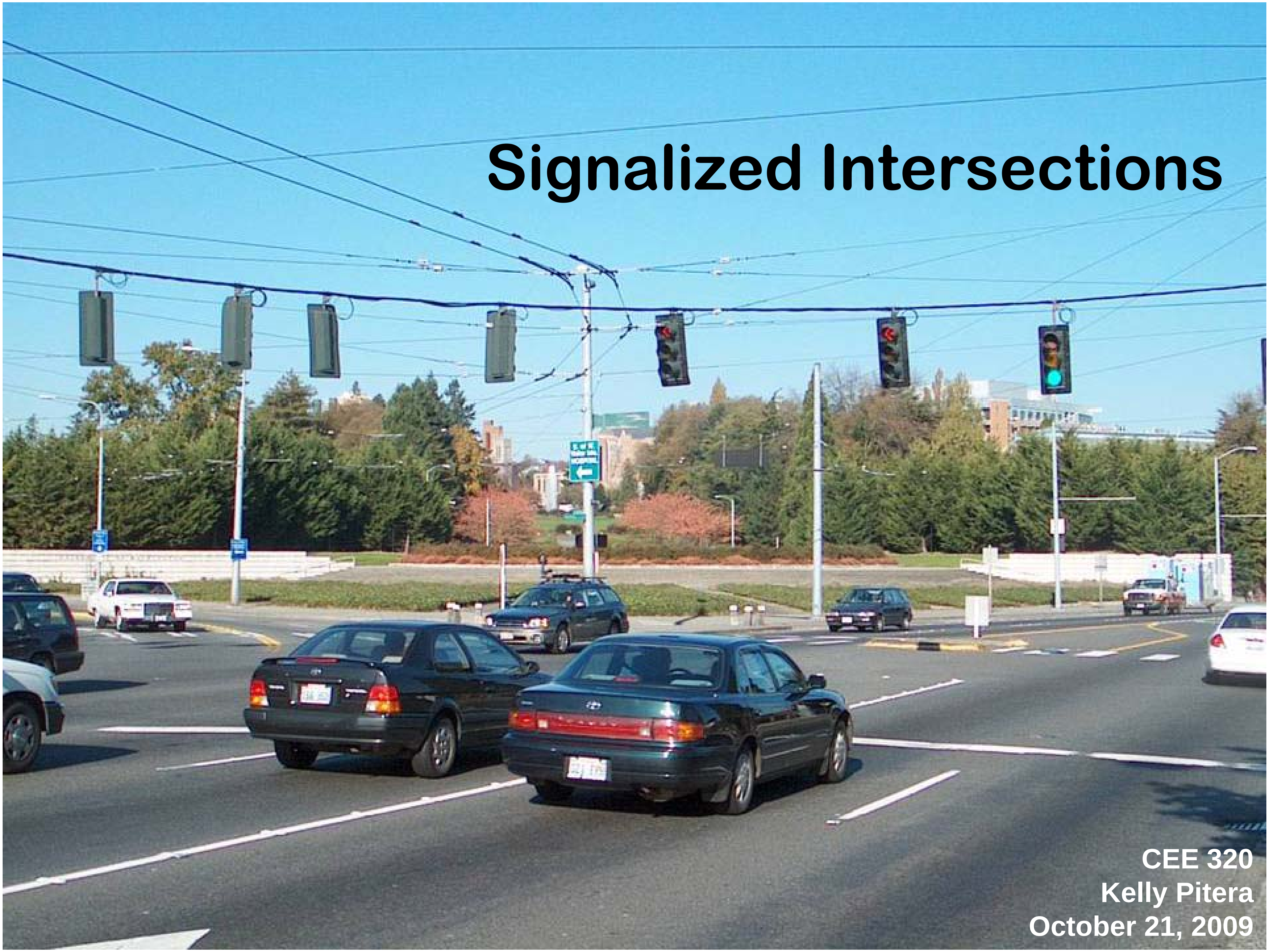
Signalized Intersections



CEE 320
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October 21, 2009

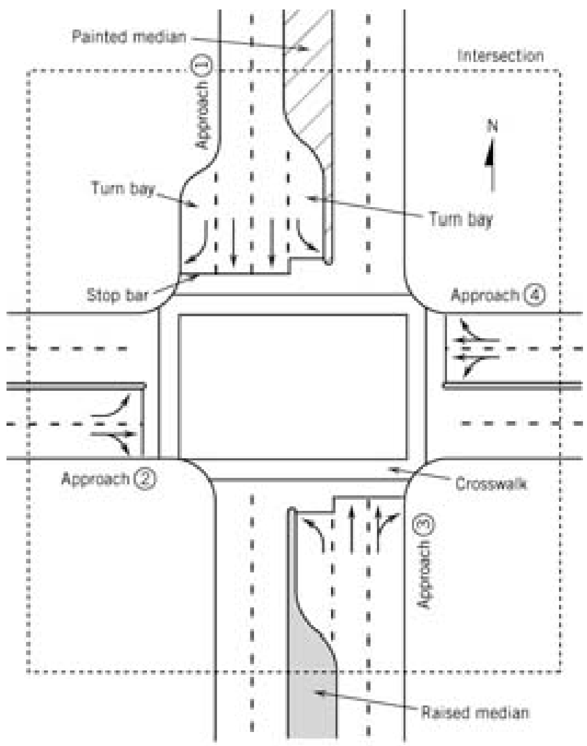
Topics to be Covered

- Introduction/Definitions
- D/D/1 Queuing
- Phasing and Timing Plan
- Level of Service (LOS)

Signalized Intersections

- The good
  - Reduce crashes
  - Allow pedestrians to cross the street
  - Allow side streets to enter into traffic flows
  - Provide progressive flow in a corridor
  - Improve capacity/reduce delay
- And the bad
  - If poorly timed, can negatively impact operations
  - Increase crashes
  - Encourage routes that are not intended for high levels of traffic

Key Definitions and Concepts



- Approaches
- Notation
  - EB/WB/NB/SB
  - Left(L)/Through(T)/Right(R)
- Pretimed
- Semi-actuated
- Fully actuated

Key Definitions and Concepts

- Cycle: one complete sequence (for all approaches) of signal indications (greens, yellow, reds)
- Cycle Length (C): the total time, in seconds, for the signal to complete one cycle
- Green Time (G): the amount of time within a cycle for which a movement or combination of movements receives a green indication
- Change Interval/Yellow Time (Y): the amount of time within a cycle for which a movement or combination of movements receives a yellow indication

Key Definitions and Concepts

- **<u>Red Time (R)</u>: the amount of time within a cycle for which a movement or combination of movements receives a red indication**
- **<u>Clearance Interval/All-Red Time (AR)</u>: the amount of time within a cycle in which all approaches have a red indication**
