

Traffic Analysis at Signalized Intersections 4

David Levinson
(based on notes
by Henry Liu
University of
Minnesota)

Signal Timing Procedure (Steps)

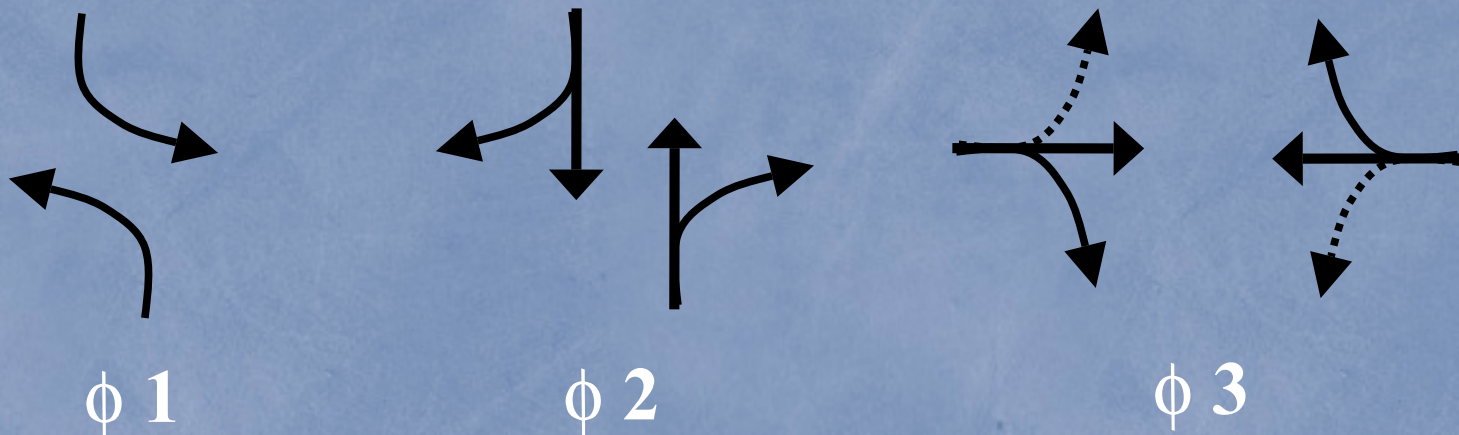
1. Determine "Phasing"
2. Establish analysis lane group
3. Choose "Critical Lane Volumes"
4. Calculate Cycle Length
5. Determine Yellow & Clearance Intervals
6. Proportion Green Time
7. Check Pedestrian Crossing Time
8. Prepare Signal Indication Diagram

Step 1: Determine phase to use

Minimum # of phases (two):



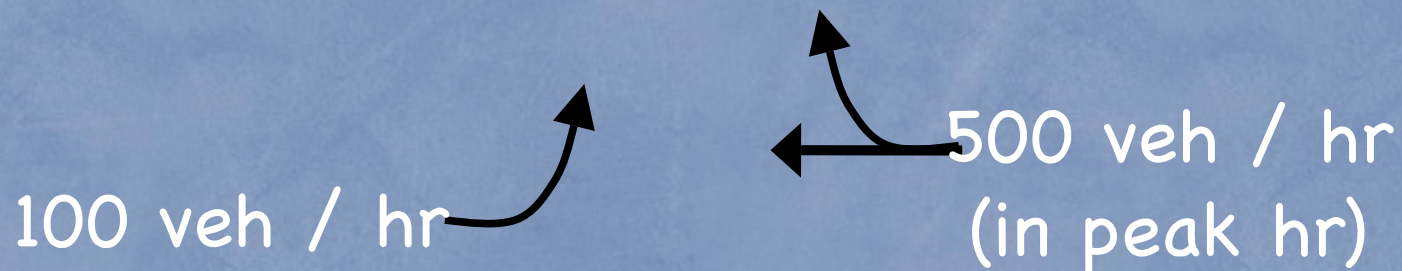
Three phases:



Step 1: Determine phasing to use (cont.)

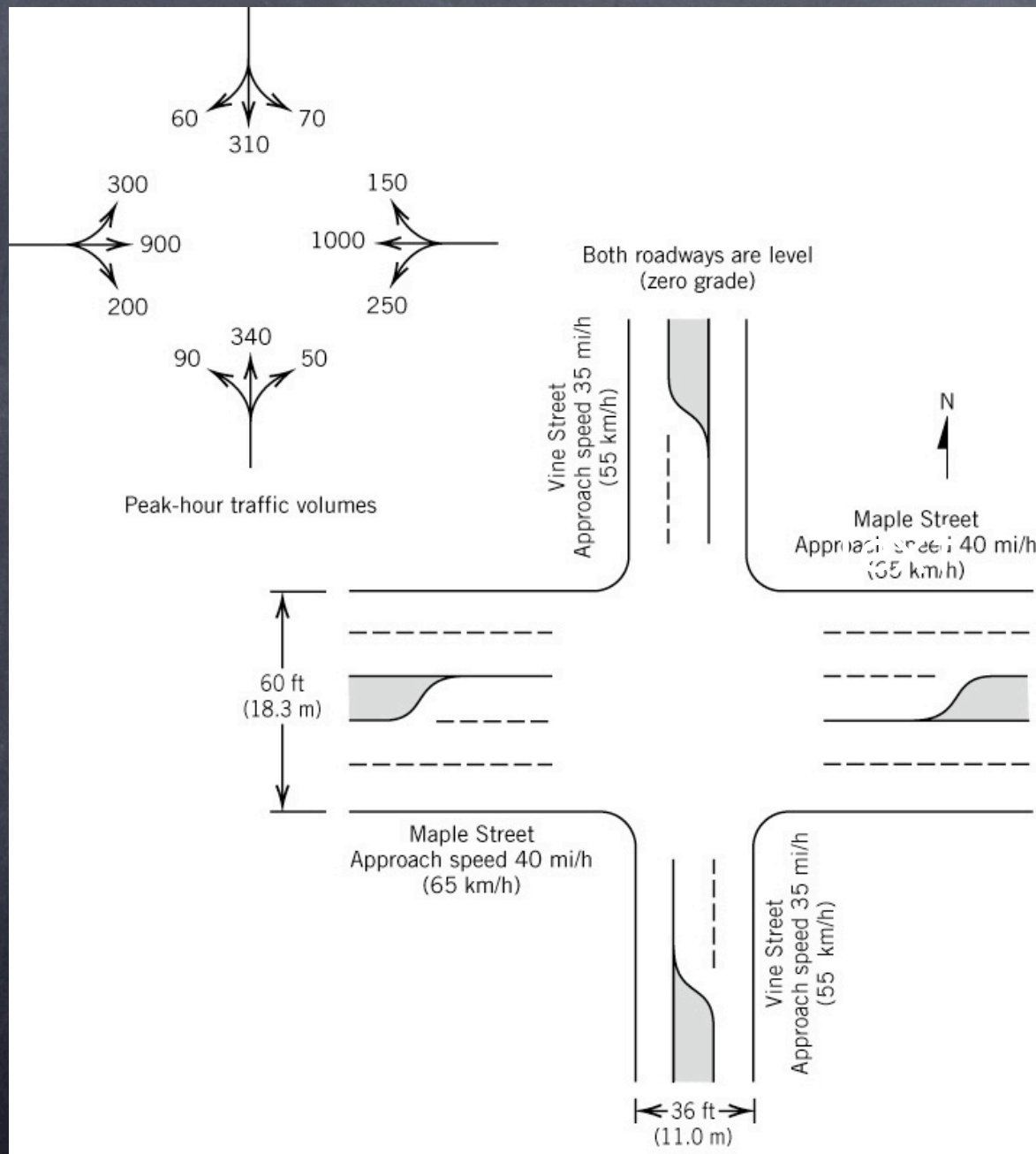
Left Turn protected phase should be considered if any of the following criteria is met:

- More than one turning lane is provided;
- The left turn has a demand over 240veh/h;
- The cross product of left turn demand and opposing through demand for 1 hour exceeds
 - 50,000 for one opposing lane,
 - 90,000 for two opposing through lanes, or
 - 110,000 for three or more lanes.



