Traffic Signals Phasing and Timing

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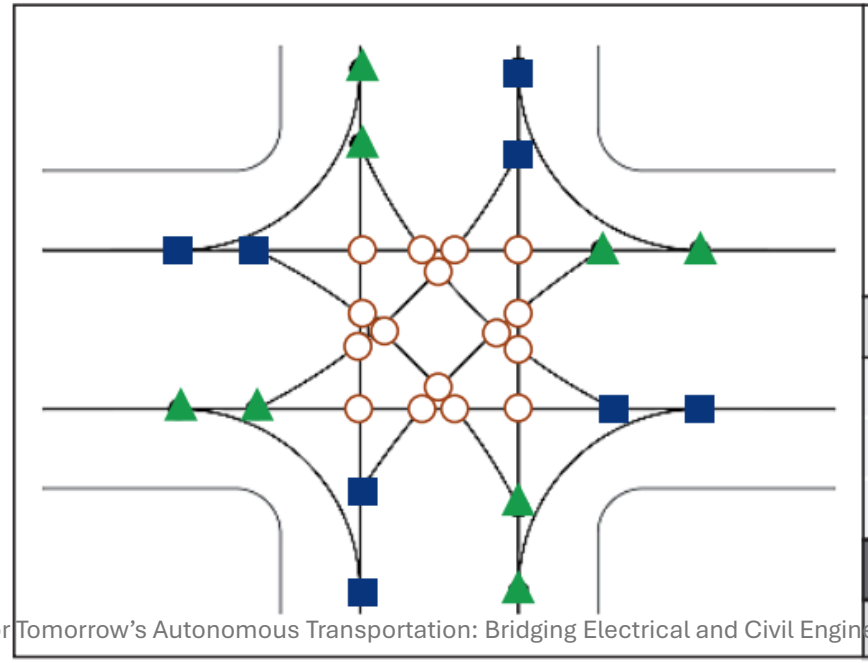
Learning Objectives

1. **Define and explain** key traffic-signal terminology, phasing concepts, and intersection control principles.
2. **Differentiate** between signal operation types and left-turn treatments.
3. **Interpret** typical signal-head configurations and their implications for safety and operations.
4. **Apply** formulas for yellow and all-red intervals to determine safe change and clearance times.
5. **Compute** critical flow ratios and **determine** appropriate cycle lengths.
6. **Develop** a basic signal timing plan including phase selection, cycle length, and green time allocation.

Introduction

- Intersections: The most complex location within transportation network.
  - 32 conflict points.

Conventional Intersection: Conflict Points



Legend

○ = Crossing

■ = Merging

▲ = Diverging

Conflict Type	Count
Crossing	16
Merging	8
Diverging	8
Total:	
32 Conflicts	

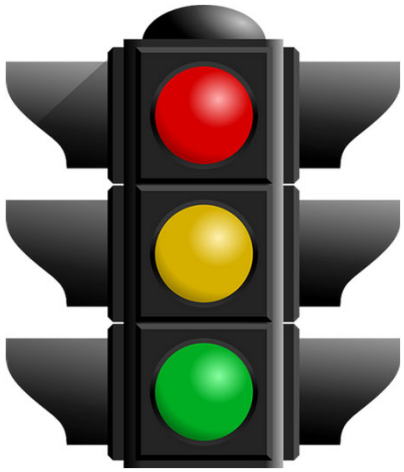
Introduction

- Three levels of intersection control:
  - Level I: Basic rules of the road.
  - Level II: YIELD or STOP signs
  - Level III: Traffic signals

- Which level to choose?
  - Driver's ability to avoid conflicts
    - See potential conflicts
    - Traffic volumes allow safe movement

Introduction

- Signalized Intersections:
  - Provide safe and efficient movement of veh/peds/bikes through the intersection.
  - Must be warranted.



