Signal Timing Design

Summary of Signal Design

Signal Phase Plans

- Treatment of Left Turns
- General Considerations
- Phase and Ring Diagrams
- Common Phase Plans and Their Use

Vehicular Needs

- Change and Clearance Intervals
- Determine Lost Times
- Determine Critical Lane Volumes
- Desired Cycle Length
- Splitting the Green

Pedestrian Needs

- Minimum Pedestrian Crossing Needs
- Adjustment of Effective Green

Treatment of Left Turns

- Left turns can be handled in two ways
- Permitted Left Turn
    - Left turn is allowed along with opposing through movement
- Protected Left Turn
    - Left turn is allowed when opposing through movement is stopped

- Two conditions needs to be met for left turn to be protected
- Condition-1 (Left Turn Flow Rate)
  $V_{LT} \geq 200$ veh/hour
- Condition-2 (Cross-Product Rule)

$$xprod = V_{LT} * (\frac{v0}{N0}) \geq 50{,}000$$

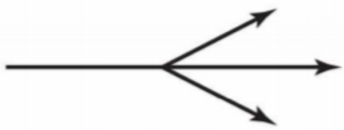
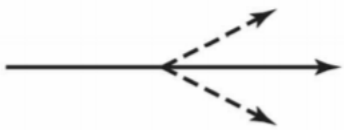
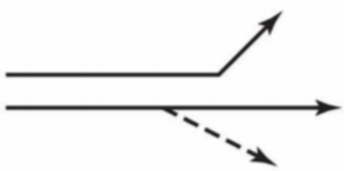
Where,

V_{LT}: Left-turn flow rate, veh/hr
V0: Opposing through movement flow rate, veh/hr
N0: Number of lanes for opposing through movement

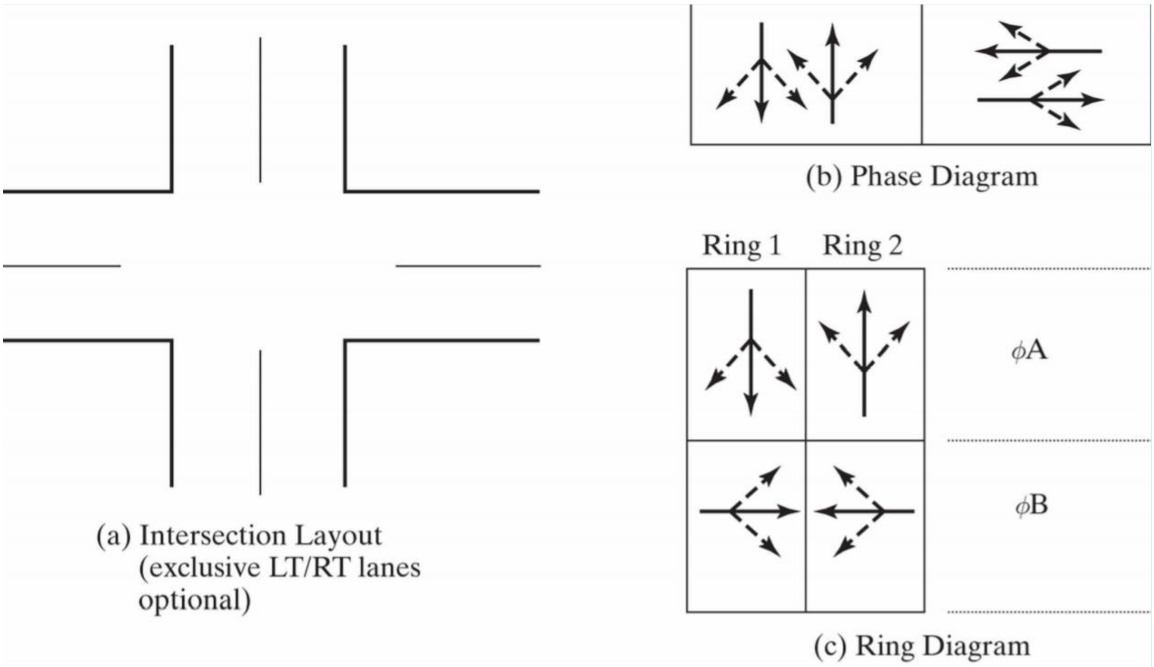
General Considerations

- Phasing can be used to minimize crash risks by separating competing movements
- All phase plans must be in accordance with MUTCD
- The phase plans must be consistent with intersection geometry