Example 7.6:

determine if the
protected left turn
should be provided
using cross product
guideline



Solution

- $275,000 = 250 \cdot (900 + 200)$
- $345,000 = 300 \cdot (100 + 150)$
- --> Protected LT lane for WB and EB LT movements
- $27,300 = 70 \cdot (340 + 50) < 50,000$
- $34,200 = 90 \cdot (310 + 70) < 50,000$
- --> No Protected LT for NB and SB LT movements.

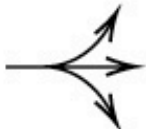
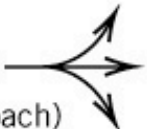
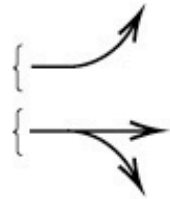
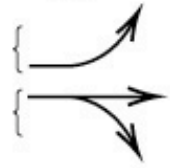
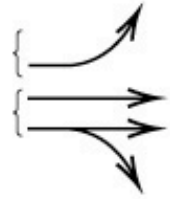
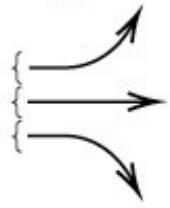
Step 2: Lane Grouping

Lane groups:

Movements from the same lane as one lane group

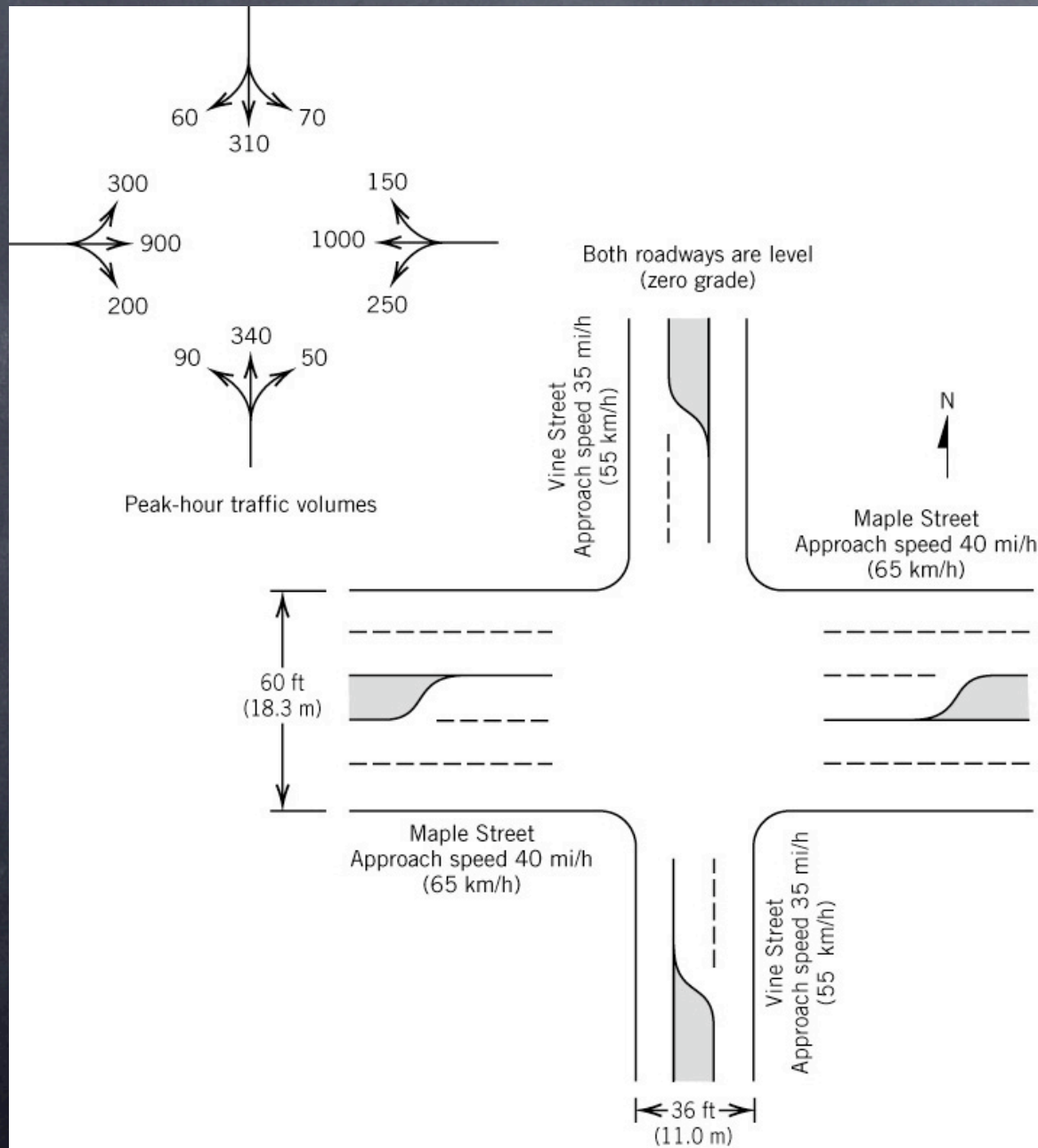
Exclusive turn lane(s) treated as separate lane group.

Judgment for shared movement lane(s)

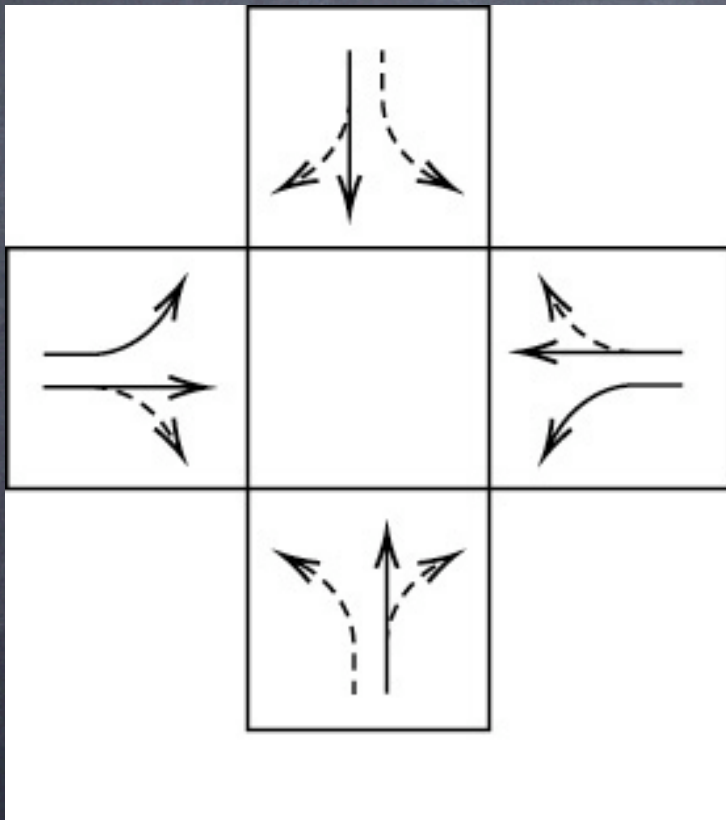
Number of lanes	Movements by lane	Number of possible lane groups
1	LT + TH + RT 	① (Single-lane approach) 
2	EXC LT  TH + RT 	② 
2	LT + TH  TH + RT 	①  or ② 
3	EXC LT  TH  TH + RT 	②  or ③ 

Example 7.7: determine lane groups

Mannering Kilareski and Washburn



Solution



Here, Exclusive LT is a lane group,
Permitted LT is also a lane group

Step 3: determine critical lane groups

- For any combination of lane group movements during a particular phase, one of these lane groups will control the necessary green time. This lane group is referred as "critical lane group".
- The lane group with highest traffic intensity v/s
- Allocation of green time for each phase is based on the v/s ratios

v/s ratios

Table 7.1 Saturation Flow Rates for Three-Phase Design at Intersection of Maple Street and Vine Street