- Important Concepts:
  - Time allocation
  - Phasing (left turns)

Traffic Signals: Terms

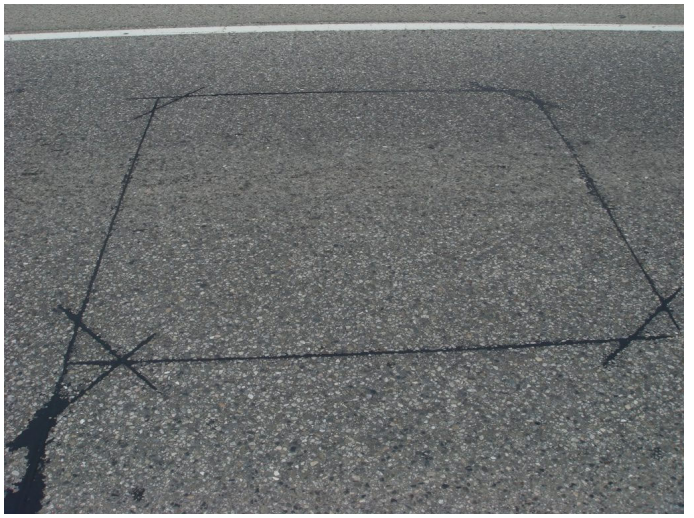
- **Cycle:** one complete rotation through all of the indications.
  - Cycle length: time to complete one full cycle (sec)

- **Interval:** period of time (sec) during which no signal indication changes.
  - Green (G_i): time (sec) when green is on
  - Change (Y_i): “yellow indication”
  - Clearance (AR_i): “all-red”
  - Red (R_i): time (sec) when red is on

- **Phase:** a set of intervals

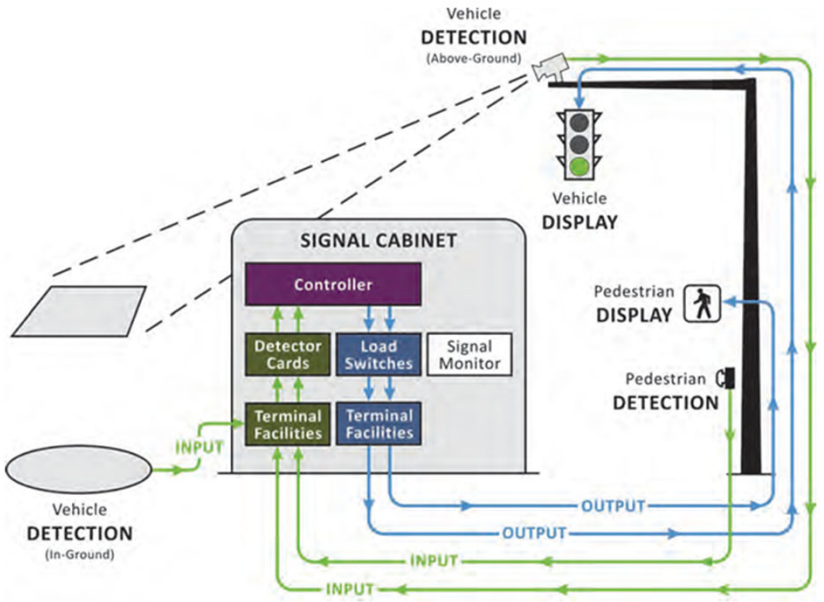
Traffic Signals: Operations

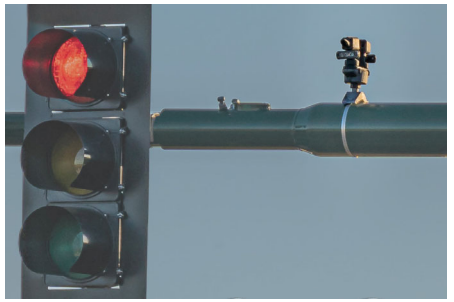
- **Pre-timed:**
  - Cycle, phase, intervals all predetermined.
  - Fixed-time of day, am/pm, off peak, weekend
- **Semi-actuated:**
  - Detectors only on minor approaches.
  - “Occupancy” sends a call for service.
- **Fully-actuated**
  - Detectors on all approaches
- **Demand Responsive**
  - Completely dynamic



Traffic Signals: Equipment

- **Detection:**
  - Inductive loop
  - Cameras
  - Radar
  - Acoustic
  - Pressure plates
  - Push buttons



