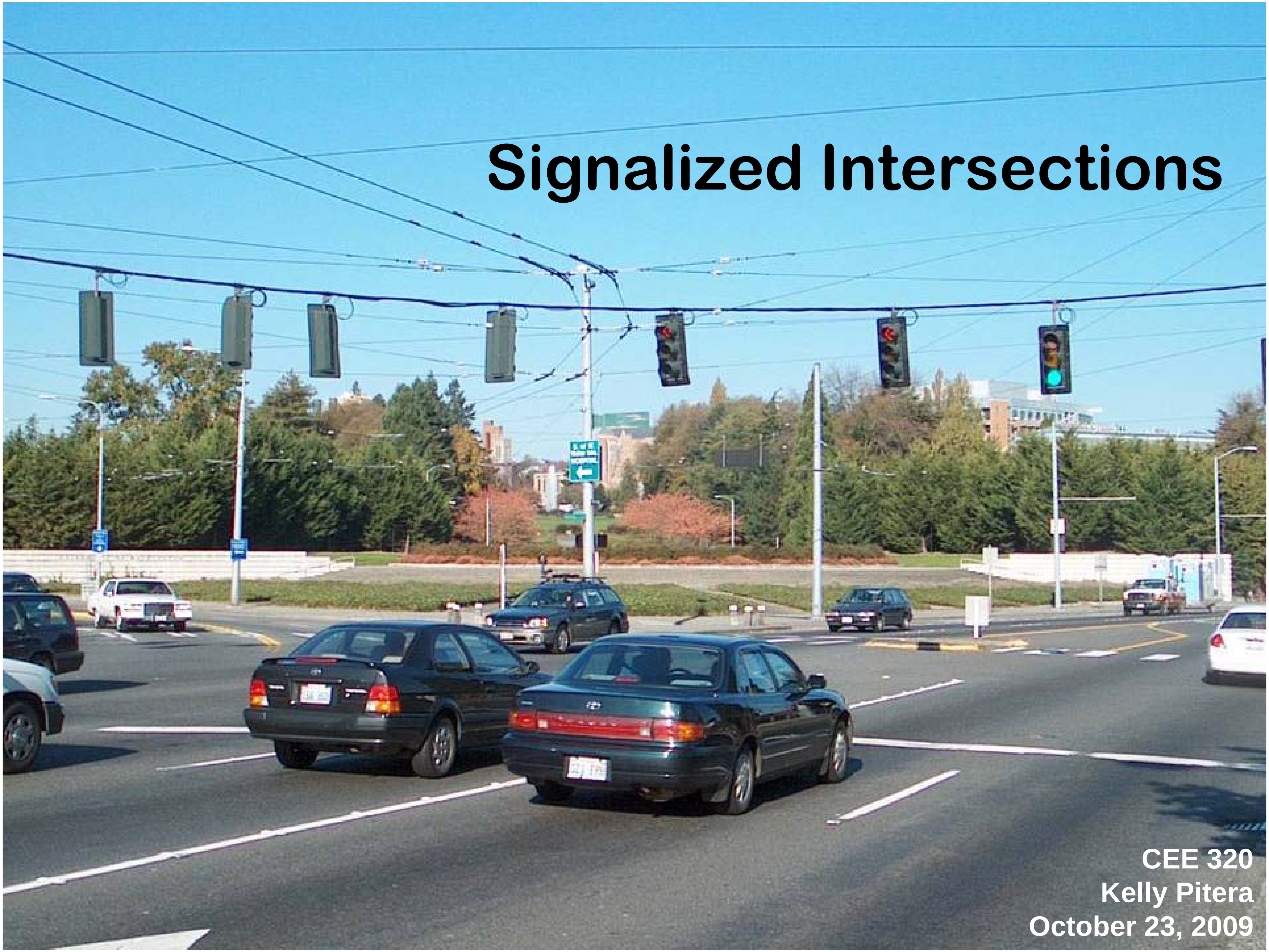


Signalized Intersections

CEE 320
Kelly Pitera
October 23, 2009

Topics to be Covered

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

Signal Optimization

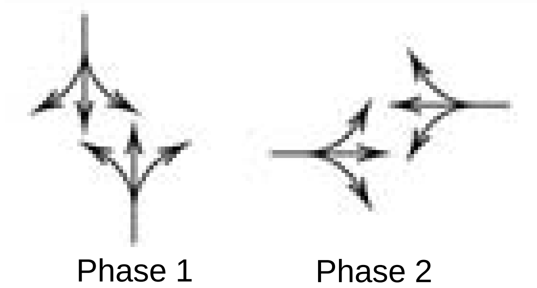
- Conflicting Operational Objectives
- What should be optimized?
  - minimize vehicle delay
  - minimize vehicle stops
  - minimize lost time
  - maximize major street green time
  - maximize pedestrian service
  - minimize accidents/severity