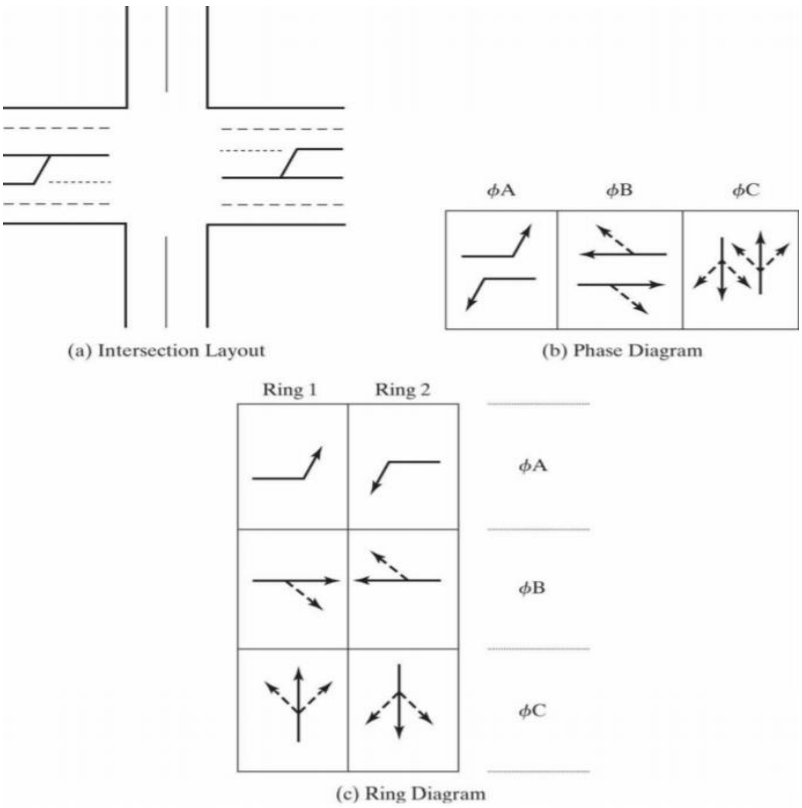
Signal Phase and Arrows Illustration

Through movement without turning movement.	
Through movement with protected right and left turns from shared lanes.	
Through movement with permitted right and left turns from shared lanes.	
Through movement with protected left turn from exclusive lane and permitted right turn from shared lane.	
Through movement with permitted left turn from exclusive lane and permitted right turn from shared lane.	