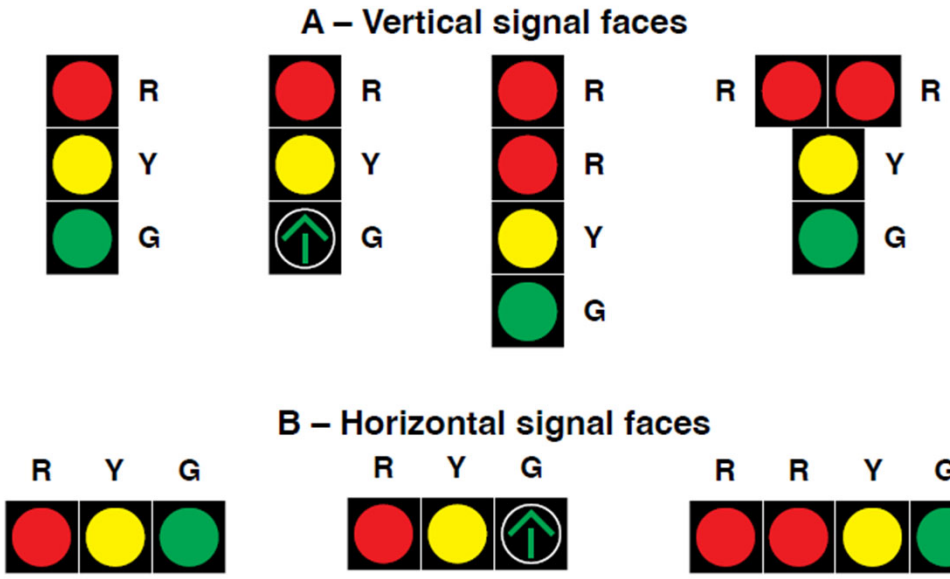


  - Emergency Vehicle Preemption (opticom)

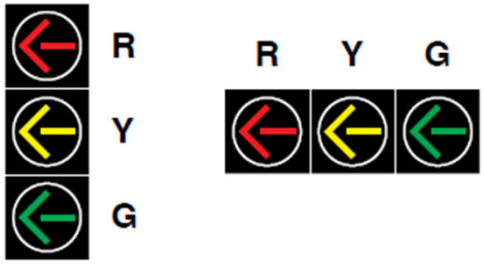
Traffic Signals: Left-Turn Treatments

- **Permitted:**
  - Made across an opposing flow
- **Protected:**
  - Made without an opposing flow
- **Compound:**
  - Protected-Permitted