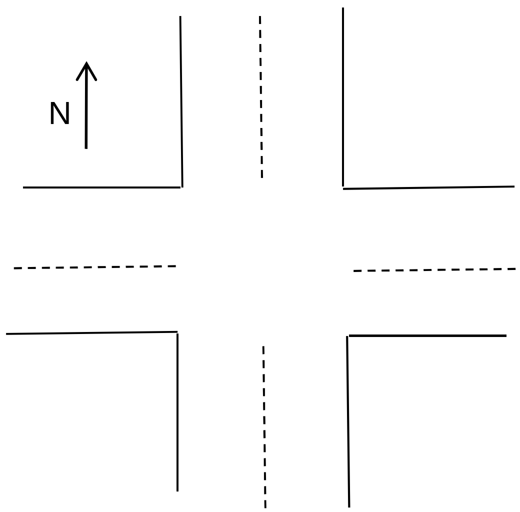
Traffic Signal Phasing & Timing Plan

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

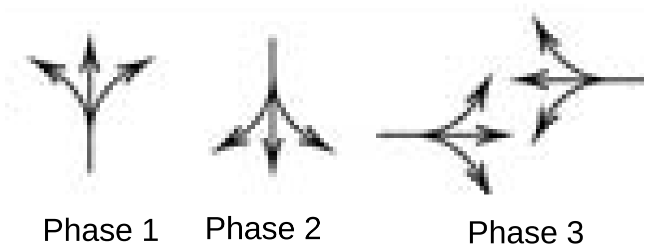
1. Select Signal Phasing

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





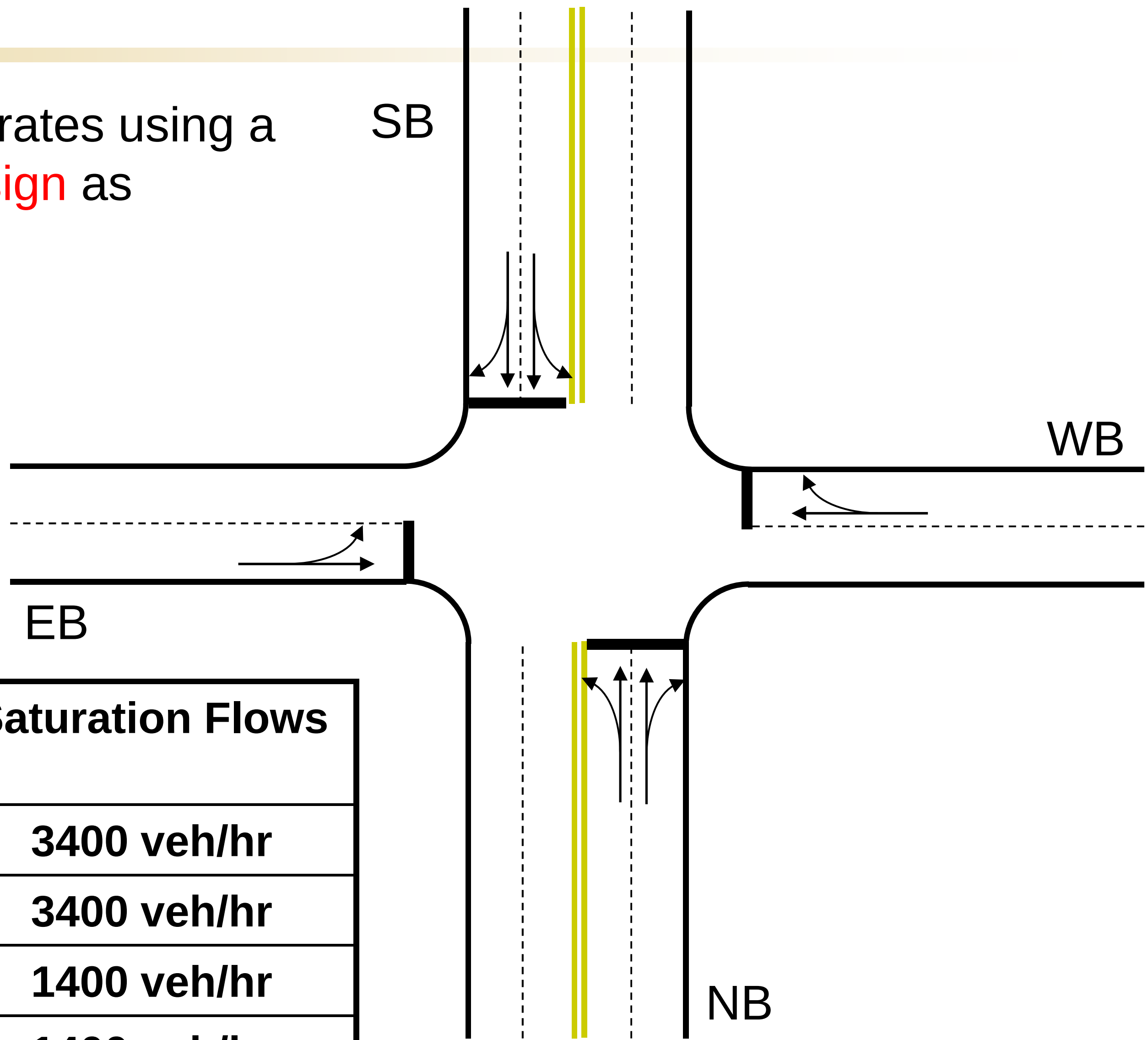
- Same street configuration but as a three-phase signal