Phase 1	Phase 2	Phase 3
EB L: 1750 veh/h	EB T/R: 3400 veh/h	SB L: 450 veh/h NB L: 475 veh/h
WB L: 1750 veh/h	WB T/R: 3400 veh/h	SB T/R: 1800 veh/h NB T/R: 1800 veh/h

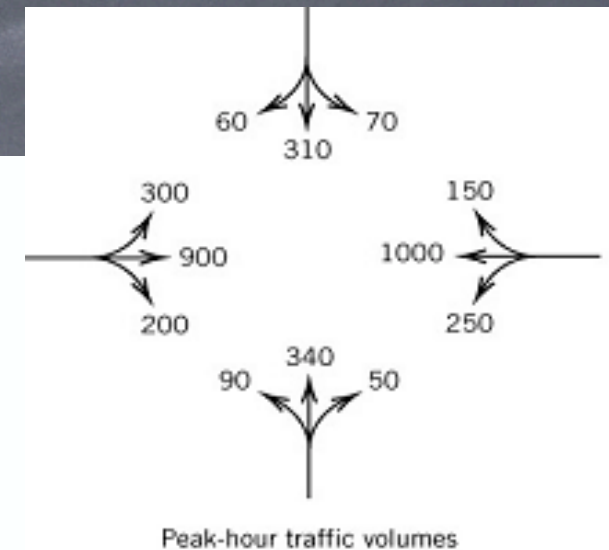
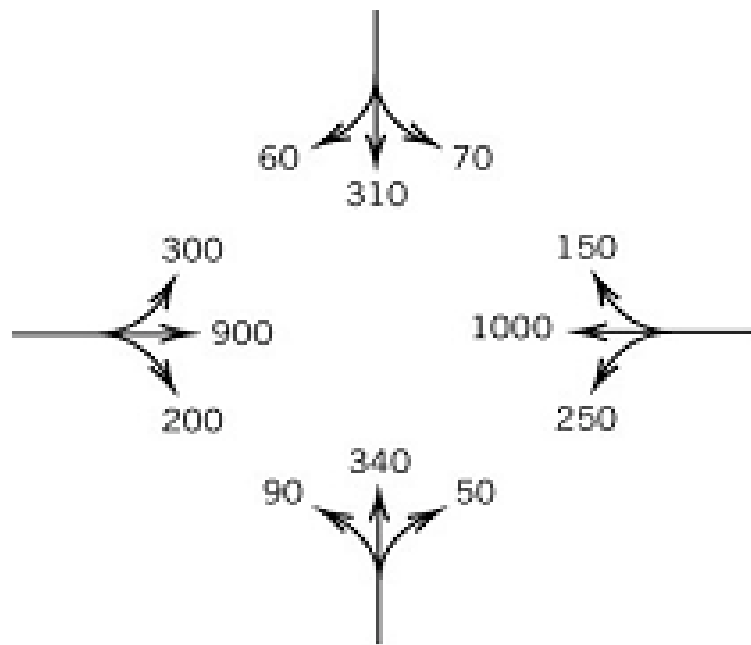


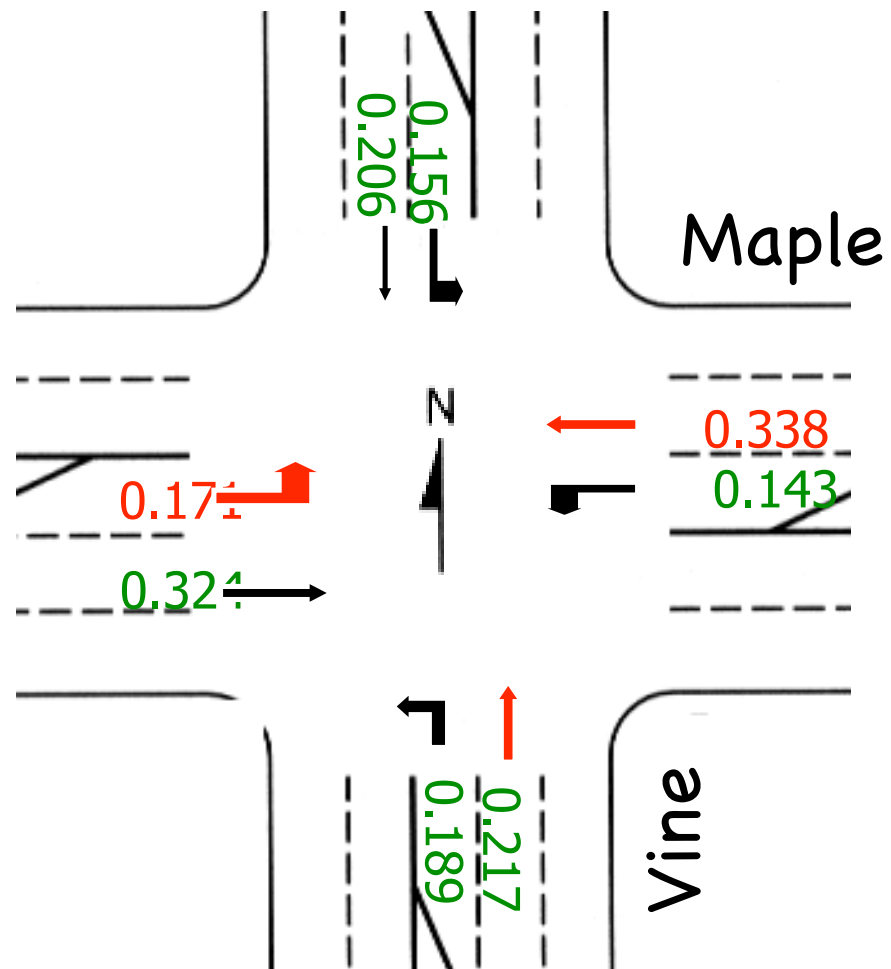
Table 7.2 Flow Ratios and Critical Lane Groups for Three-Phase Design at Intersection of Maple Street and Vine Street

Phase 1	Phase 2	Phase 3
EB L: $\frac{300}{1750} = 0.171 \checkmark$	EB T/R: $\frac{1100}{3400} = 0.324$	SB L: $\frac{70}{450} = 0.156$ NB L: $\frac{90}{475} = 0.189$
WB L: $\frac{250}{1750} = 0.143$	WB T/R: $\frac{1150}{3400} = 0.338 \checkmark$	SB T/R: $\frac{370}{1800} = 0.206$ NB T/R: $\frac{390}{1800} = 0.217 \checkmark$

Critical v/s



Peak-hour traffic volumes



Sum of critical v/s and total lost time

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

where

Y_c = sum of flow ratios for critical lane groups,
 $(v/s)_{ci}$ = flow ratio for critical lane group i , and
 n = number of critical lane groups.

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

where

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

Minimal Necessary Cycle Length

$$C_{\min} = \frac{L * X_c}{X_c - \sum_{i=1}^n Y_i}$$

C = cycle length (minimum)
(round-up to nearest 5 sec. int.)

X_c = critical v/c ratio

Step 4: Calculate Cycle Length

Webster's Delay Formula:

$$C = [(1.5 * L) + 5] / \left(1.0 - \sum_{i=1}^n Y_i \right)$$

C = cycle length (optimal)
(round-up to nearest 5 sec. int.)