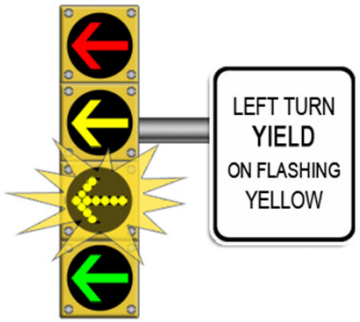
Traffic Signals: Configurations



Permitted Left-Turns



Protected Left-Turns

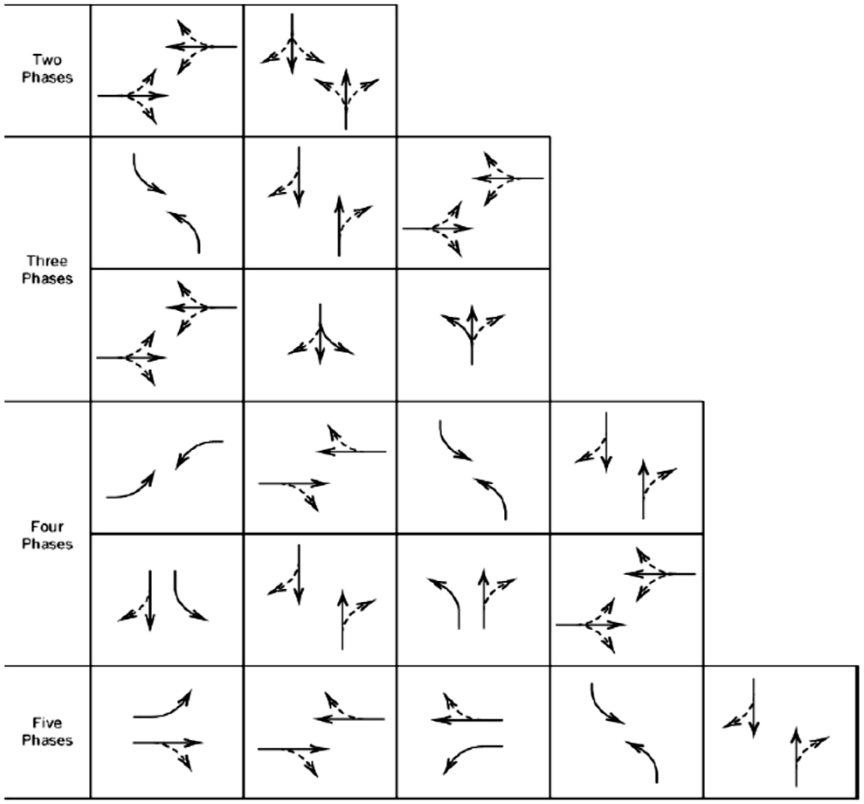


Protected/ Permitted Left-Turns

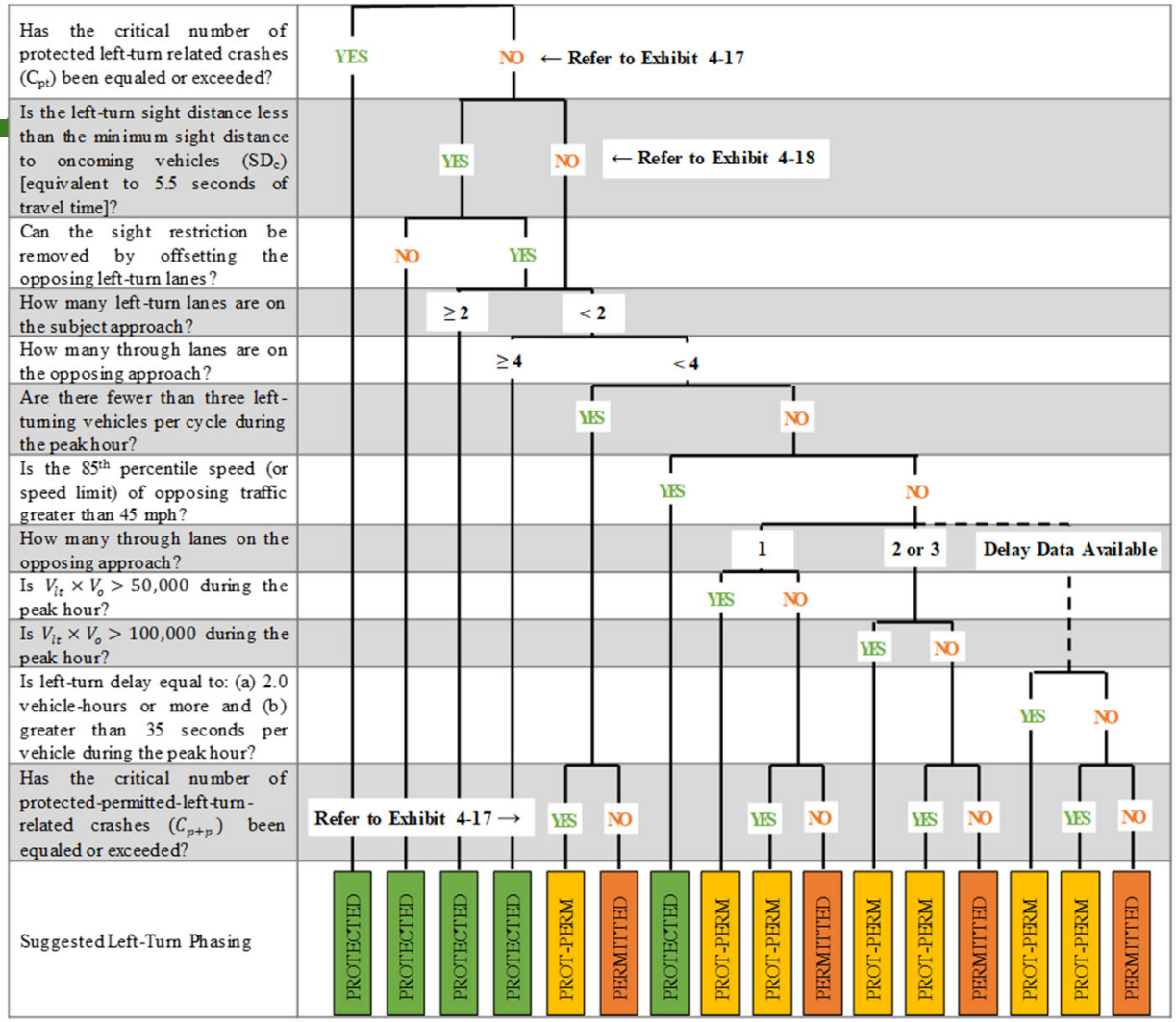
Select Signal Phasing

- Minimize number of phases to minimize lost times
  - 3 to 5 seconds total lost time per phase