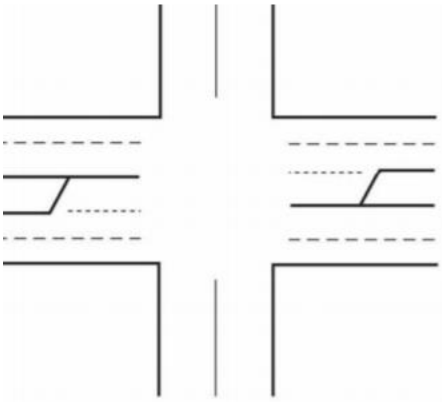
Two Phase Signal

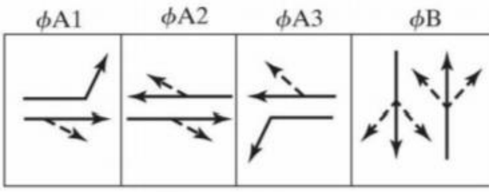


Exclusive Left Turn Phase

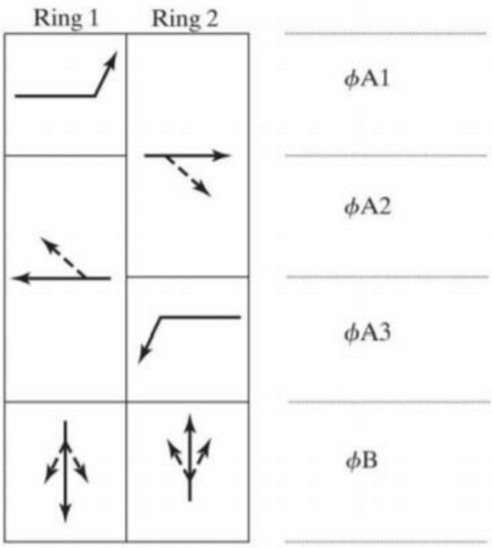


Lead / Lag Green


(a) Intersection Layout

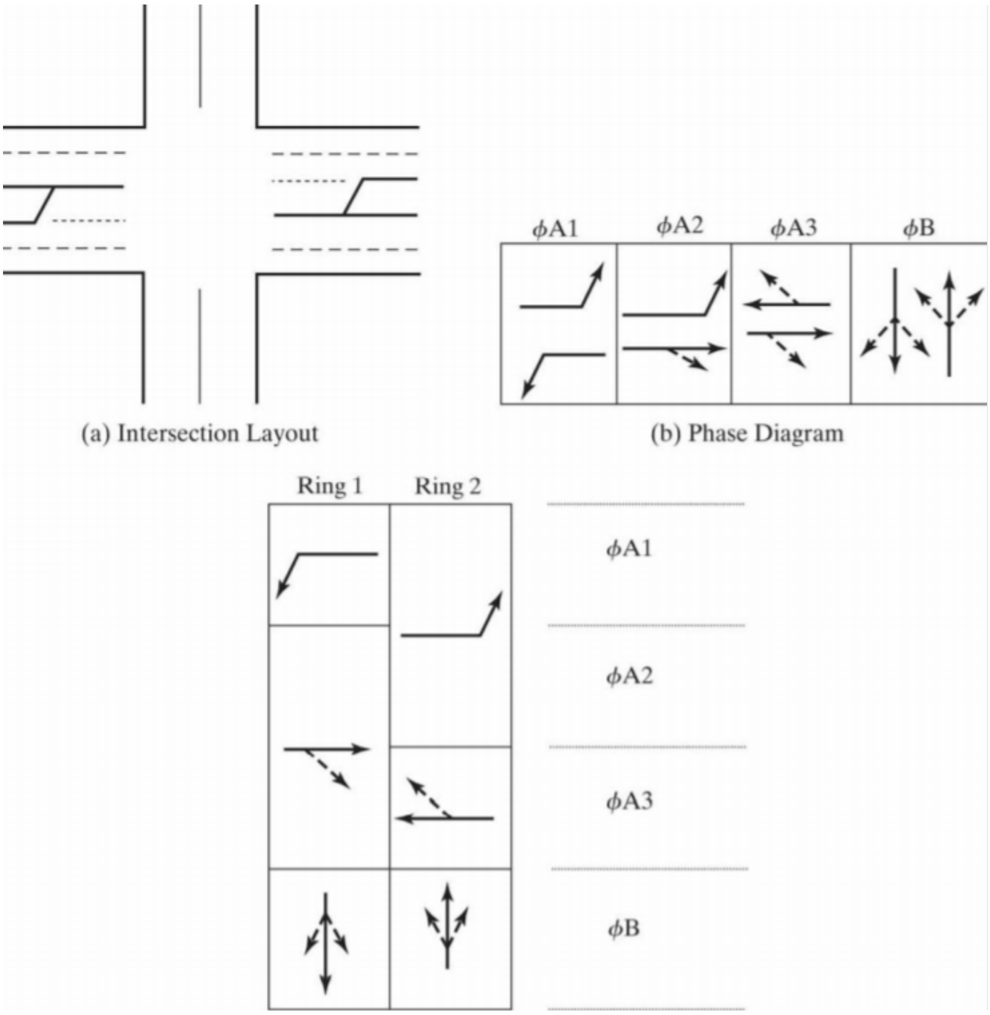


(b) Phase Diagram

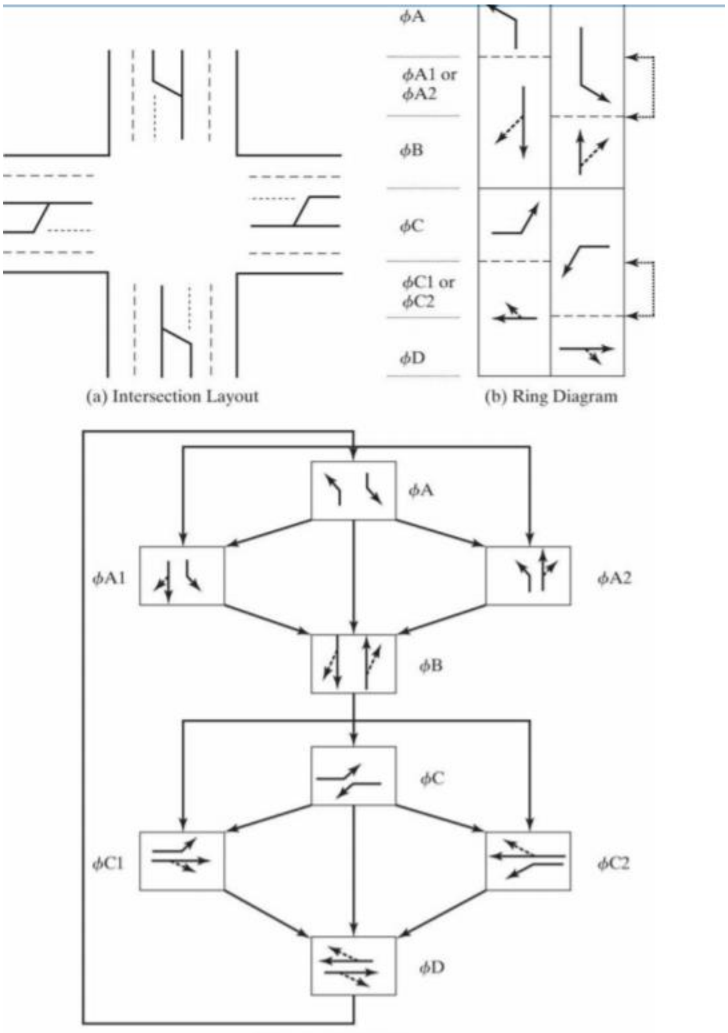


(c) Ring Diagram

Exclusive Left Turn Phase and Leading Green Phase