- **<u>Phase</u>: the sum of the displayed green, yellow, and red times for a movement or combination of movements that receive the right of way simultaneously during the cycle**

Lost Time

- **Start-up Lost Time (t_{sl})**
  - **Time lost when vehicles in a queue react to the initiation of the green phase and have to accelerate *2 seconds/phase is typical***
- **Clearance Lost Time (t_{cl})**
  - **Time lost between signal phases during which an intersection is not used by traffic *2 seconds/phase is typical***
- **Lost Time (t_L)**
  - **Total time when an intersection is not effectively utilized *4 seconds/phase is typical***

$$t_L = t_{sl} + t_{cl}$$

Effective Green and Red Times

- Effective Green Time (g)
  - Green time effectively utilized for movement
  - $g = G + Y + AR - t_L$
- Effective Red Time (r)
  - Time during which a movement is not effectively utilizing the intersection.
  - $r = R + t_L$
  - $r = C - g$

Saturation Flow Rate (s)

- The maximum hourly volume that can pass through an intersection, from a given lane or group of lanes, if that lane (or lanes) were allocated constant green over the course of an hour

$$s = \frac{3600}{h}$$

  - s = saturation flow rate in veh/hr
  - h = saturation headway in s/veh
  - 3600 = number of seconds per hour
- Ideally 1900 pc/hr/ln

Capacity

- **Approach Capacity (c)**
  - The hourly volume that can be accommodated on an approach given that the approach does not receive 100% green time
  - Saturation flow times the proportion of effective green