- Determinant: **Left-Turns**

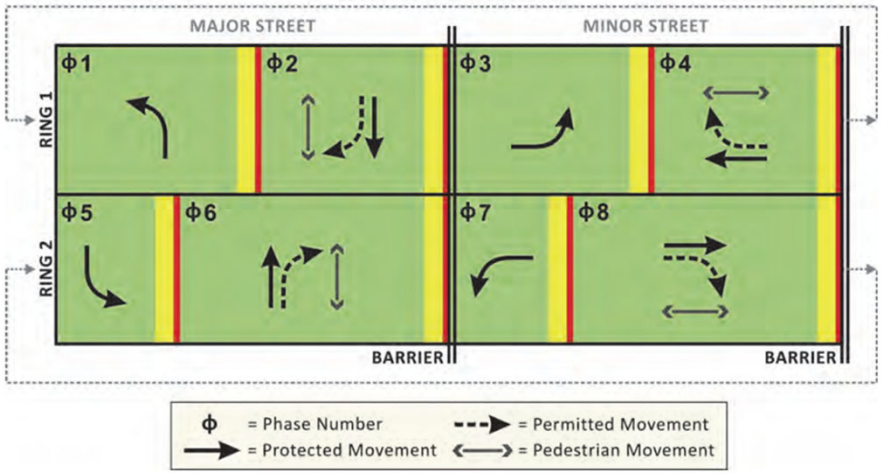


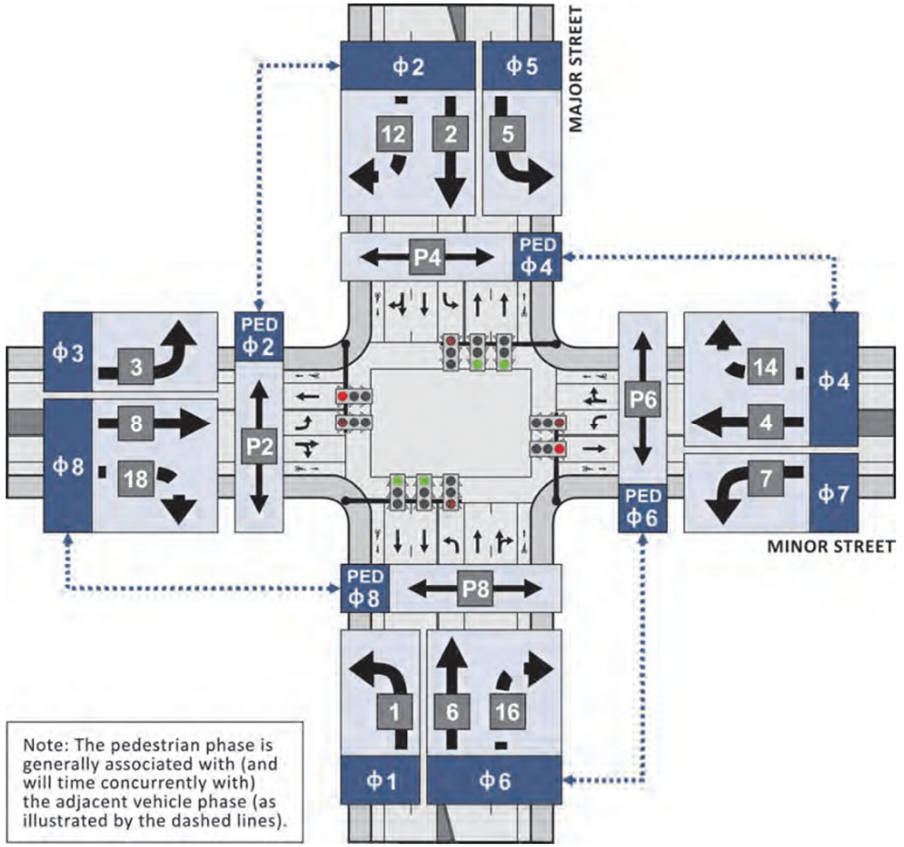
Left Turn Treatment



(Adopted from "Signal Timing Manual", NCHRP, Second Edition, 2015)