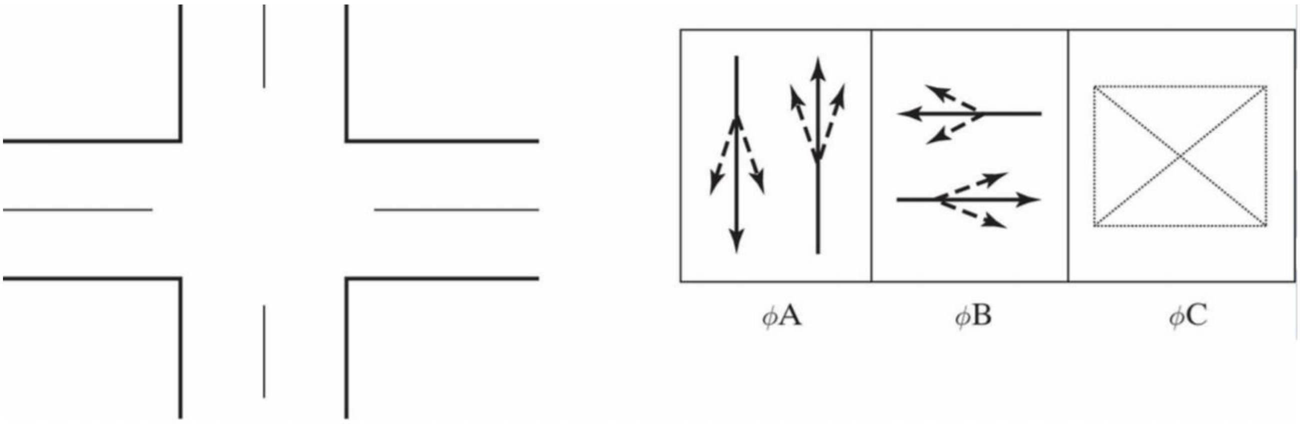


Eight Phase Actuated Control

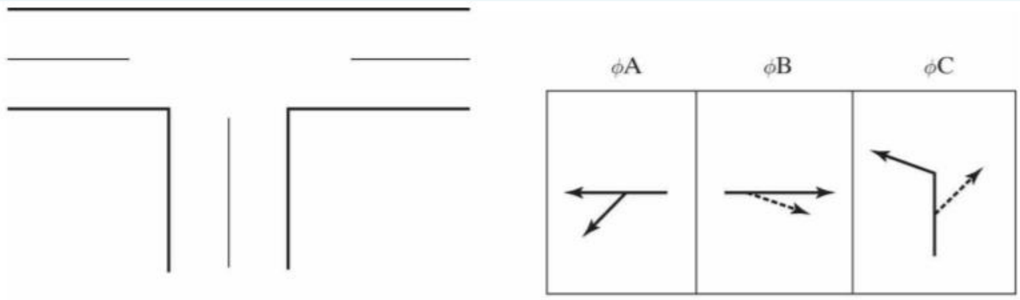


(c) Actuated Phase Diagram

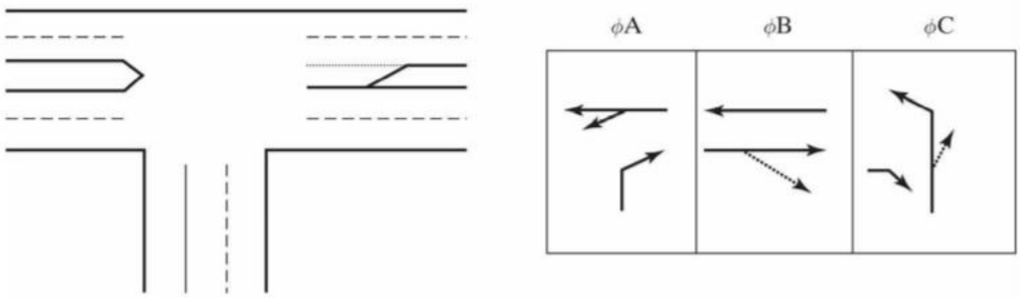
Exclusive Pedestrian Phase



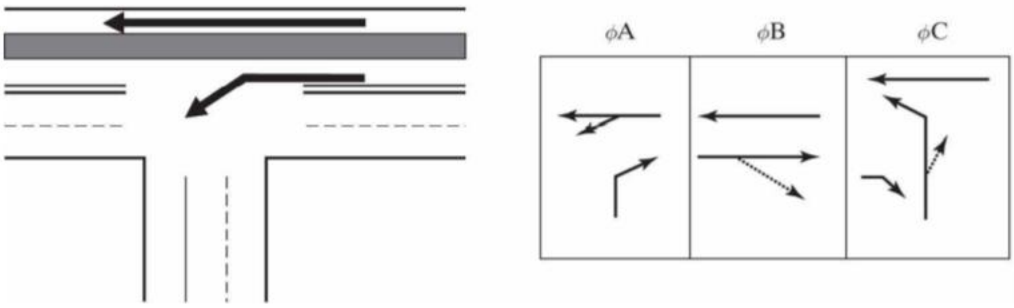
Operations at T-intersections



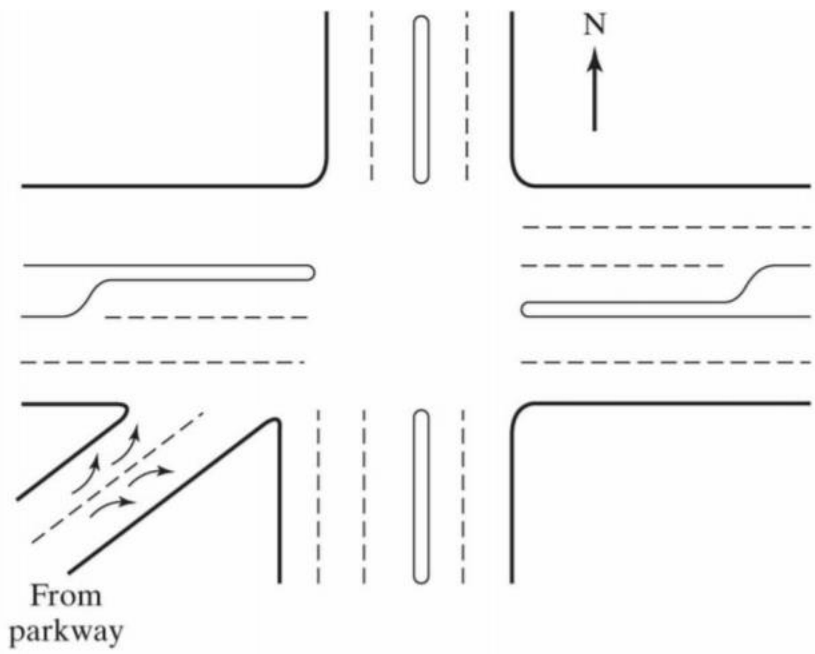
(a) T-Intersection, No LT Lane, Protected Phasing

