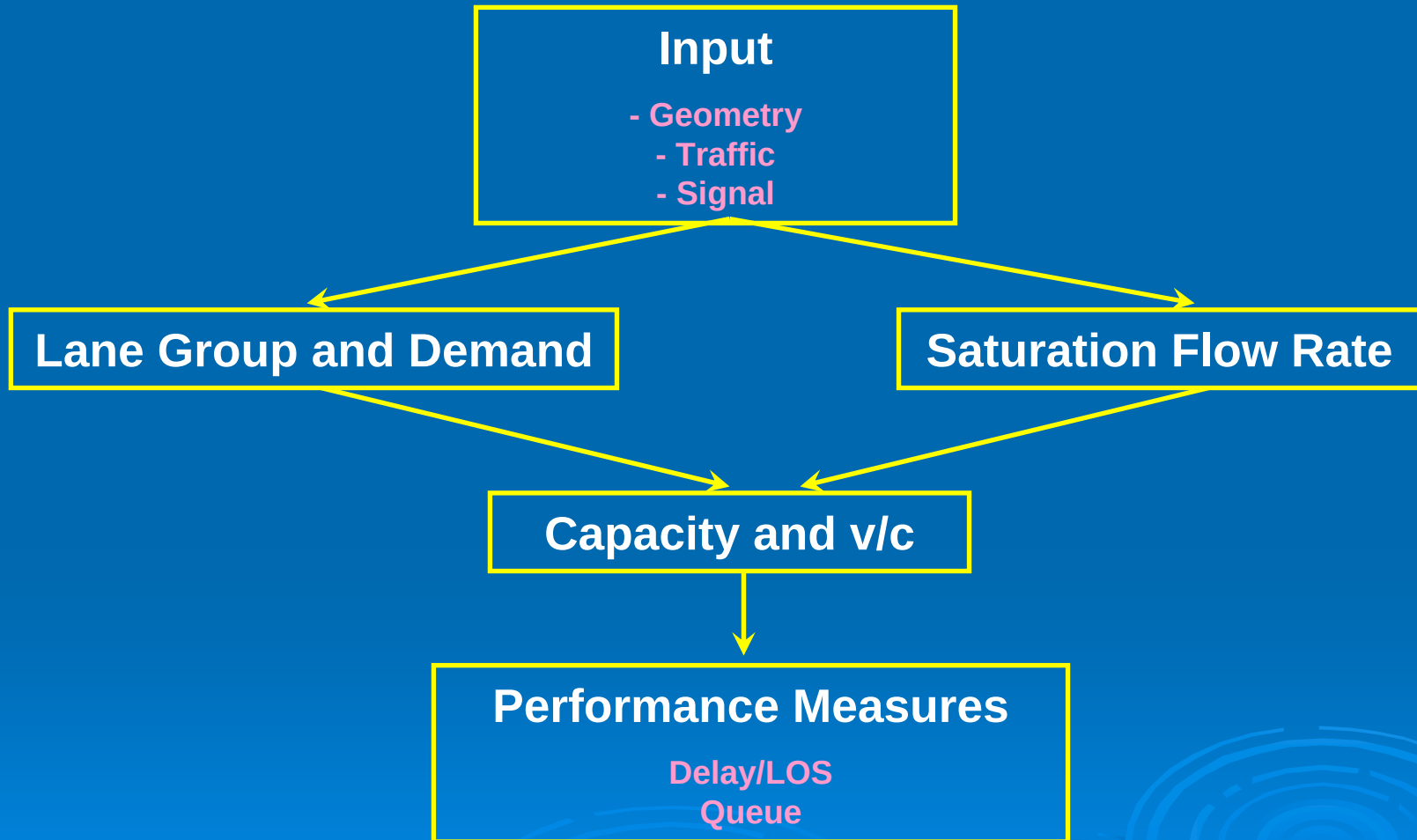


Topic 5

(Chapters 21, 22)