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

EXAMPLE

An intersection operates using a simple 3-phase design as pictured.



Phase	Lane group	Saturation Flows
1	SB	3400 veh/hr
2	NB	3400 veh/hr
3	EB	1400 veh/hr
	WB	1400 veh/hr

2. Establish Analysis Lane Groups

- **<u>Lane Group:</u> A set of lanes established at an intersection <u>approach</u> 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**

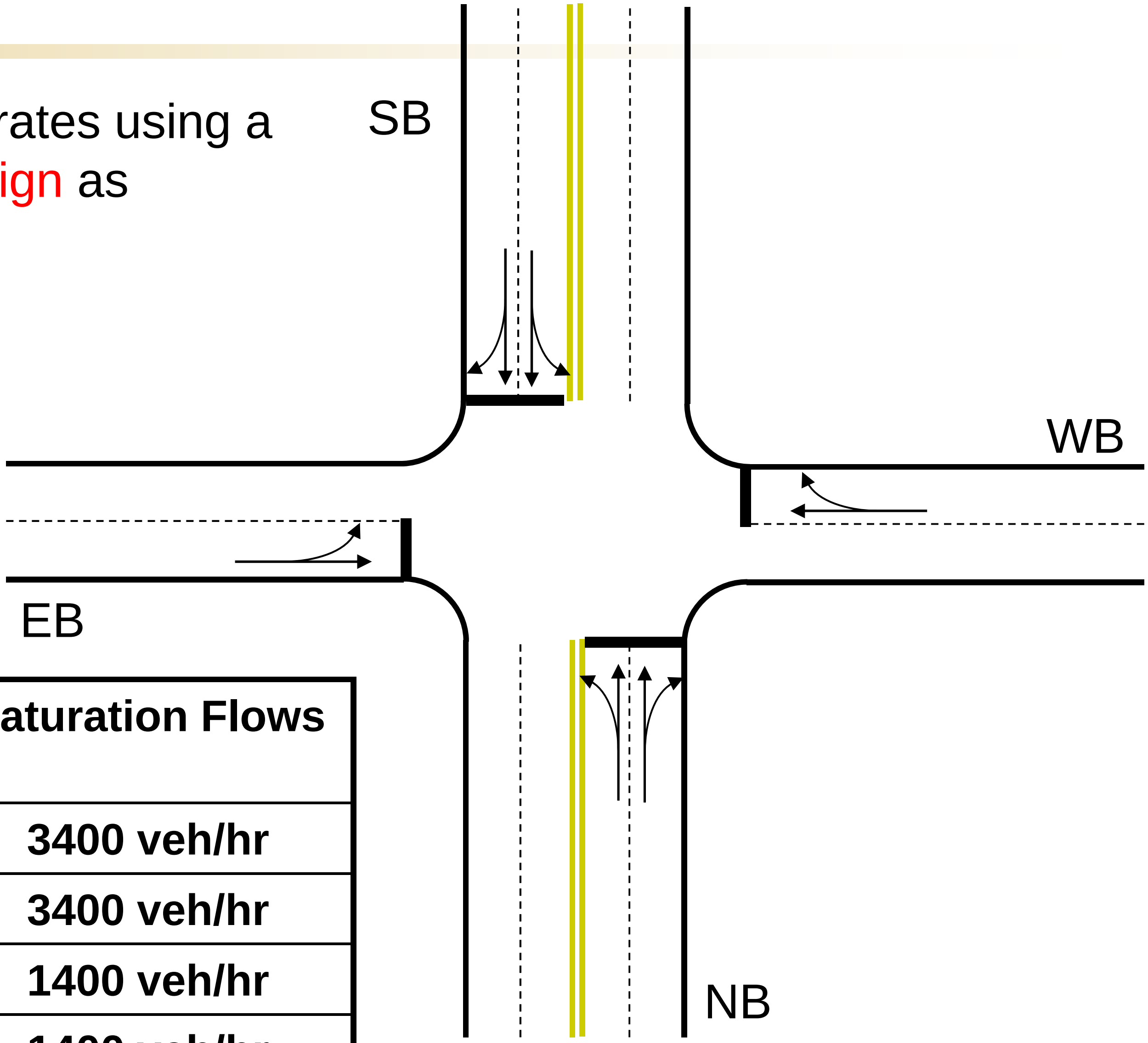
2. Establish Analysis Lane Groups