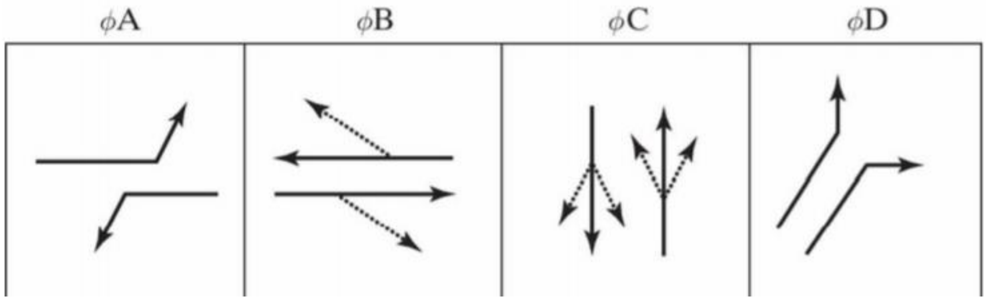


(b) T-Intersection, LT Lane, Protected Phasing



Five Leg Intersection





Vehicular Signal Requirements – Change and Clearance Interval

- Change Interval (Yellow)
  - This interval allows that is one safe stopping distance away from the STOP line when GREEN is withdrawn to continue at the approach speed and enter the intersection legally on yellow.

- Clearance Interval (**All-Red**)
  - Assuming that a vehicle has just entered the intersection legally on yellow, the **all-red** must provide sufficient time for the vehicle to cross the intersection and clear its back bumper past the far curb line (crosswalk line) before conflicting vehicles that are given GREEN.

Change Interval

ITE recommends the following methodology for determining length of yellow or change interval

$$\mathbf{y = t + \frac{1.47S_{85}}{2a + (64.4 * 0.01G)}}$$

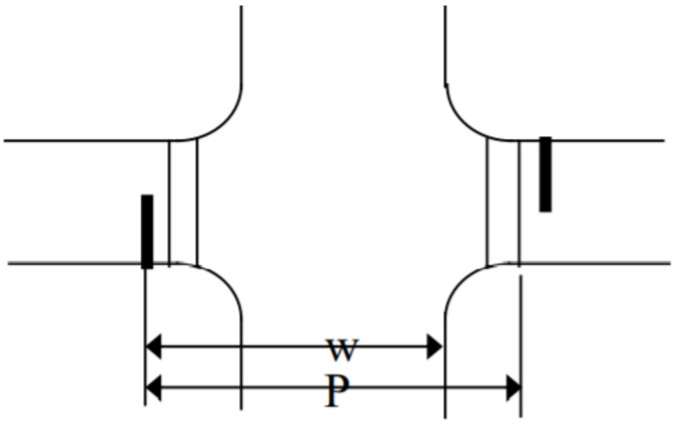
Where:

- Y: length of the yellow interval
- t: driver reaction time, s
- *S*85: 85th percentile speed of approaching vehicles or speed limit in mi/hr
- A: deceleration rate of vehicles, ft/sec
- G: Grade of approach, %

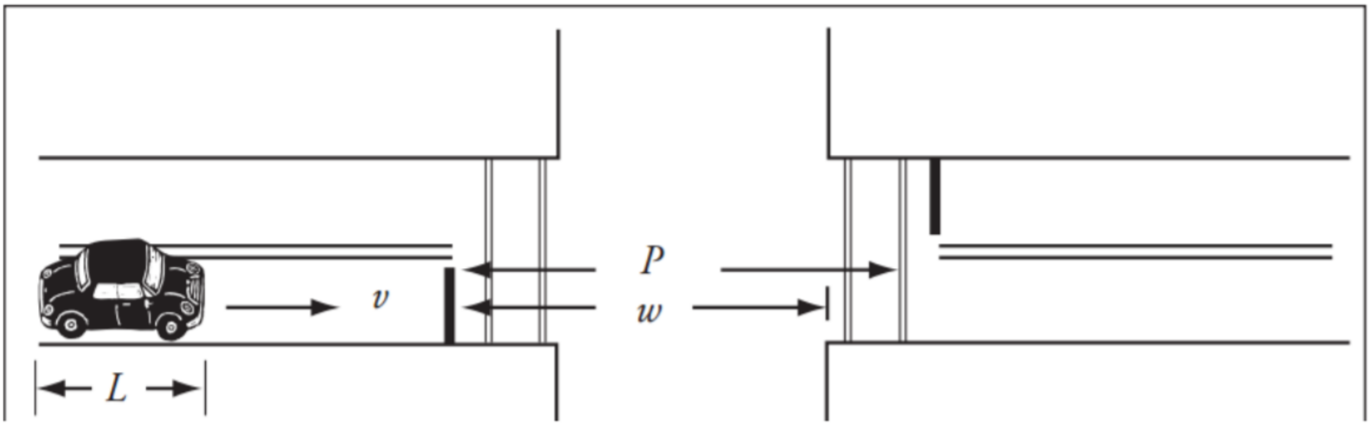
Clearance Interval

All Red = $\mathbf{AR = \frac{W+L}{V} \;\; or \;\; \frac{P}{V} \;\; or \;\; \frac{P+L}{V}}$

- L = length of the clearing vehicle, normally 20 feet
- W = width of the intersection in feet, measured from the upstream stop bar to the downstream extended edge of pavement
- P = width of the intersection (feet) measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk along an actual vehicle path



Equation	Usage
$r = (w + L) / v$ (4)	This red time places the vehicle outside the area of conflict with traffic that is about to receive the green indication (typically used when there is no pedestrian traffic).
$r = P / v$ (5)	This red time places the vehicle at a point directly in front of pedestrians waiting to use the crosswalk (typically used when there is very little pedestrian traffic, in which case the larger of Equations 4 or 5 is used).
$r = (P + L) / v$ (6)	This red time provides time for the vehicle to clear both the cross street and the pedestrian crosswalks.
* Note: r = all-red time; v = velocity. The terms w, L and P are defined in Figure 2.	