Numbering Movements and Phases



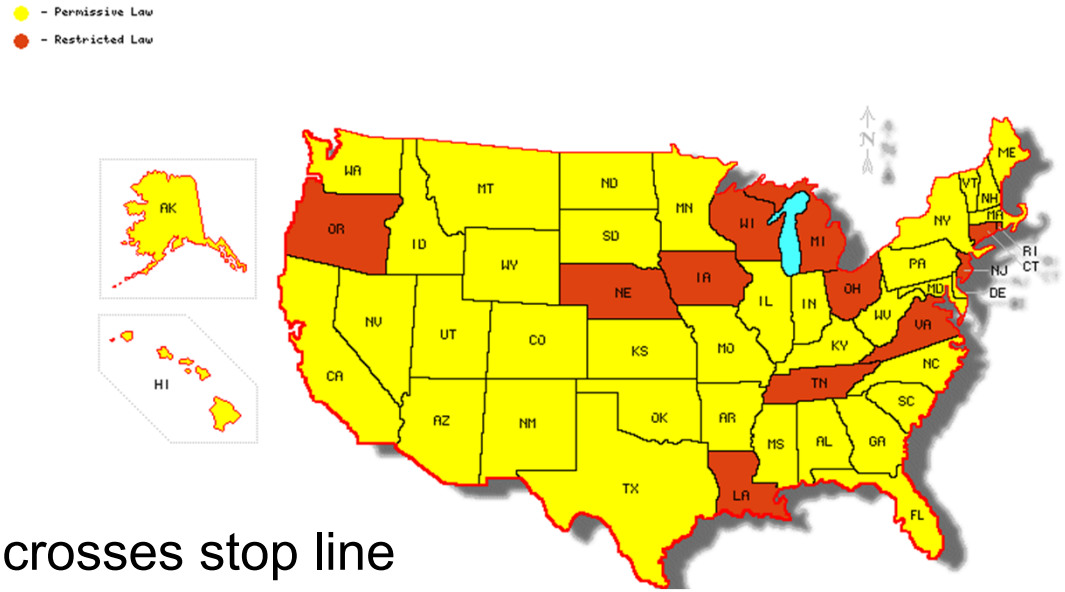


Signal Timing Plan

- Vehicular Signal Needs
  - Determine “Y+AR”
  - Determine V_c
  - Determine L_t
  - Determine C_{des}
  - Allocate effective green
- Pedestrian Signal Needs

Change Interval

- Indication: Circular Yellow (CY)
- Purpose: To warn drivers that signal indication (right-of-way) is about to change from CG to CR.
- Laws
  - Permissive
    - Can enter on CY if front axle crosses stop line
  - Restricted
    - Don't enter on CY unless unsafe to stop
    - Can't be in intersection on CR



Change Interval

- Duration of Yellow
  - No national standard
  - Adequate time for a driver to safely/conveniently stop [MUTCD: 3-6 sec]
  - Rule of thumb: ~10% of speed limit
  - ITE Recommendation:

$$Y = t_r + \frac{V}{2a + 2g_r G}$$

- t_r = driver perception/reaction time (~ 1.0 sec)
- V = vehicle speed (ft/s)
- a = vehicle deceleration (~ 10 ft/s^2)
- g_r = acceleration due to gravity (32.2 ft/s^2)
- G = grade (% divided by 100)

Clearance Interval (All-Red)

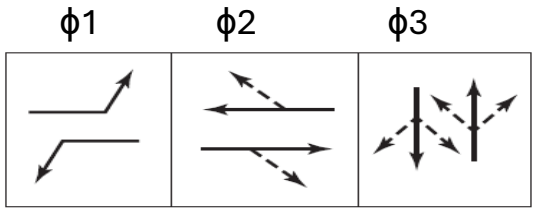
- If a vehicle enters at the end of the yellow, allow that vehicle to clear before conflict.
- Duration of AR
  - No national standard
  - Rule of thumb: ~ 1 sec
  - ITE Recommendation:

$$AR = \frac{w + l}{V}$$

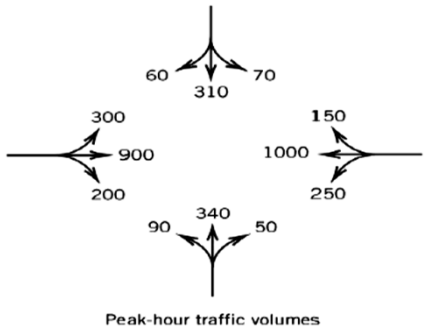
- w = width of street that vehicle must travel (ft)
- l = vehicle length (20 ft)