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)

EXAMPLE

An intersection operates using a simple 3-phase design as pictured.



Phase	Lane group	Saturation Flows
1	SB	3400 veh/hr
2	NB	3400 veh/hr
3	EB	1400 veh/hr
	WB	1400 veh/hr

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)**

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

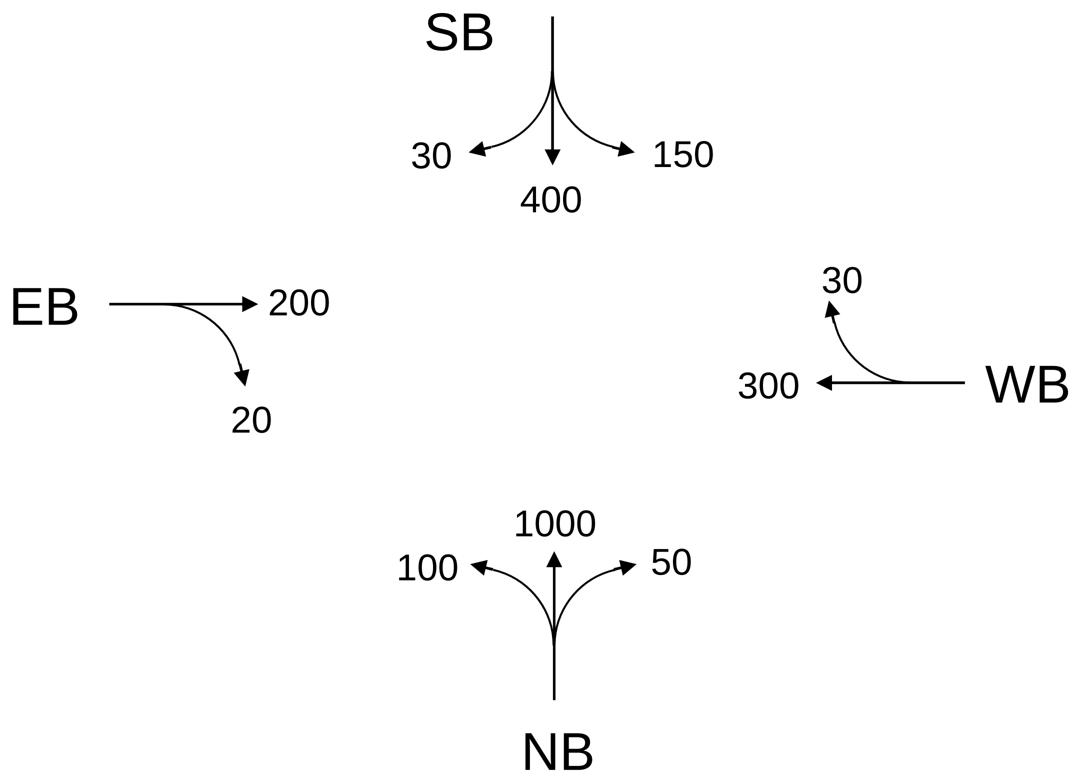
$(t_L)_{ci}$ = total lost time for critical lane group i, in seconds
n = number of critical lane groups