L = Lost Time / Cycle {seconds}
= sum total yellow + sum all red

$Y_i = \frac{\sum \text{critical lane volume \{vph\}}}{\text{saturation flow \{vph\}}}$

Cycle Length

$$C_{opt} = [(1.5 * L) + 5] / \left(1.0 - \sum_{i=1}^n Y_i \right)$$

$$= [1.5 * 4 * 3 + 5] / [1.0 - (0.171 + 0.338 + 0.217)]$$

$$= 83.9$$

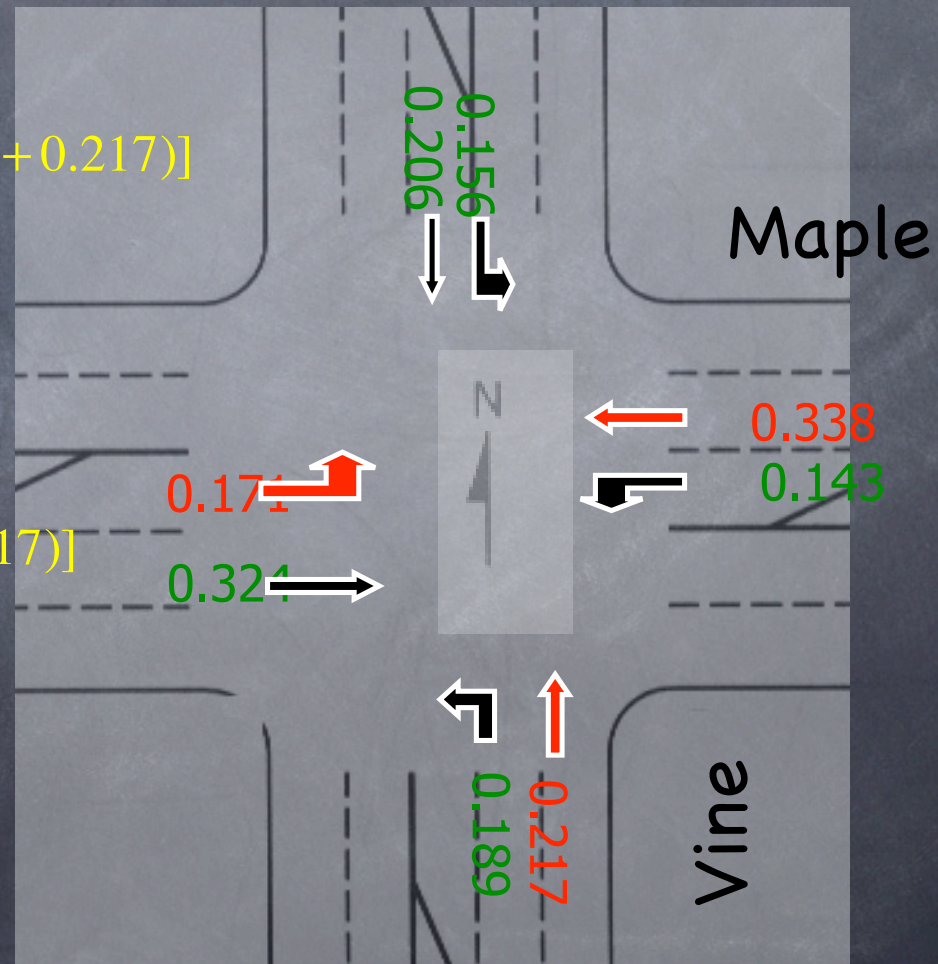
→ 85 s

$$C_{min} = L * X_c / (X_c - \sum Y_i)$$

$$= [12 * 0.9] / [0.9 - (0.171 + 0.338 + 0.217)]$$

$$= 62.1$$

→ 65 s



Step #5: Allocate Green Time

- Distribute green time such that the v/c ratios are equalized for the critical lane groups

$$X_i = \frac{v_i}{c_i} = \frac{v_i}{s_i * g_i / C} = \frac{v_i / s_i}{g_i / C}$$

Equalize $X_i = X_c$

$$g_i = (v_i / s_i) * (C / X_c)$$

g_i : effective green for phase i

v_i / s_i : flow ratio for phase i from the critical lane group

C: cycle length

c_i : capacity for phase i

X_c : degree of saturation for the intersection

X_i : v/c ratio (degree of saturation) for phase i

$$\sum g_i = \sum (v_i / s_i) * (C / X_c) = C - L$$

$$X_c = \sum (v_i / s_i) * \frac{C}{C - L}$$

Example 7.11

Mannering Kilareski and Washburn

- Determine the green time allocations for the 85-second cycle length in example 7.10 using the method of v/c ratio equalization.

$$X_c = \sum (v_i / s_i) * \frac{C}{C - L}$$

$$= (0.171 + 0.338 + 0.217) * 85 / (85 - 4 * 3)$$

$$= 0.845$$

$$g_i = (v_i / s_i) * (C / X_c)$$

$$g_1 = 0.171 * 85 / 0.845 = 17.2s \rightarrow 17s$$

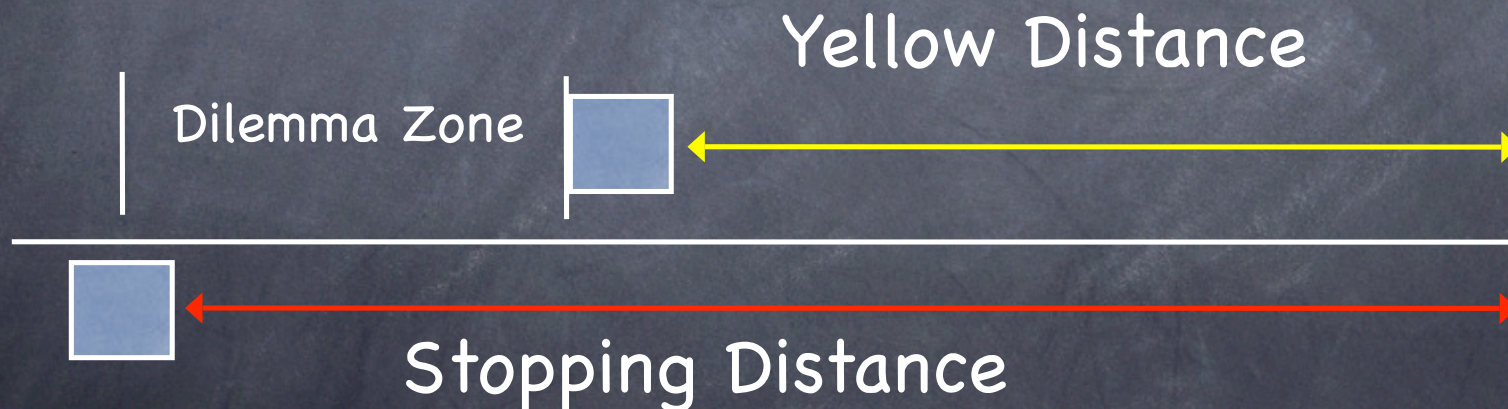
$$g_2 = 0.338 * 85 / 0.845 = 34s$$

$$g_3 = 0.217 * 85 / 0.845 = 21.8s \rightarrow 22s$$

$$g_1 + g_2 + g_3 = 73 = C - L$$

Step 6: Determine Yellow and Clearance Intervals

- “Dilemma Zone” -- driver can neither stop safely nor clear the intersection before the cross street green phase starts!



Determine Yellow & Clearance Intervals (cont.)

Yellow Time (ITE):

$$y = T + \left(\frac{v}{2a + 2Gg} \right)$$

T = the driver perception / reaction time (1.0 sec)

v = speed of the vehicle in ft / s

a = deceleration rate for the vehicle (10.0 ft / s²)

G = the percent grade divided by 100

g = acceleration due to gravity (32.2 ft / s²)

Determine Yellow & Clearance Intervals (cont.)

All-Red time (ITE):

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

AR = the all-red time

w = the width of the cross street (ft)

l = length of the vehicle (20ft)

Determine Yellow & Clearance Intervals (cont.)

