic Control

- 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

Conflict Points at Intersections

- Conflicts occur when traffic streams moving in different directions interfere with each other
- Three types of conflicts:
  -
  -
  -
- The number of possible conflict points at any intersection depends on:
  -
  -
  -

– Example: conflict points at a four-leg intersection



● Crossing =

■ Diverge =

♦ Merge =

Total =

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
- Conditions for the different types of traffic control devices are given in the MUTCD

Types of Intersection Control

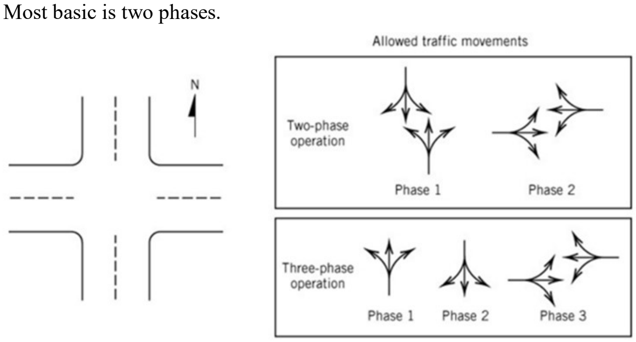
1. Yield Signs:
   – Drivers on approaches with yield signs are required to slow down and yield the right of way to all conflicting vehicles at the intersection
2. Stop Signs:
   – Approaching vehicles are required to stop before entering the intersection
3. Intersection Channelization:
   – Used to 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
4. 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

Intersection Control and Signal Design

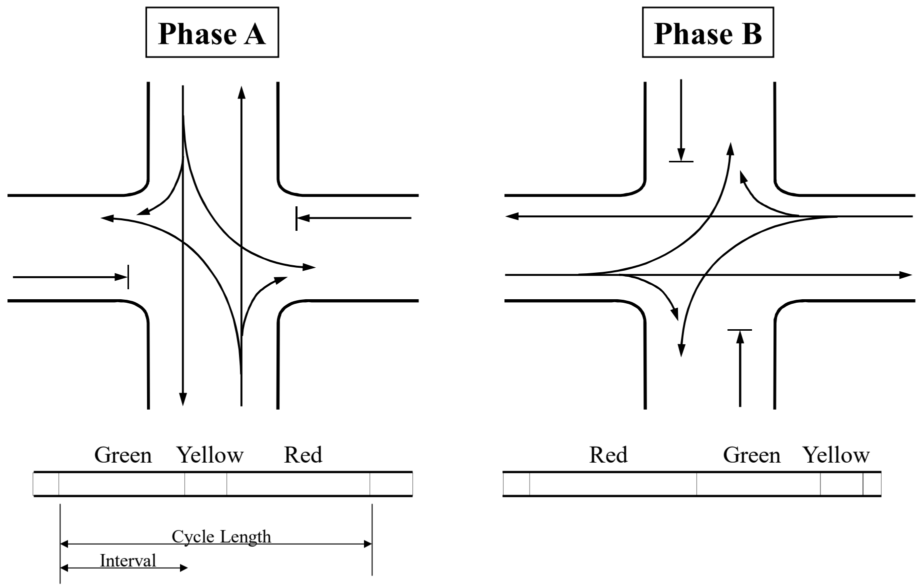
Signal Timing at Isolated Intersections

Step 1: Determine Phasing at Intersection

– **Definitions**:
  - **Phase (signal phase):**
    – 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.
    – Most basic is two phases.

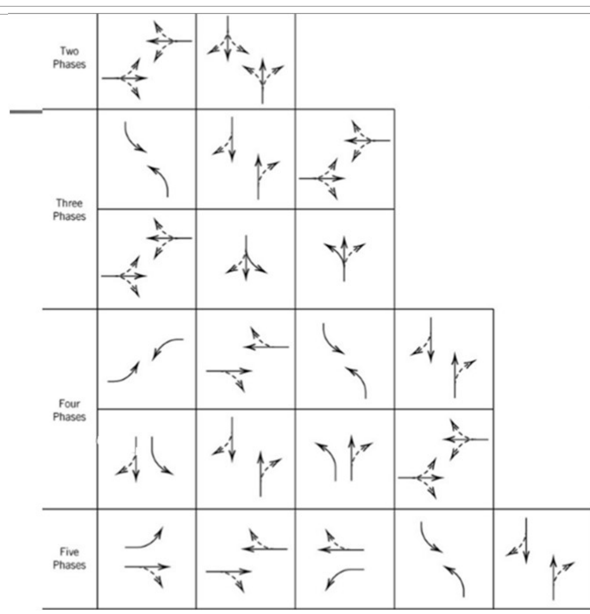


Intersection Control and Signal Design



Intersection Control and Signal Design

Phase (signal phase):