- **Assume the total lost time for each critical lane group (or phase) is 4 seconds**

EXAMPLE

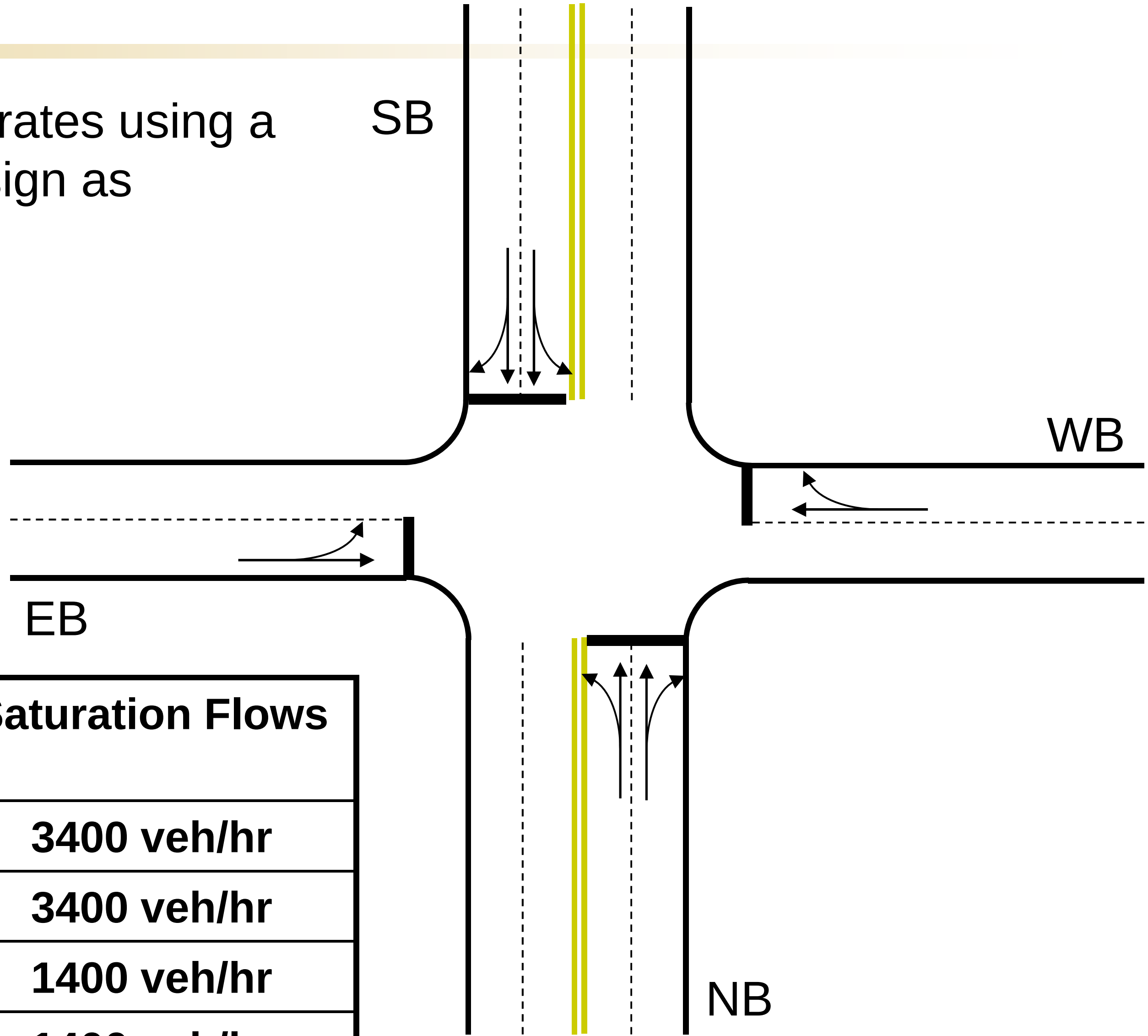
What is the sum of the flow ratios for the critical lane groups (Y_c)?