Determining Lost Time

- Start-up lost time, l1 =2.0 sec/phase
- Motorist use of yellow and all-red, e=2.0 sec/phase
- l2=Y-e
- Y = y + ar
- TL=l1+l2

Determining the Sum of Critical Lane Volumes

- CLV is the per lane volume that controls the required length of a particular phase
- What is the need?
  - Volumes cannot be simply compared. Trucks require more time than passengers, left and right turns require more time than through vehicles.
  - Intensity of demand is not captured by volume
  - When phasing involves overlapping elements, then ring diagrams must be carefully examined to determine which flows constitute CLVs

Through Vehicle Equivalents-Left Turn

Through Vehicle Equivalents-Left Turn vehicles, V_{LT}

Opposing Flow V_o (veh/h)	Number of Opposing Lanes, N_o		
	1	2	3
0	1.1	1.1	1.1
200	2.5	2.0	1.8
400	5.0	3.0	2.5
600	10.0*	5.0	4.0
800	13.0*	8.0	6.0
1,000	15.0*	13.0*	10.0*
≥1,200	15.0*	15.0*	15.0*
E_{LT} for all *protected* left turns = 1.05			

*The LT capacity is only available through "sneakers."

Through Vehicle Equivalents Right Turn

Pedestrian Volume in Conflicting Crosswalk, (peds/h)	Equivalent
None (0)	1.18
Low (50)	1.21
Moderate (200)	1.32
High (400)	1.52
Extreme (800)	2.14

Determining Desired Cycle Length

$$\mathbf{C_{des}} = \frac{\mathbf{L}}{\mathbf{1} - \left[\frac{\mathbf{V_c}}{\mathbf{1615 * PHF * (\frac{v}{c})}}\right]}$$

- C_{des}: Desirable cycle length, s
- L: total lost time per cycle, s/cycle
- PHF: Peak Hour Factor
- v/c: target v/c ratio for the critical movements in the intersection
- V_c: Sum of critical lane volumes

Splitting Green

- Total Effective Green Time,

$$g_{TOT} = C - L$$

Where,

- g_{TOT}: Total effective green time in the cycle, sec
- C: Cycle length, sec
- L: Total lost time, sec

- Effective Green Time for phase i,

$$g_i = g_{TOT} * \left(\frac{V_{ci}}{V_c}\right)$$

Where,

- g_i: effective green time for phase i, sec
- g_{TOT}: total effective green time per cycle, sec
- V_{ci}: CLV for phase or sub-phase i, veh/hr
- V_c: Sum of all CLVs

Pedestrian Signal Requirements

- Till this point we have covered vehicular requirements.
- Pedestrians however, must be accommodated by the signal timing.
- Problems arise because vehicular and pedestrian are quite different.
- Consider the case of an intersection between a major arterial and minor collector.
- More green time is given to the major arterial, while pedestrians are given more time to cross the collector.
- However, less green time is given to the collector, and the pedestrians have less time to cross the major arterial.
- A minimum green time requirement must be followed to accommodate the requirements of pedestrians.

Minimum Pedestrian Crossing Time

$$\mathbf{G_p = 3.2 + \left(2.7 * \frac{N_{ped}}{W_E}\right) + \frac{L}{S_p} \text{ for } W_E > 10 \text{ ft}}$$

$$\mathbf{G_p = 3.2 + (2.7 * N_{ped}) + \frac{L}{S_p} \text{ for } W_E \leq 10 \text{ ft}}$$

Where:

- Gp: Minimum pedestrian crossing time
- L: Length of the crosswalk, ft
- Sp: Average walking speed of the pedestrians
- N_{ped}: Number of pedestrians crossing per cycle in a single crosswalk, N_{ped}
- WE: Width of the crosswalk, ft

Significance of each Term

- 3.2: Allocated as minimum start-up time for pedestrians
- L/Sp: Time to cross safely
- Additional start up time based on the volume of pedestrians that need to cross the street

Pedestrian WALK Indication

$$\mathbf{WALK_{min} = 3.2 + \left(2.7 * \frac{N_{ped}}{W_E}\right) for W_E > 10ft}$$

$$\mathbf{WALK_{min} = 3.2 + (2.7 * N_{ped}) for W_E \leq 10ft}$$

Where

- G_p: Minimum pedestrian crossing time
- L: Length of the crosswalk, ft
- Sp: Average walking speed of the pedestrians
- N_{ped}: Number of pedestrians crossing per cycle in a single crosswalk, N_{ped}
- WE: Width of the crosswalk, ft

DO NOT WALK Indication

- The flashing DON'T WALK indication is most often given by L/Sp
- Generally measured from the end of the vehicular all-red phase