Intersection Control and Signal Design

Signal Timing at Isolated Intersections

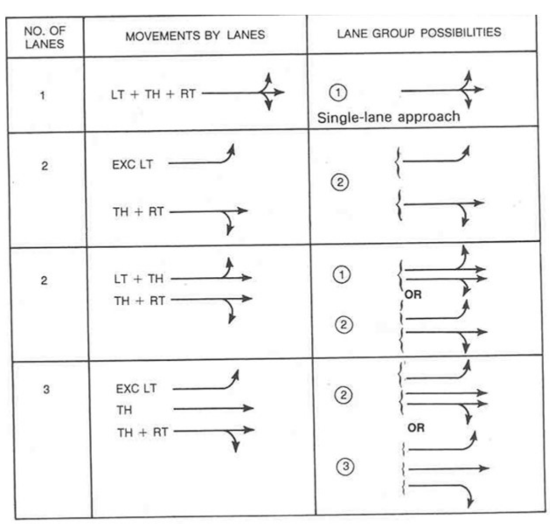
Step 2: Determine Critical Lane Groups at Intersection

– Definitions (cont'd):

- **Lane Group:**
  - Consists of one or more lanes on an intersection approach having the same green phase.
  - Movements made simultaneously from the same lane are treated as lane group.
  - Exclusive turn lanes are treated as a separate lane group.
  - Judgement used for shared lanes.

Signal Timing at Isolated Intersections

– Typical Lane Groups for Analysis



Source: Highway Capacity Manual

Signal Timing at Isolated Intersections

Step 2: Determine Critical Lane Groups at Intersection

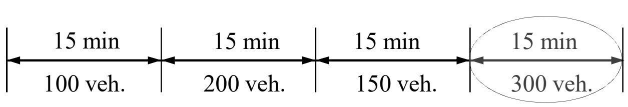
– **Definitions (cont'd)**:

- **Critical lane group:** the lane group that requires the longest green time in a phase. The critical lane group determines the required green time that is allocated to that phase.
- It is the lane group with the highest traffic intensity (q/S)
- q= peak hour volume (veh/h)
- S= saturation flow (veh/h)
- $Y_i = q_{ij}/S_j$ = maximum value of the ratios of approach flows to saturation flows for all traffic streams using phase i

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 × 4 = 1200 veh/h
PHF = 750/1200 = 0.625

Signal Timing at Isolated Intersections

– **Definitions (cont'd)**:

1 2

Signal design is based on through traffic movements and passenger cars. 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)

Intersection Control and Signal Design

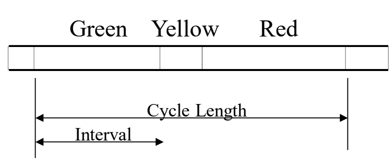
Signal Timing at Isolated Intersections

Step 3: Determine Cycle Length

– **Definitions (cont'd)**:

- **Cycle (cycle length):**
  - a cycle is made up of individual phases.
  - The time in seconds required for one complete colour sequence of signal indication (G+Y+R) is a cycle.

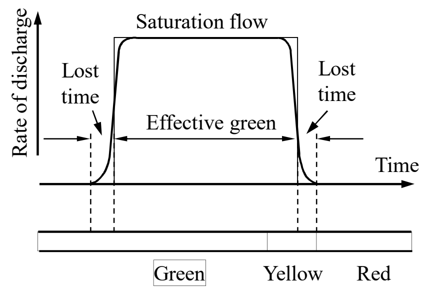
- **Interval:**
  - any part of the cycle length during which signal indications do not change



Intersection Control and Signal Design

Signal Timing at Isolated Intersections

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*)
- The rate of discharge then falls to zero when the yellow signal changes to red
- The effective green is less than the sum of the green and yellow; the difference is considered lost time

Intersection Control and Signal Design

Signal Timing at Isolated Intersections

Webster Method

- Cycle Length:

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

- 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

Intersection Control and Signal Design

– Total lost time is given as:

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

- R : **All-red interval:** the display time of a red indication for all approaches

Signal Timing at Isolated Intersections

Step 4: Allocate Effective Green Time per Phase

– Total effective green time per cycle is:

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

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

$$g_{ei} = \frac{Y_i}{\sum_{i=1}^{\phi} Y_i} G_{te} = \frac{\left(\frac{q_{ij}}{S_j} \right)}{\sum_{i=1}^{\phi} \left(\frac{q_{ij}}{S_j} \right)} G_{te}$$

– The actual green time is obtained as:

$$g_{ai} = g_{ei} + \ell_i - y_i$$

ℓ_i = *lost* time for phase *i*

g_{ai} = actual green time for phase *i*

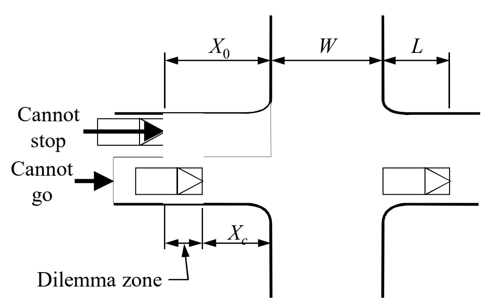
y_i = yellow time for phase *i*

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

Signal Timing at Isolated Intersections

Step 5: Calculate Yellow Interval (*y*) and all red 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