What is the total lost time for a signal cycle assuming 2 seconds of clearance lost time and 2 seconds of startup lost time per phase?



EXAMPLE

An intersection operates using a simple 3-phase design as pictured.



Phase	Lane group	Saturation Flows
1	SB	3400 veh/hr
2	NB	3400 veh/hr
3	EB	1400 veh/hr
	WB	1400 veh/hr

EXAMPLE

EXAMPLE

5. 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} = estimated minimum cycle length (seconds)

L = total lost time per cycle (seconds), 4 seconds per phase is typical

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

X_c = critical v/c ratio for the intersection

5. Calculate Cycle Length

- **X_c, the critical v/c ratio, indicates the desired degree of intersection utilization**
- **X_c = 1.0 would mean the intersection operates a full capacity, *which is desired but not practical***
- **Therefore, often values less than 1 are assumed for X_c (such as 0.90)**
- **C_{min} formula calculates the minimum cycle length needed for the intersection to operate at the given capacity utilization, *but does not necessarily minimize delay***

5. Calculate Cycle Length

- **Calculate the cycle length to minimize delay using:**

$$C_{opt} = \frac{1.5(L) + 5}{1 - \sum_{i=1}^{n} \left(\frac{v}{s} \right)_{ci}}$$

C_{opt} = estimated optimum cycle length (seconds) to minimize vehicle delay

L = total lost time per cycle (seconds), 4 seconds per phase is typical

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

5. Calculate Cycle Length

- **Round C up to the nearest 5 seconds**
- **Which C should we use???**
  - **In practice, an engineer would test out both cycle lengths in the field to see which works "better"**
  - **In this example and in the homework, lets just use C_{min}**

EXAMPLE

Calculate both an optimal cycle length and a minimum cycle length

6. Allocate Green Time

- **Decide how much green time should be allotted to each phase**

$$g_i = \left(\frac{v}{s}\right)_i \left(\frac{C}{X_c}\right)$$

g	=	effective green time for phase, *i* (seconds)
$(v/s)_i$	=	flow ratio for lane group, *i* (seconds)
C	=	cycle length (seconds)
X_c	=	v/c ratio

- **There will be a g value for each phase**

6. Allocate Green Time

- Used a desired X_c to calculate C_{min}, but then rounded up C_{min}
- Recalculate X_c using:

$$X_c = \frac{\sum_{i=1}^{n} \left(\frac{v}{s} \right)_i \times C}{C - L}$$

EXAMPLE

Determine the green times allocation (assume C=70 seconds)

EXAMPLE

Steps 7 and 8

- **Calculate change and clearance intervals**
  - In other words, find the yellow (Y) and all-red (AR) times
  - Based on how long (distance) it takes a vehicle to safely stop
- **Check pedestrian crossing time**
  - Make sure there is adequate crossing time

- **Sections 7.5.7-7.5.8**
- **Simple plug and chug formulas**

Level of Service (LOS) Analysis

- Based on <u>control delay</u> measure
- Applies to both signalized and not signalized intersections
- Referred to as signal delay for a signalized intersection
- Total delay experienced by the driver as a result of the control
- Includes deceleration time, queue move-up time, stop time, and acceleration time

Signalized Intersection LOS

- **Based on control delay per vehicle**
  - **How long you wait, on average, at the stop light**

EXHIBIT 16-2. LOS CRITERIA FOR SIGNALIZED INTERSECTIONS

LOS	Control Delay per Vehicle (s/veh)
A	≤ 10
B	> 10–20
C	> 20–35
D	> 35–55
E	> 55–80
F	> 80

from *Highway Capacity Manual 2000*

- **LOS determination approach:**

  Lane group → Approach → Intersection

Typical Approach (from HCM)

- **Split control delay into three parts**
  - **<u>Part 1</u>: Delay calculated assuming uniform arrivals (d_1) (this is essentially a D/D/1 analysis)**
  - **<u>Part 2</u>: Delay due to random arrivals (d_2)**
  - **<u>Part 3</u>: Delay due to initial queue at start of analysis time period (d_3)**

$$d = d_1\left(PF\right) + d_2 + d_3$$

d	=	Average signal delay per vehicle in s/veh
PF	=	progression adjustment factor
d_1, d_2, d_3	=	as defined above