Clearance Time:

$$ci = T + \left(\frac{V}{2a + 2Gg} \right) + \frac{(w + l)}{V}$$

Perception-Reaction
Time +
time to stop

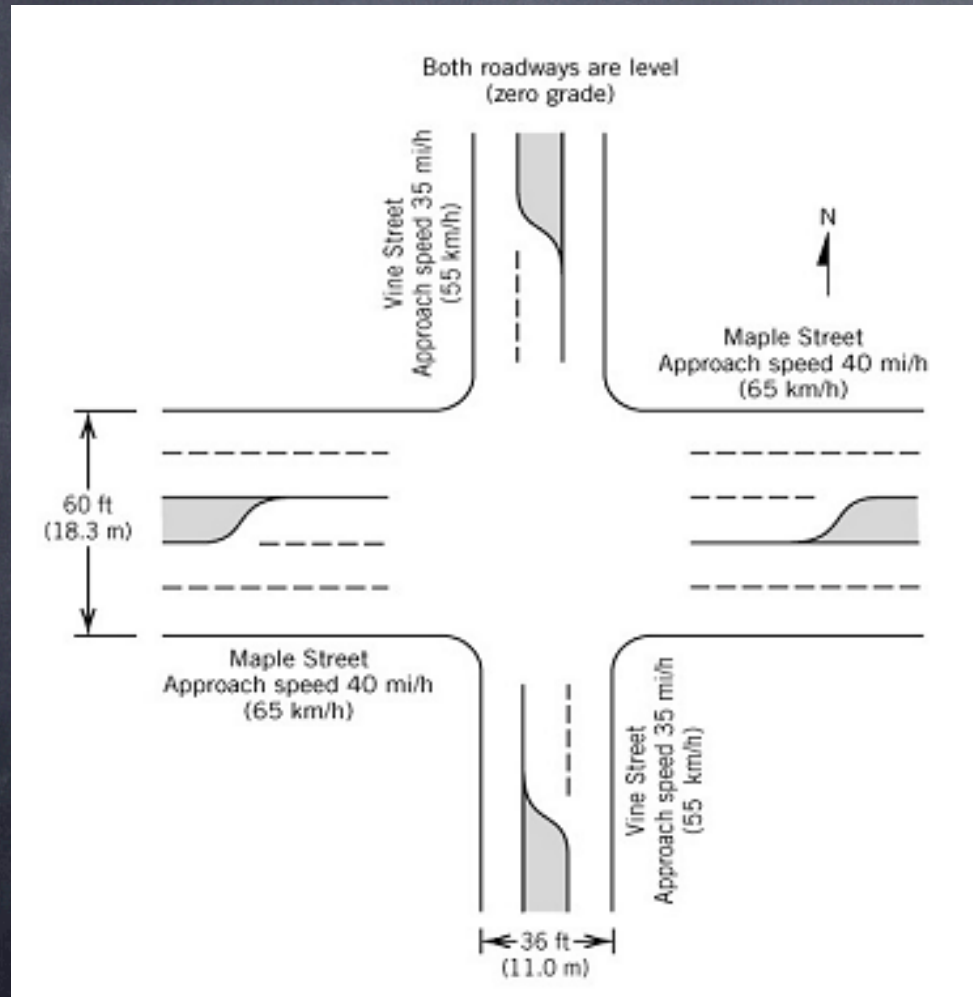
time to clear
intersection

Determine Yellow & Clearance Intervals (cont.)

- Yellow time: Minimum = 3 sec
Maximum = 5 sec
 - 3 sec $\Rightarrow$ 16 to 56 k/h
 - 4 sec $\Rightarrow$ 56 to 80 k/h
 - 5 sec $\Rightarrow$ greater than 80 k/h
- If more than 5 sec of yellow is needed
 $\Rightarrow$ All red must be increased to 2 sec

Clearance Time Example

Maple Street:



$$y = T + \left(\frac{v}{2a + 2Gg} \right)$$

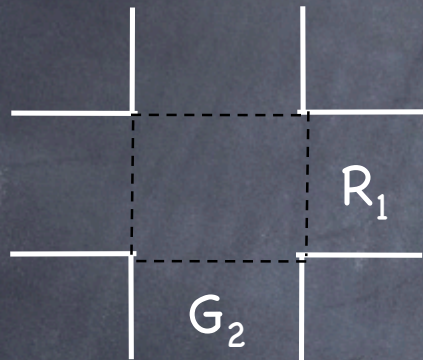
$$y = 1.0 + \left(\frac{40 * 5280 / 3600}{2 * 10} \right)$$

$$y = 3.9 \Rightarrow 4.0 \text{ s}$$

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

$$AR = \frac{36 + 20}{40 * 5280 / 3600} = 1.0 \text{ s}$$

Step 7: Check Pedestrian Crossing Time



$$\text{Walk "Clearance Time"} = \frac{\text{Roadway Width}}{\text{Walking Speed}}$$

(Walking Speed = 4.0ft / sec)

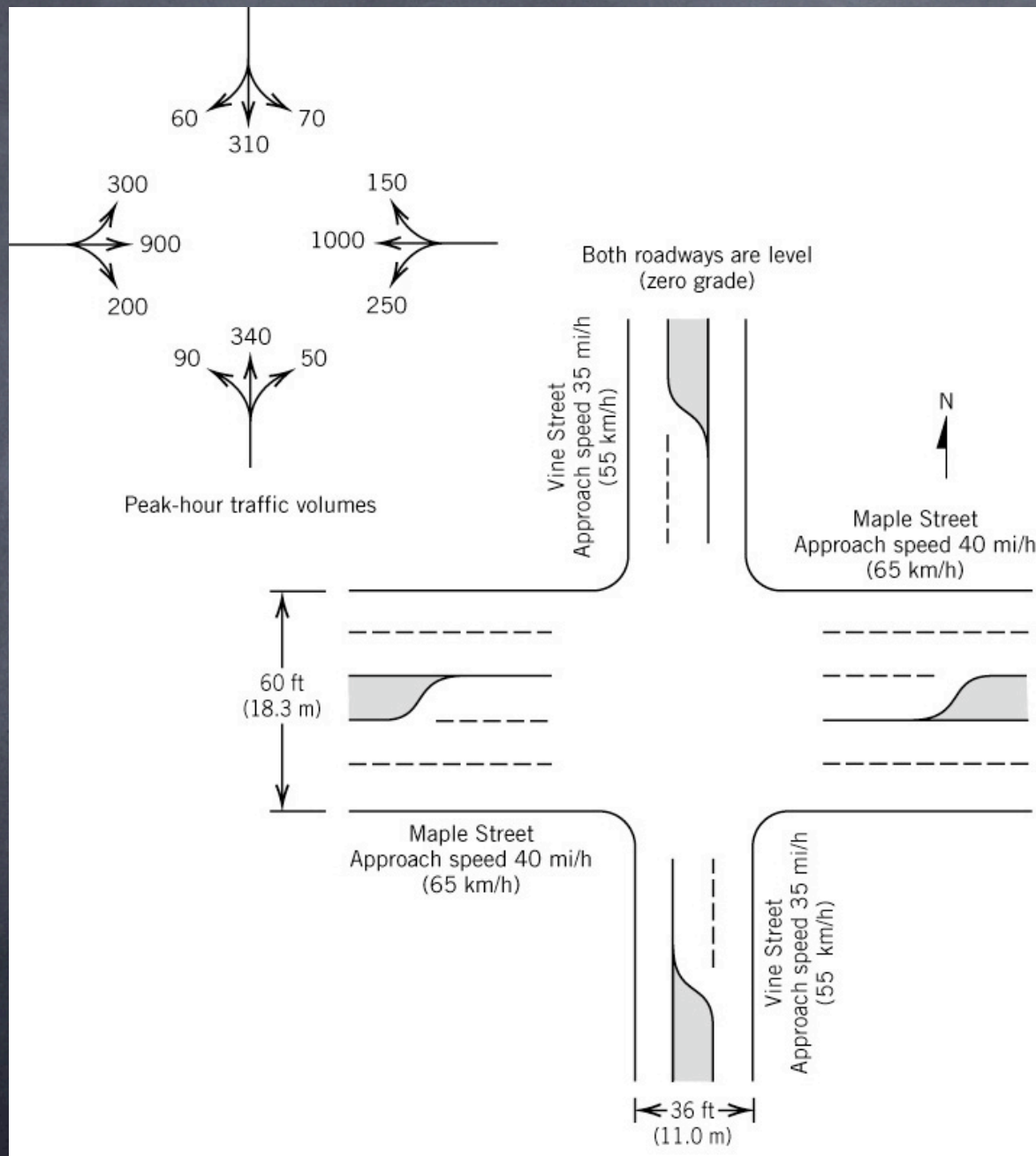
$$G_p = 3.2 + \frac{L}{S_p} + \left(2.7 \frac{N_{ped}}{W_E}\right) \text{ for } W_E > 10 \text{ ft}$$