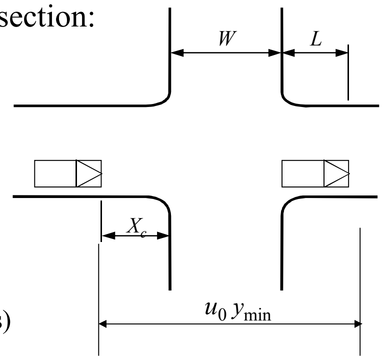


Yellow Interval

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

$$\boldsymbol{X_0 = X_c}$$

• For vehicles to just clear the intersection:



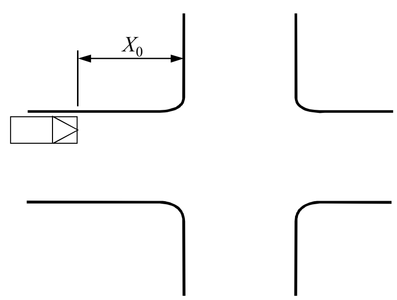
$$X_c = u_0\, y_{\min} - (W + L)$$

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

Intersection Control and Signal Design

Yellow Interval

• For vehicles to stop before the intersection:



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

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

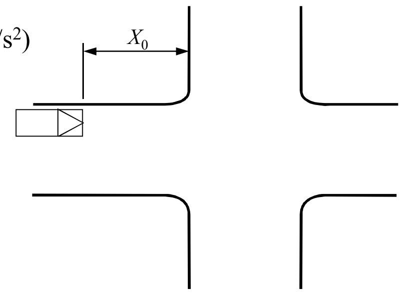
Intersection Control and Signal Design

Yellow Interval

- For vehicles to stop before the intersection:

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

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



- Therefore,

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

- and

$$\boxed{y_{\min} = t + \frac{(W + L)}{u_0} + \frac{u_0}{2a}}$$

- If the effect of grade is added:

$$\boxed{y_{\min} = t + \frac{(W + L)}{u_0} + \frac{u_0}{2(a + Gg)}}$$

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

Intersection Control and Signal Design

Yellow Interval

$$\mathbf{X_0 = X_c}$$

- Therefore,

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

- and

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

Intersection Control and Signal Design

- 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

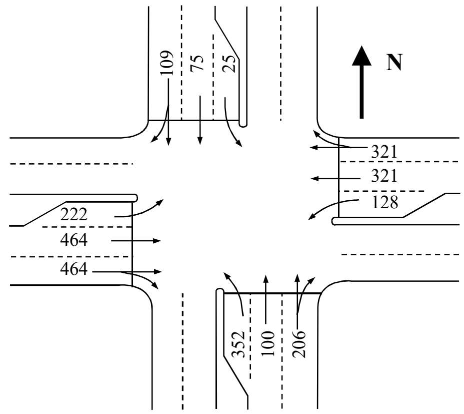
Summary of Signal Design

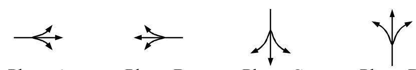
1. Determine the phasing to use
2. Determine critical lane groups
3. Calculate cycle length
4. Allocate effective green time
5. Calculate yellow and all red intervals

•Example

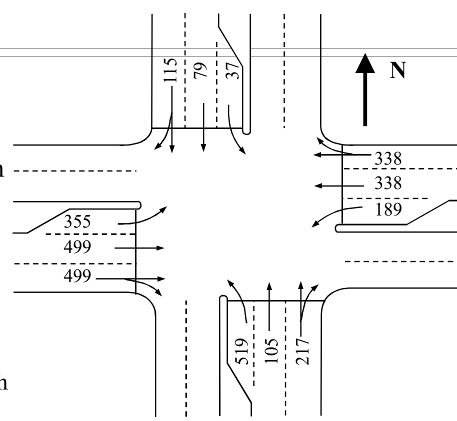
The following figure shows peak-hour volumes for a major intersection on an expressway. Using the Webster method, determine suitable signal timing for the intersection using a four-phase system and the additional data given in the figure. Use a yellow interval of 3 s and assume the total lost time is 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





- First, convert mixed volumes to equivalent straight-through passenger cars
- Example: EB (West Approach) through traffic
  - DHV =
  - q = veh/h
  - Among them:
    - = trucks & buses
    - = PC
  - PCE = + × ≈ PC/h
- Calculations are based on an assumption of RT equivalency factor = 1.0
- You may then calculate the critical lane volume for each phase



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												
Y_i												
$\sum Y_i$												

– Optimum cycle length:
- Total lost time $L = 3.5 \times$ number of phases =

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

– Total effective green time:
$G_{te} =$

– Effective and actual green times for each phase:

$$g_{ei} = \frac{Y_i}{\sum Y_i} G_{te} = \frac{Y_i}{0.74} \times 86$$

$g_{ai} =$
- $g_{aA} =$
- $g_{aB} =$
- $g_{aC} =$
- $g_{aD} =$

– Check:
- Sum of all actual green, yellow, and all-red is equal to cycle length