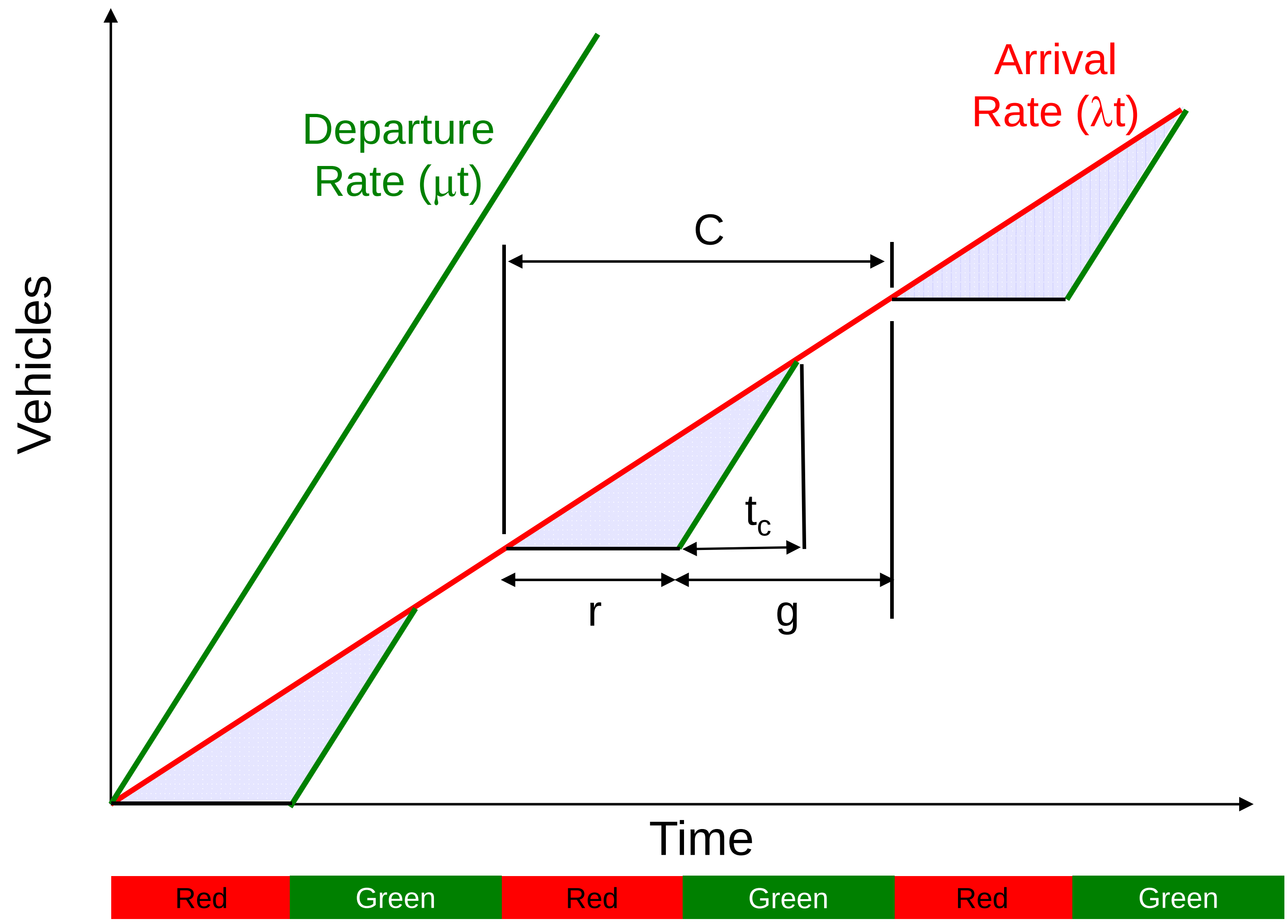
$$c = s \times g/C$$

EXAMPLE

- **Given (for <u>one</u> approach)**
  - **- G= 20 seconds**
  - **- Y= 3 seconds**
  - **- R= 18 seconds**
  - **- AR= 2 seconds**

- **What are the <u>effective red and green times</u>?**
- **What is the <u>cycle length</u> and the <u>capacity</u> if the saturation flow rate is 1800 veh/hr?**

D/D/1 Signal Analysis



Also assuming…

- **Approach arrivals < departure capacity**
  - **Meaning no queue exists at the beginning/end of a cycle**