W_E : effective crosswalk width

N_{ped} : number of pedestrians crossing

If Min. Ped Grn > Grn for $\phi \implies$ Grn for ϕ must be increased (also increase total cycle length)

Signal Timing Example



Traffic Signal Timing Example

1. Determine phasing for signal:

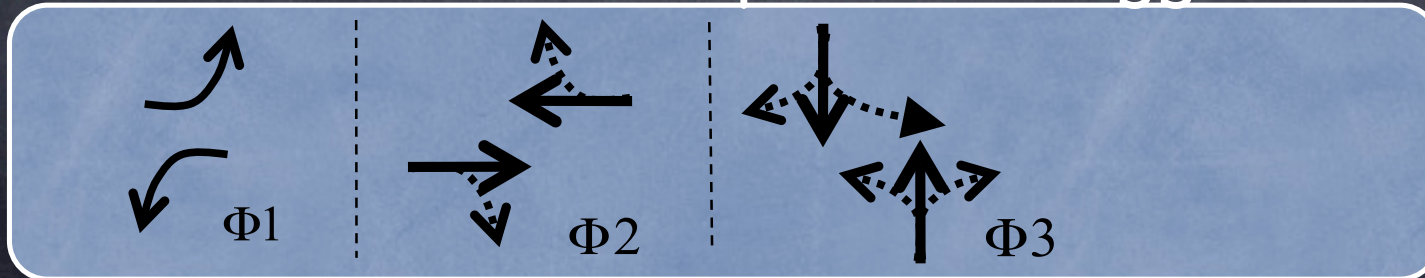
Eastbound left = 300 veh

Westbound thru + rt = 1150 veh

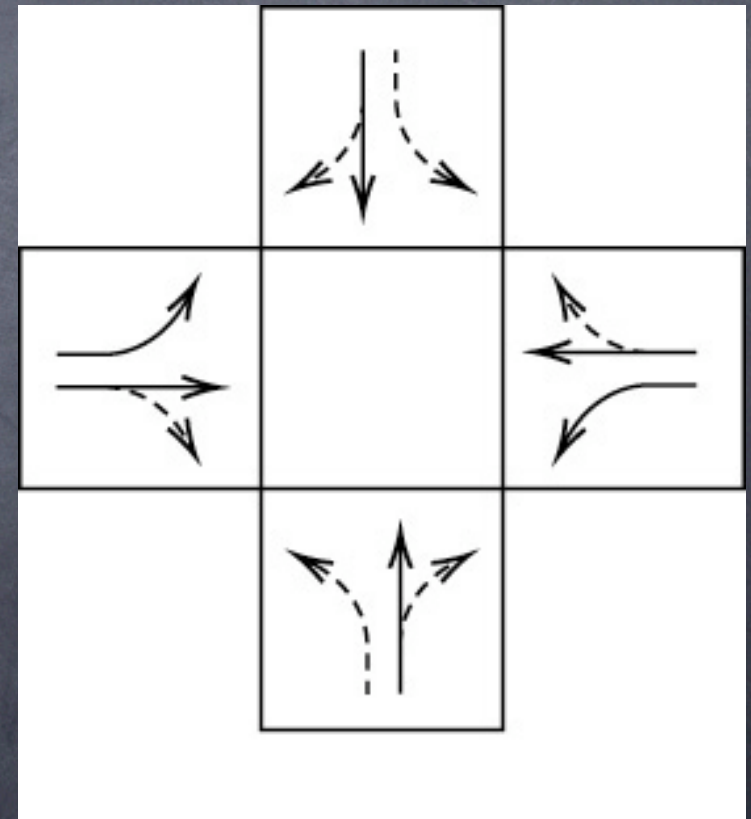
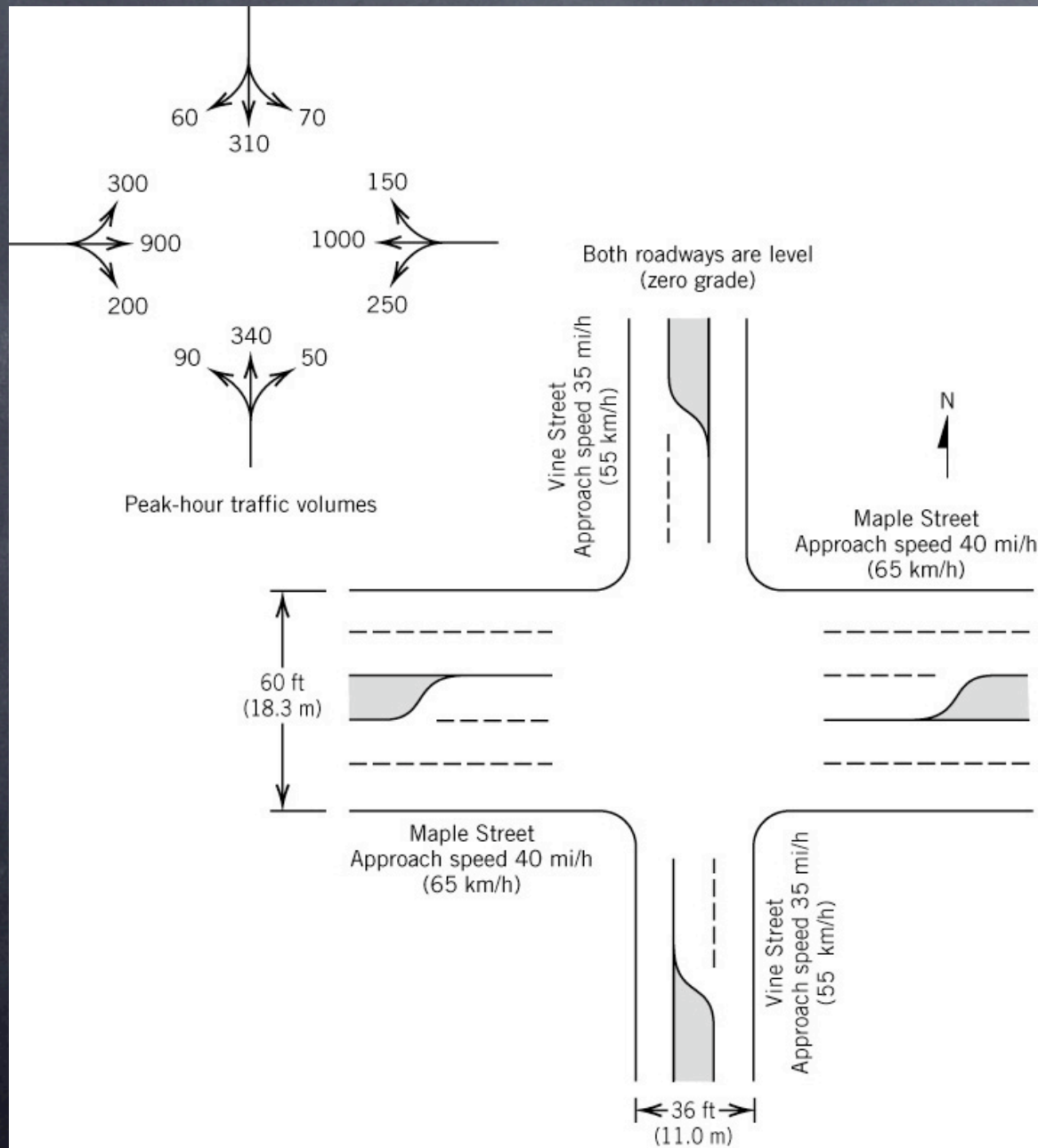
North-South approach volumes are greater than 90,000

300 veh / hr  1150 veh / hr
(in peak hr)