Determine Critical Flow Ratios

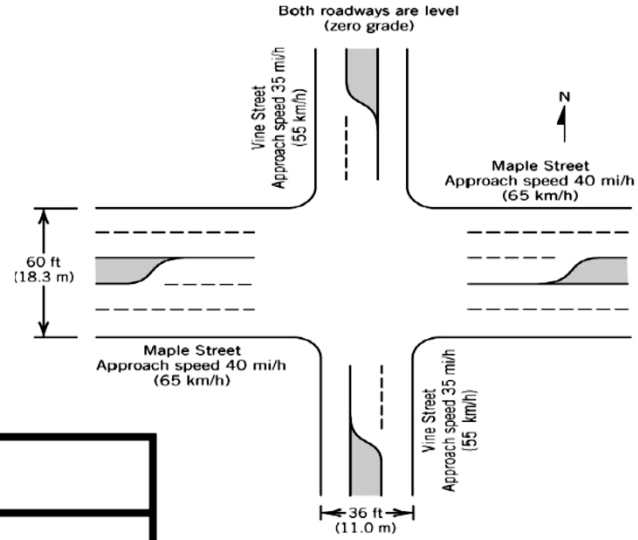
- Example



Phase Diagram



Peak-hour traffic volumes



Phase	$Ø_1$	$Ø_2$	$Ø_3$
Sat. Flows	EBL: 1750 vph WBL: 1750 vph	EBTR: 3400 vph WBTR: 3400 vph	SBTR: 1800 vph NBTR: 1800 vph SBL: 450 vph (permitted) NBL: 475 vph (permitted)
v/s	EBL: 300/1750 = 0.171 WBL: 250/1750 = 0.143	EBTR: 1100/3400 = 0.324 WBTR: 1150/3400 = 0.338	SBTR: 370/1800 = 0.206 NBTR: 390/1800 = 0.217 SBL: 70/450 = 0.156 NBL: 90/475 = 0.189

Calculate Cycle Length

- Minimum Cycle Length

$$C_{\min} = \frac{L \times X_c}{X_c - \sum_{i=1}^{n} \left(\frac{v}{s} \right)_{ci}}$$

C_{min}	=	Minimum necessary cycle length (sec)
L	=	Total lost time for cycle (sec)
X_c	=	Critical v/c ratio (intersection utilization)
$(v/s)_{ci}$	=	Flow ratio for critical lane group i
n	=	Number of critical lane groups

Calculate Cycle Length

- Optimum Cycle Length

$$C_{opt} = \frac{1.5L + 5.0}{1.0 - \sum_{i=1}^{n} \left(\frac{v}{s}\right)_{ci}} \quad \text{(Webster)}$$

C_{opt}	=	Optimum cycle length to minimize delay (sec)
L	=	Total lost time for cycle (sec)
$(v/s)_{ci}$	=	Flow ratio for critical lane group i
n	=	Number of critical lane groups

Allocate Green Time

- How much green time should be allocated to each phase
- Multiple strategies.
  - One of the most popular and simplest is to distribute the green time so that v/c ratios are equalized for the critical lane groups.

$$g_i = \left(\frac{v}{s}\right)_{ci}\left(\frac{C}{X_i}\right)$$

g_i	=	Effective green time for phase *i* (sec)
C	=	Cycle length (sec)
X_i	=	*v*/*c* ratio for critical lane group *i*
$(v/s)_{ci}$	=	Flow ratio for critical lane group *i*

Check Pedestrian Crossing

- The minimum pedestrian green time is given by:

$$G_{ped} = 3.2 + \frac{L}{S_{ped}} + \left(0.27 N_{ped}\right) \quad \text{for } W_E \le 10 \text{ ft}$$

$$G_{ped} = 3.2 + \frac{L}{S_{ped}} + \left(2.7 \frac{N_{ped}}{W_E}\right) \quad \text{for } W_E > 10 \text{ ft}$$

where

- G_{ped} = pedestrian green time
- W_E = effective crosswalk width
- L = crosswalk length (ft)
- S_{ped} = pedestrian walking speed (3.5 – 4.0 ft/s)
- N_{ped} = number of pedestrians

For each crosswalk confirm: $G_{ped} < G$. (If $G_{ped} > G$, then set $G = G_{ped}$)

References

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- Roess, R.P., Prassas, E.S., and McShane, W.R. (2019) Traffic Engineering, 5th Edition.
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