- **Traffic Intensity**

$$\rho = \frac{\lambda}{\mu} \qquad \rho < 1.0$$

D/D/1 Signal Analysis

- **Time to queue dissipation after the start of effective green**

$$t_c = \frac{\rho r}{(1-\rho)}$$

- **Proportion of the cycle with a queue**

$$P_q = \frac{r + t_c}{C}$$

- **Proportion of vehicles stopped**

$$P_s = \frac{\lambda(r + t_c)}{\lambda(r + g)} = \frac{r + t_c}{C} = P_q \qquad P_s = \frac{\lambda(r + t_c)}{\lambda(r + g)} = \frac{\mu t_c}{\lambda C} = \frac{t_c}{\rho C}$$

D/D/1 Signal Analysis

- **Maximum number of vehicles in a queue**

$$Q_m = \lambda r$$

- **Total delay per cycle**

$$D_t = \frac{\lambda r^2}{2(1-\rho)}$$

- **Average delay per vehicle**

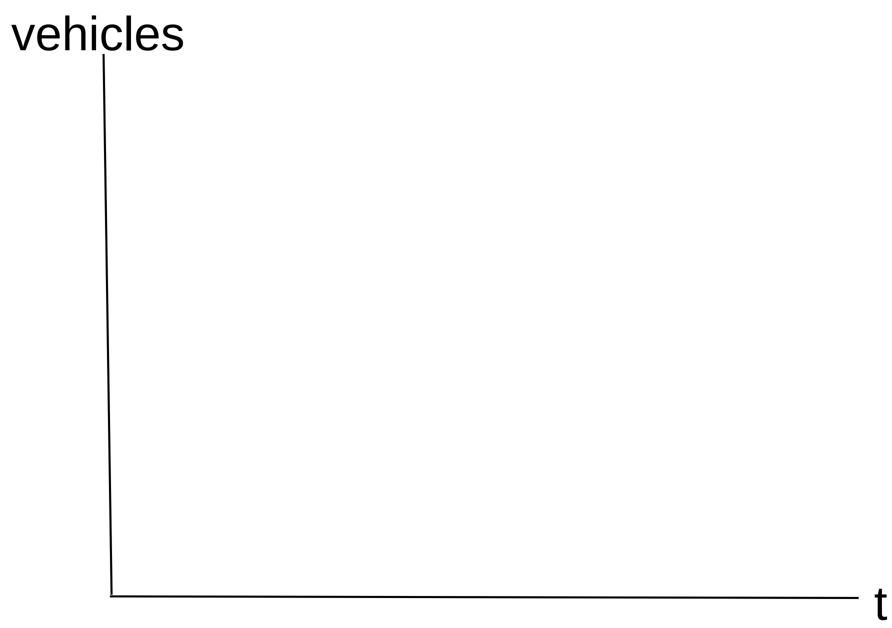
$$D_{avg} = \frac{\lambda r^2}{2(1-\rho)} \times \frac{1}{\lambda C} = \frac{r^2}{2C(1-\rho)}$$

- **Maximum delay of any vehicle (assume FIFO)**

$$d_{\max} = r$$

EXAMPLE

The intersection of 15th Ave NE and NE 75th St is controlled by a pre-timed signal. The saturation flow rate on westbound NE 75th St is 3200 veh/hr and is allocated 32 seconds of effective green in a 60-second signal cycle. If the flow at the approach is 960 veh/hr, provide an analysis of the intersection assuming D/D/1 queuing.



EXAMPLE

Arrival Rate

Departure Rate

Traffic Intensity

Effective Red

Time to Queue Clearance

Proportion of the Cycle with a Queue

EXAMPLE

Proportion of Vehicles Stopped

Max # of Vehicles in Queue

Total Delay/Cycle for WB 75th St

Average Delay per vehicle

Maximum Delay

Signal Optimization

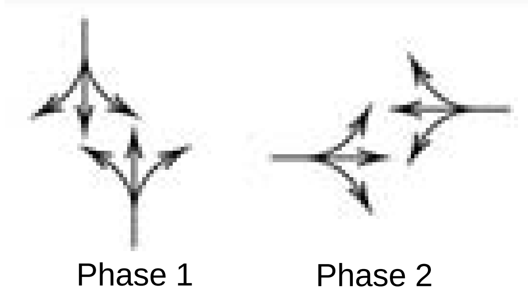
- Conflicting Operational Objectives
- What should be optimized?
  - minimize vehicle delay
  - minimize vehicle stops
  - minimize lost time
  - maximize major street green time
  - maximize pedestrian service
  - minimize accidents/severity