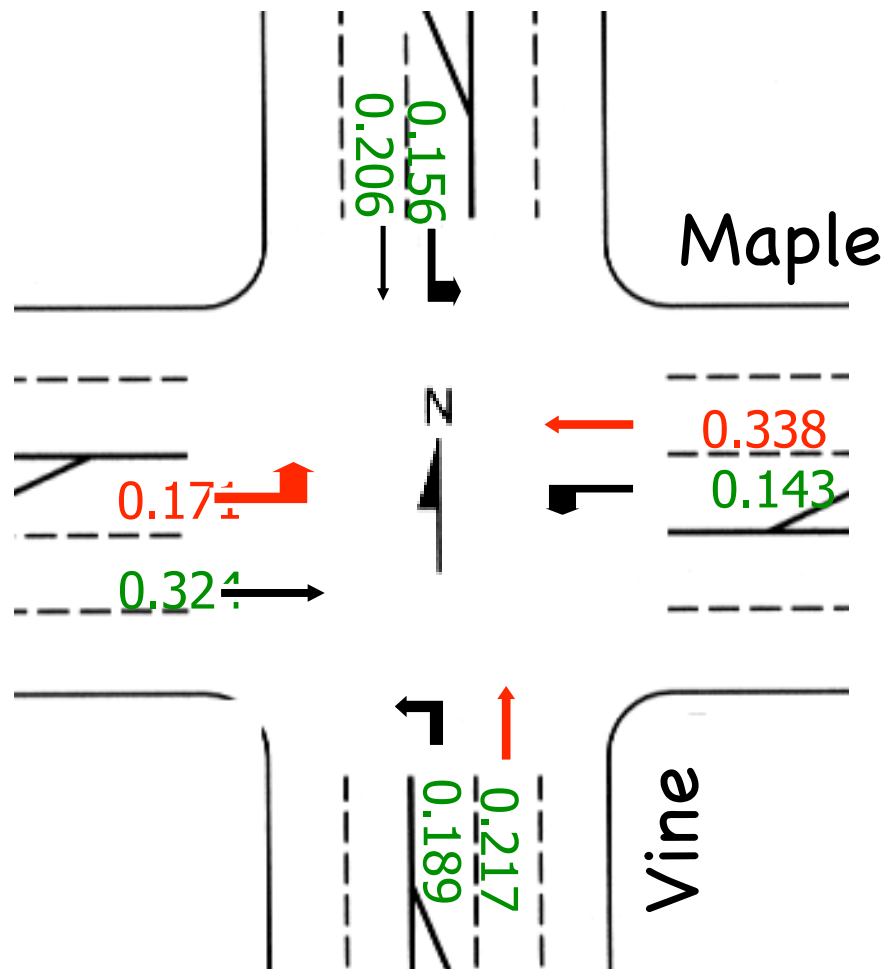
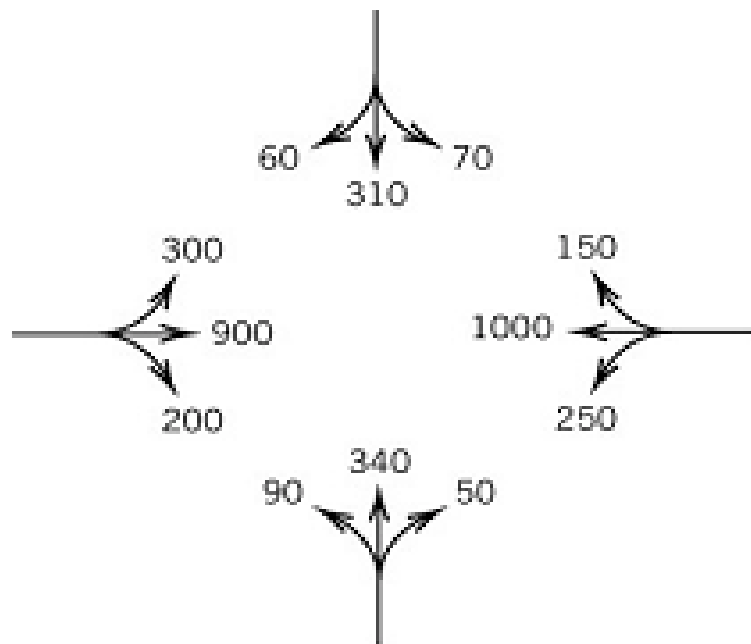
Therefore, left turn phase is suggested.