Uniform Delay (d_1)

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1, X_c)\frac{g}{C}\right]}$$

d_1 = delay due to uniform arrivals (s/veh)

C = cycle length (seconds)

g = effective green time for lane group (seconds)

X_c = v/c ratio for lane group

- **PF accounts for the effect of signal progression on quality of delay**
- **Use PF = 1**

Incremental/Random Delay (d_2)

$$d_2 = 900T\left[(X_c - 1) + \sqrt{(X_c - 1)^2 + \frac{8kIX_c}{cT}}\right]$$

d_2 = delay due to random arrivals (s/veh)

T = duration of analysis period (hours). If the analysis is based on the peak 15-min flow then T = 0.25, if flow based on the peak 1-hr flow then T = 1 hr…

k = delay adjustment factor that is dependent on signal controller mode. For pretimed intersections k = 0.5. For more efficient intersections k < 0.5.

I = upstream filtering/metering adjustment factor. Adjusts for the effect of an upstream signal on the randomness of the arrival pattern. I = 1.0 for completely random. I < 1.0 for reduced variance.

c = lane group capacity (veh/hr)

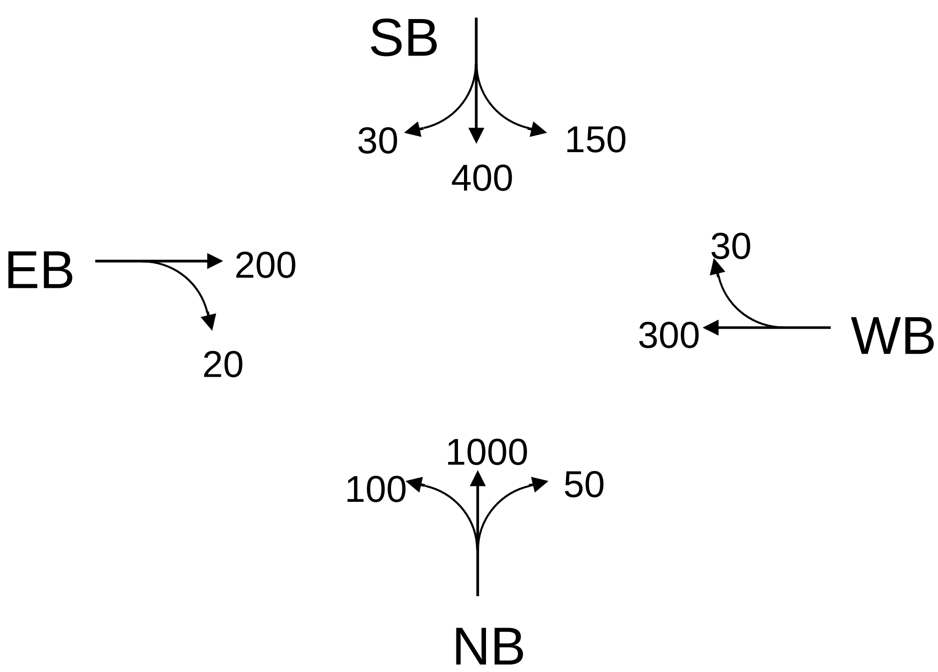
X_c = v/c ratio for lane group

Initial Queue Delay (d_3)

- **Applied in cases where X > 1.0 for the analysis period**
  - **Vehicles arriving during the analysis period will experience an additional delay because there is already an existing queue**
- **When no initial queue…**
  - $d_3 = 0$

EXAMPLE

What is the intersection LOS? Assume in all cases that PF = 1.0, T = 1.0 (flow based on 1-hr volumes), k = 0.5 (pretimed intersection), I = 1.0 (no upstream signal effects).



Phase	Lane group	Saturation Flows
1	SB	3400 veh/hr
2	NB	3400 veh/hr
3	EB	1400 veh/hr
	WB	1400 veh/hr

1. Calculate delay for each lane group in an approach
2. Calculate delay for each approach in an intersection
3. Calculate delay for the intersection

EXAMPLE

There is only 1 lane group for each approach, therefore lane group delay = approach delay in this example

Determine delay for Southbound Approach:

EXAMPLE

- **Northbound Approach**

EXAMPLE

- Eastbound Approach

EXAMPLE

- **Westbound Approach**

EXAMPLE

- To get intersection delay, find the weighted average (by flow) of delay for the four approaches