Signal Timing Viable for Pedestrians

$$G_p \leq G + y + ar$$

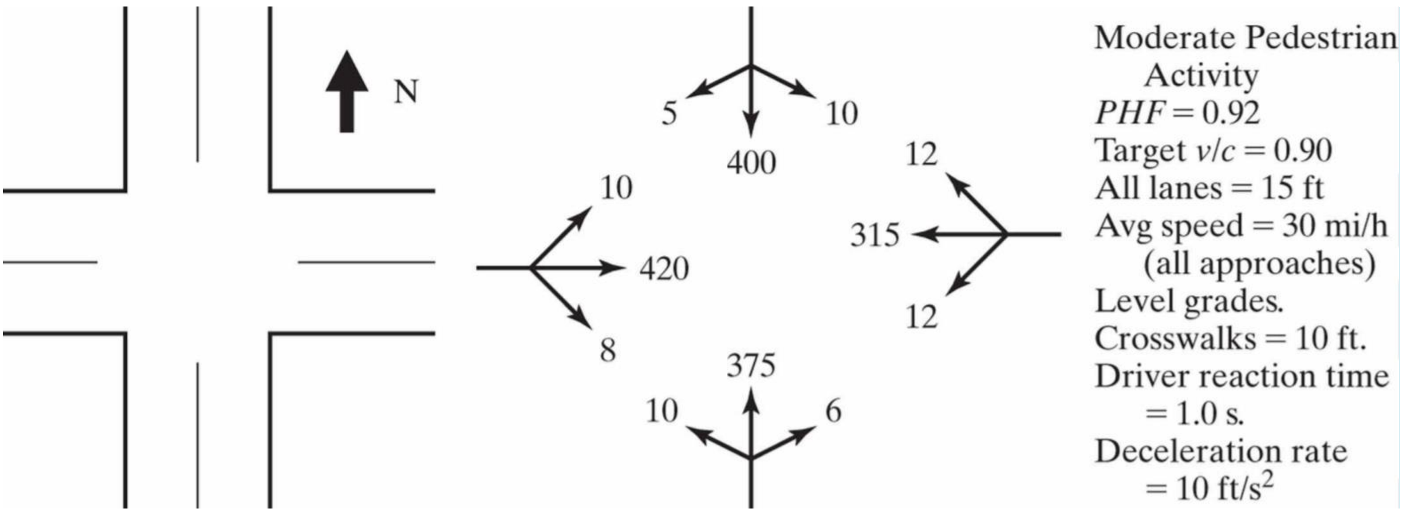
or

$$G_p \leq G + y$$

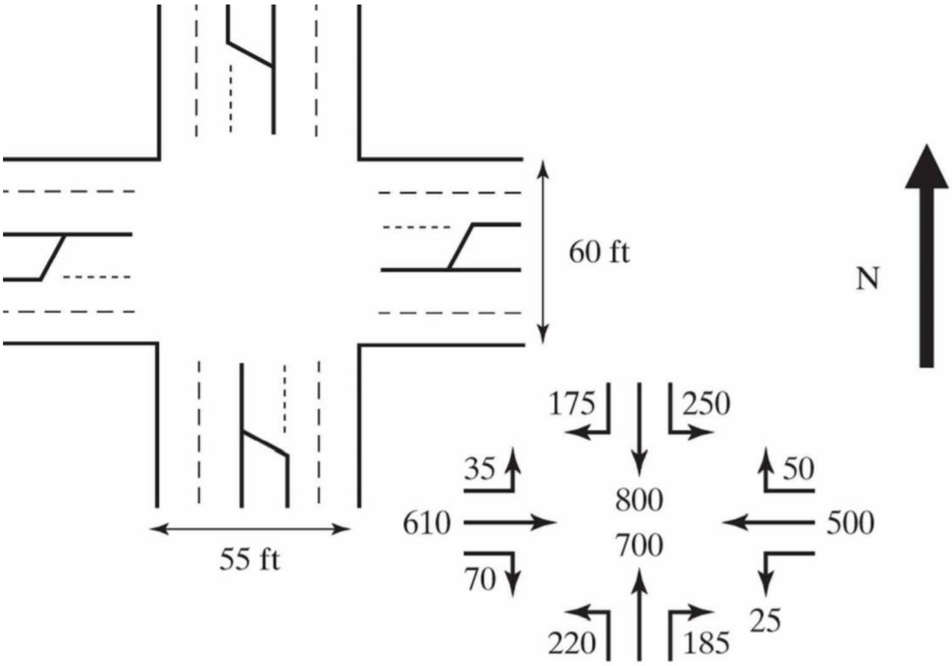
Or

$$G_p \leq G$$

Example 1

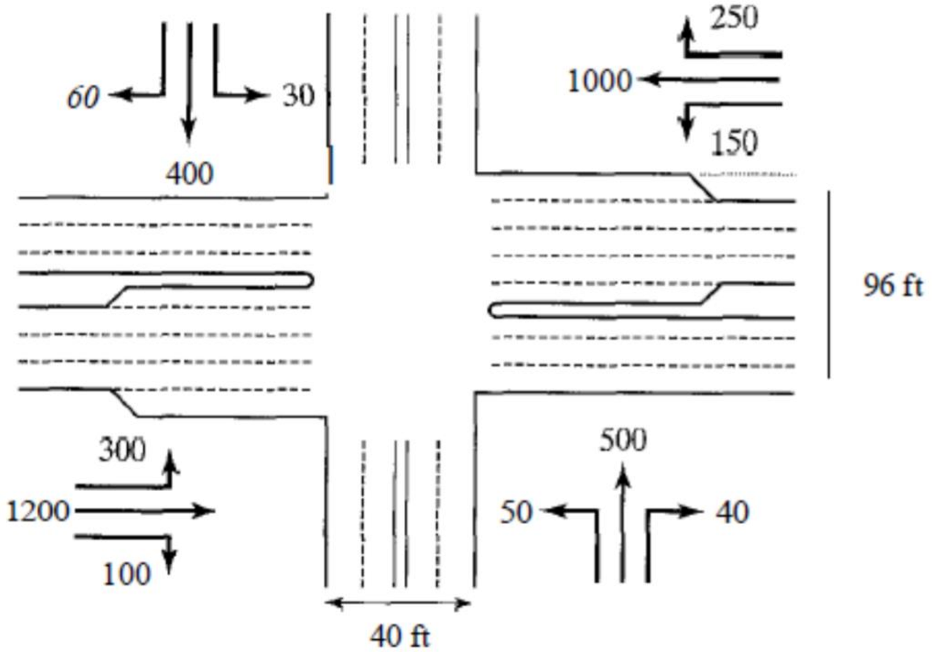


Example 2



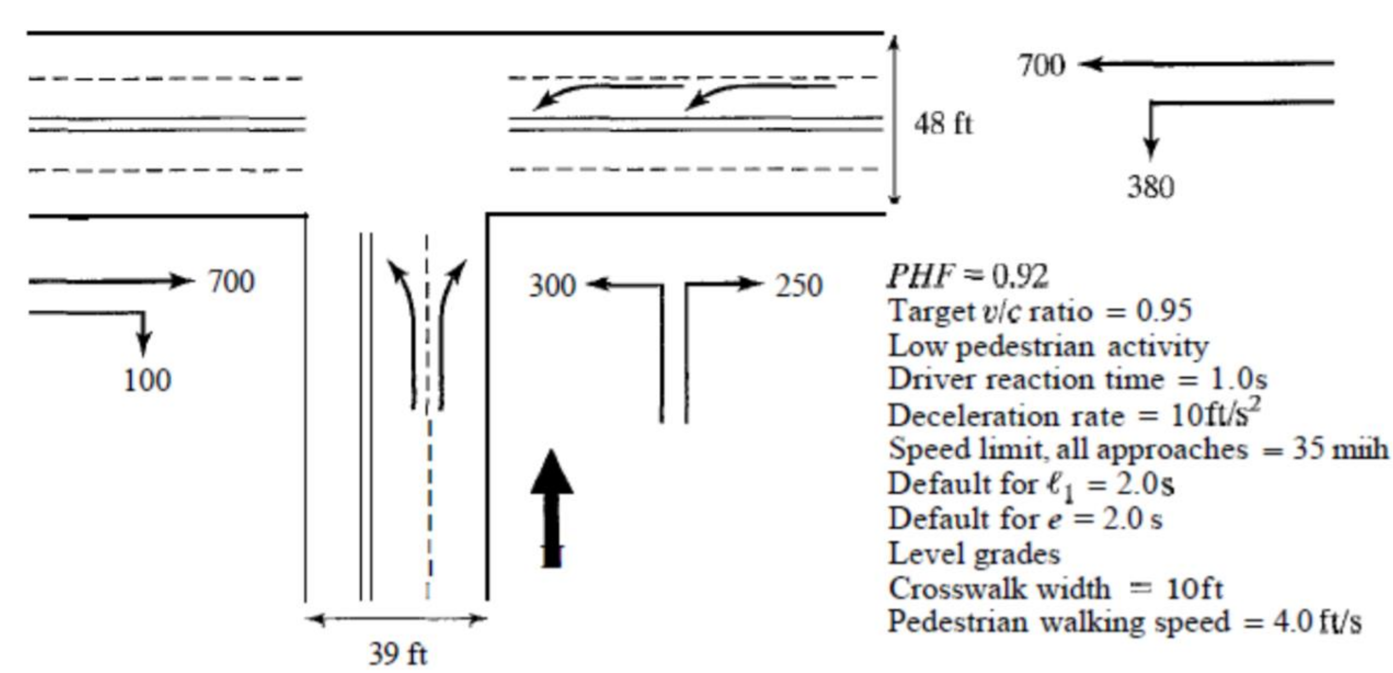
$PHF = 0.92$
Target v/c ratio = 0.90
Driver reaction time = 1.0 s
Ped walking speed = 4.0 fps
Speed limit = 45 mi/h
(all approaches)
Moderate pedestrian volumes
Level grades
Deceleration rate = 10 ft/s^2
Crosswalk width = 10 ft
Default ℓ_1 = 2.0 s
Default e = 2.0 s

Example 3



$PHF = 0.85$
Target v/c = 0.90
E-W Avg. speed = 50 mi/h
N-S Avg. speed = 35 mi/h
Deceleration = 10ft/s^2
Level grades
Driver reaction time = 1.0 s
Default ℓ_1 = 2.0 s
Default e = 2.0 s

Example 4


700
380
48 ft
700
100
300
250
39 ft
$PHF = 0.92$
Target v/c ratio = 0.95
Low pedestrian activity
Driver reaction time = 1.0s
Deceleration rate = 10ft/s^2
Speed limit, all approaches = 35 miih
Default for ℓ_1 = 2.0s
Default for e = 2.0 s
Level grades
Crosswalk width = 10ft
Pedestrian walking speed = 4.0 ft/s