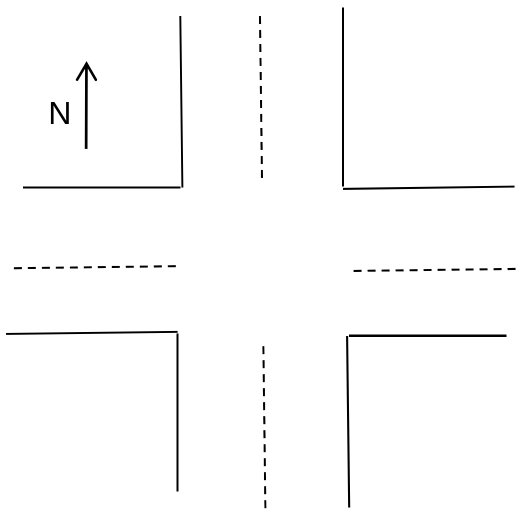
Traffic Signal Phasing & Timing Plan

1. Select signal phasing
2. Establish analysis lane groups
3. Calculate analysis flow rates and adjusted saturation flow rates
4. Determine critical lane groups and total cycle lost time
5. Calculate cycle length
6. Allocate green time
7. Calculate change and clearance intervals
8. Check pedestrian crossing time

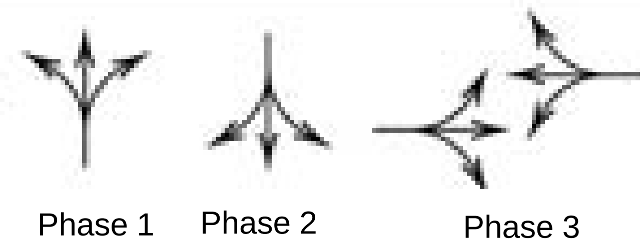
1. Select Signal Phasing

- A <u>cycle</u> is made up of <u>phases</u>
- Most basic: Two-phase signal:





- Same street configuration but as a three-phase signal



- In this class, number of phases will be given to you

2. Establish Analysis Lane Groups

- Lane Group: A set of lanes established at an intersection approach for separate analysis

- Guidelines for establishing lane groups
  - Movements made simultaneously from the same lane must be treated as a lane group
  - If an exclusive turn lane (or lanes) is present, it is usually treated as a separate lane group
  - If a lane (or lanes) with shared movements exists in a multiple lane approach, it must first be determined whether it really serves multiple movements or whether it is a de facto lane for one of the movements

2. Establish Analysis Lane Groups

Number of lanes	Movements by lane	Number of possible lane groups
1	LT + TH + RT	1 (Single-lane approach)
2	EXC LT TH + RT	2
2	LT + TH TH + RT	1 or 2
3	EXC LT TH TH + RT	2 or 3

(Figure 7.12 in text)

3. Calculate Analysis Flow Rates and Adjusted Saturation Flow Rates

- Need to account for the peak 15-minute flow within an hour (calculate PHF)
- Similar to analysis of uninterrupted flow (chapter 6)
- For our work, assume that the approach volumes and saturation flow rates have already been adjusted

4. Determine critical lane groups and total cycle lost time

- **<u>Critical Lane Group:</u> The lane group that has the highest flow ratio/traffic intensity (v/s) for a given signal phase (lane group with the greatest demand)**

- **Calculate the sum of flow ratios for critical lane groups, Y_c (to be used in step 5)**

$$Y_c = \sum_{i=1}^{n} \left(\frac{v}{s} \right)_{ci}$$

$(v/s)_{ci}$ = flow ratio for critical lane group i

n = number of critical lane groups

4. Determine critical lane groups and total cycle lost time

- Total lost time for the cycle, L (to be used in step 5)

$$L = \sum_{i=1}^{n} \left(t_L\right)_{ci}$$

$(t_L)_{ci}$ = total lost time for critical lane group i, in seconds
n = number of critical lane groups

- Assume the total lost time for a lane group is 4 seconds