Step #2: determine lane groups



Step #3: Critical Lane Group v/s ratio



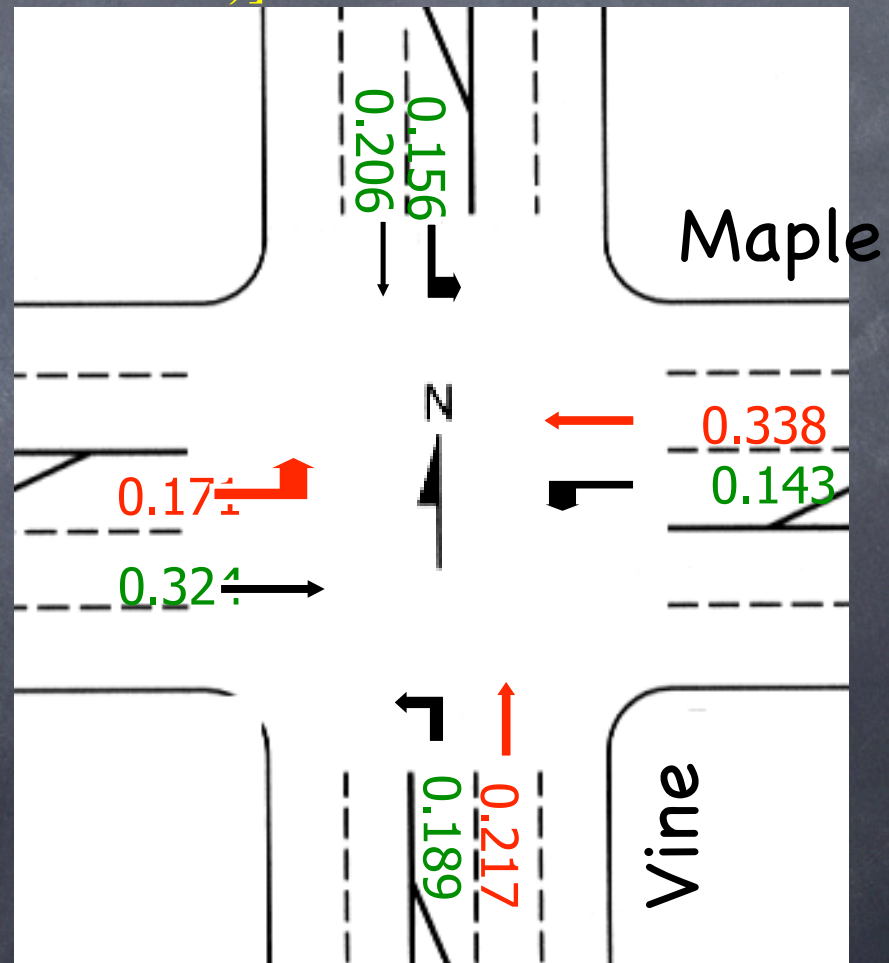
Step #4: Cycle Length

$$C_{opt} = [(1.5 * L) + 5] / \left(1.0 - \sum_{i=1}^n X_i \right)$$

$$= [1.5 * 4 * 3 + 5] / [1.0 - (0.171 + 0.338 + 0.217)]$$

$$= 83.9$$

$$\rightarrow 85s$$



Step #5: Allocate Green Time

C= 85-second cycle length

$$X_c = \sum (v_i / s_i) * \frac{C}{C - L}$$

$$= (0.171 + 0.338 + 0.217) * 85 / (85 - 4 * 3)$$

$$= 0.845$$

$$g_i = (v_i / s_i) * (C / X_c)$$

$$g_1 = 0.171 * 85 / 0.845 = 17.2s - > 17$$

$$g_2 = 0.338 * 85 / 0.845 = 34s - > 34$$

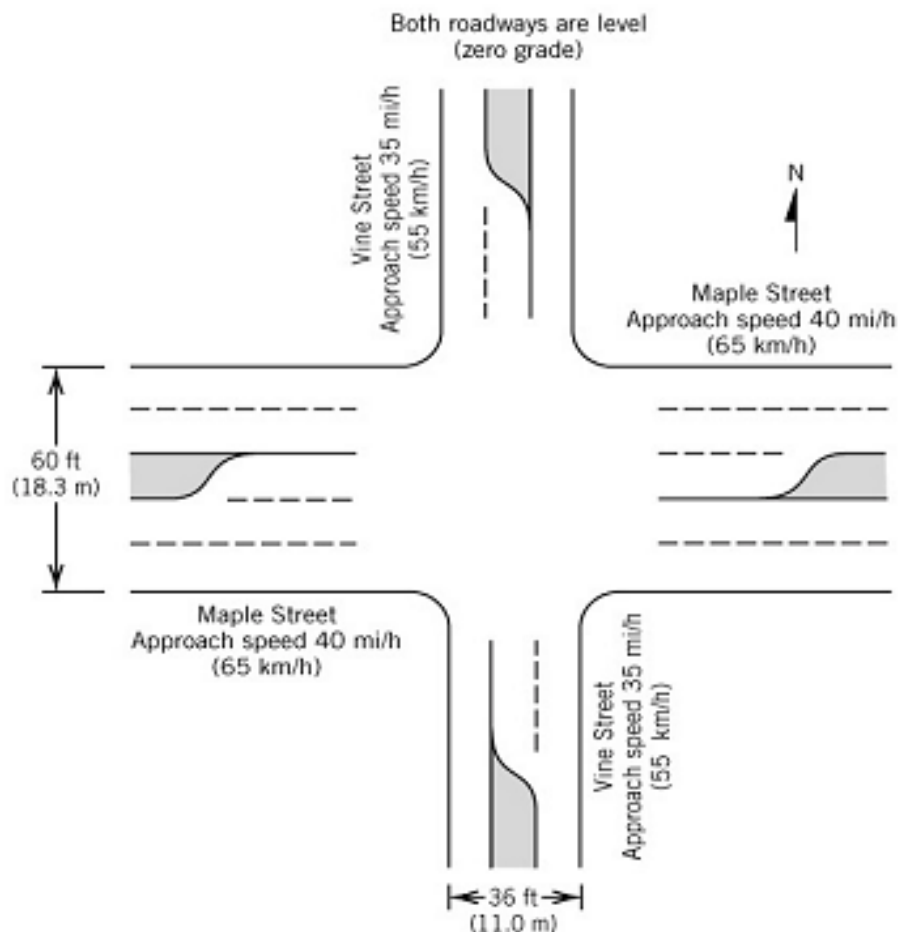
$$g_3 = 0.217 * 85 / 0.845 = 21.8s - > 22$$

$$g_1 + g_2 + g_3 = 73 = C - L$$

Step #6: Clearance Time

Example

Maple Street:



$$y = T + \left(\frac{v}{2a + 2Gg} \right)^{\frac{1}{2}}$$

$$y = 1.0 + \left(\frac{40 * 5280 / 3600}{2 * 10} \right)^{\frac{1}{2}}$$

$$y = 3.9 \Rightarrow 4.0 \text{ sec}$$

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

$$AR = \frac{36 + 20}{40 * 5280 / 3600} = 1.0 \text{ sec}$$

Step#6 (cont.)

- Vine Street

$$y = T + \left(\frac{v}{2a + 2Gg} \right)$$
$$y = 1.0 + \left(\frac{35 * 5280 / 3600}{2(10)} \right)$$

$$y = 3.6 \longrightarrow y = 4.0 \text{ sec}$$

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

$$AR = \frac{60 + 20}{35 * 5280 / 3600}$$

$$AR = 1.6 \text{ say}$$

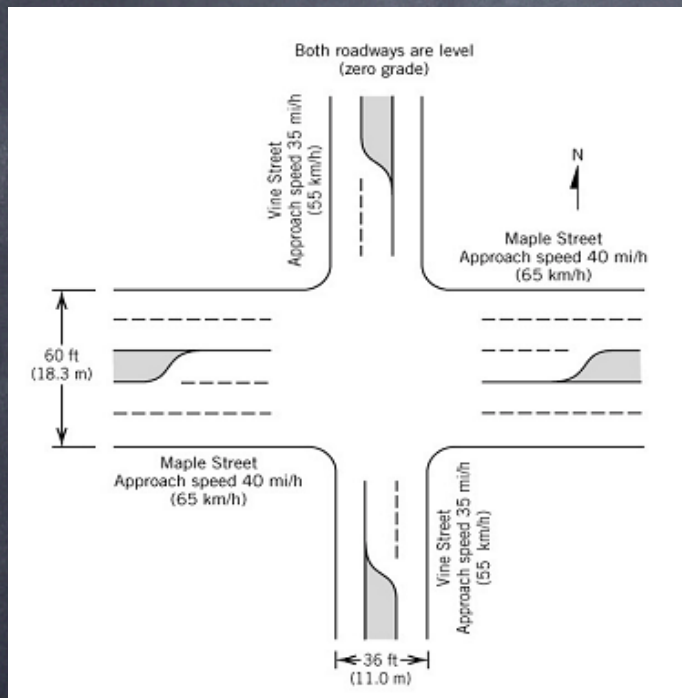
→

$$AR = 2.0 \text{ sec}$$

Yellow and All Red Time (summary):

	Vine	Maple (Lt)	Maple	
Yellow	4	4	4	
All Red	2	1	1	
Total	6	5	5	16

Step #7: Check Pedestrian Time



Maple

$$Ped\ Grn = 3.2 + \left(\frac{36}{4.0} \right) + 0.27 * 15 = 16 \text{ sec}$$

Φ2: 34 sec of Green is OK

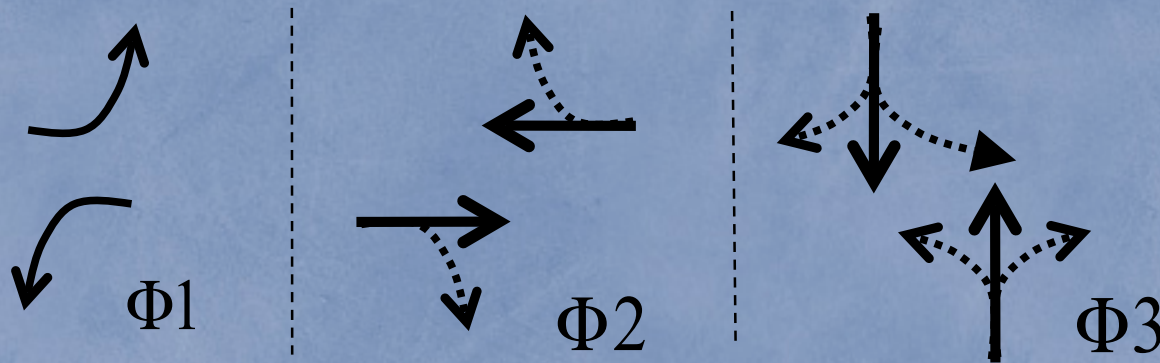
Vine

$$Ped\ Grn = 3.2 + \left(\frac{60}{4.0} \right) + 0.27 * 15 = 22 \text{ sec}$$

Assume $N_{ped} = 15$.

Φ3: 22 sec of Green is OK

Step 8: Signal Timing



Green Display = Effective Green + lost time - Y - AR

$$\Phi 1: G = 17 + 4 - 4 - 1 = 16, Y=4, AR=1$$

$$\Phi 2: G = 34 + 4 - 4 - 1 = 33, Y=4, AR=1$$

$$\Phi 3: G = 22 + 4 - 4 - 2 = 20, Y=4, AR=2$$

$$C = 85 \text{ s}$$

Questions

- Questions?

Abbreviations

Key Terms

Variables