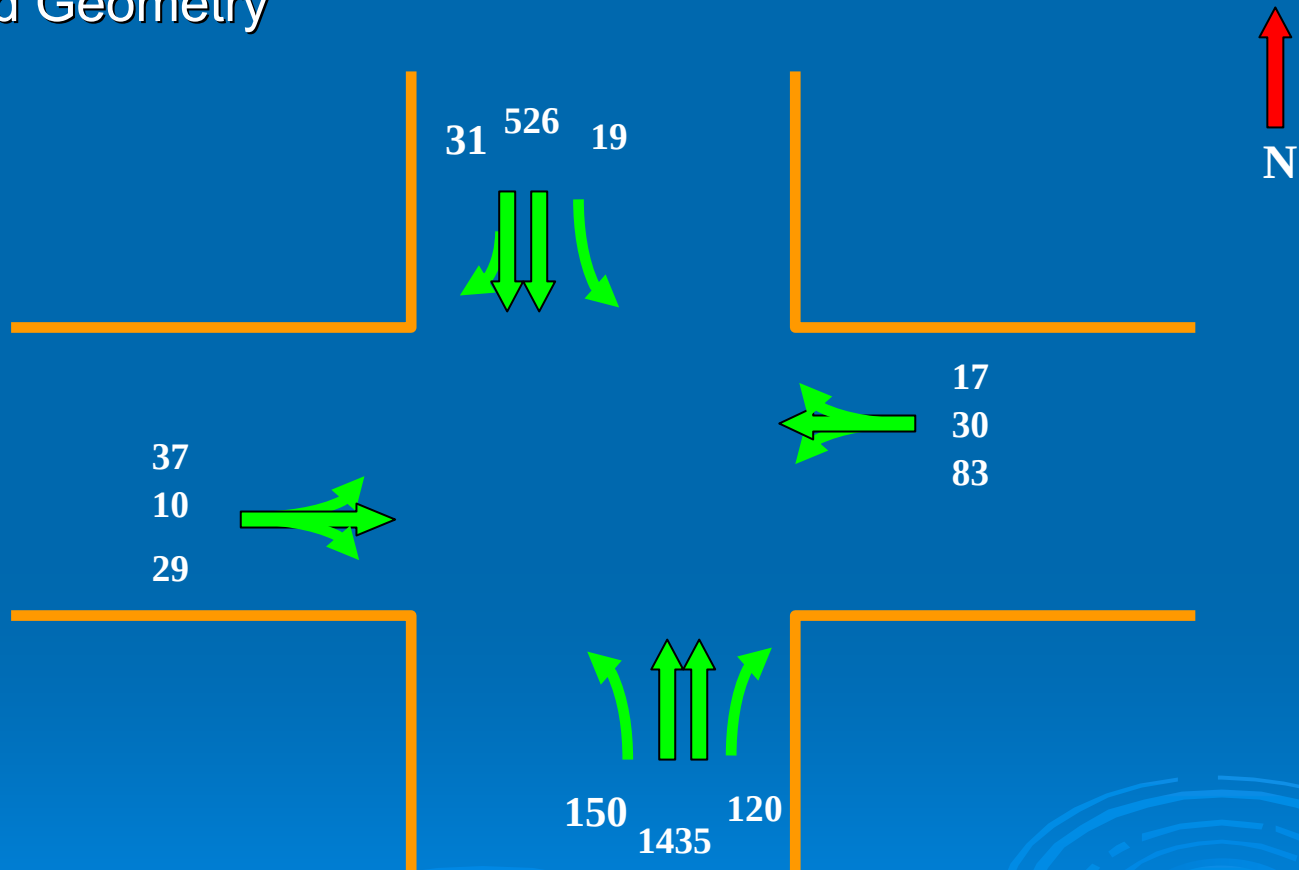
Analysis of Signalized Intersections

HCM - Capacity and LOS



HCM Procedure - Example

Volume and Geometry



HCM Procedure - Example

➤ Other information

- Area type: non-CBD
- Lane width: NS Left-turn lanes: 11 ft, all other 12 ft
- Grade: NB: +2%; SB: -2%
- Length of turn bays: LT: 150 ft; RT: 300 ft
- Parking: No

Geometry

-
- Base saturation flow: 2000 vph
 - PHF: 0.95
 - % HV: NS: 4%; EW: 2%
 - No bus stops
 - Pedestrian: 10/hr on each direction; WALK: 5 s; FDW: NS: 15 s; EW: 20 s
 - Arrival type: EW: 3; NS: 5

Traffic

-
- Protected LT
 - Phases: 1-SBL, 2-NBT, 4-EW, 5-NBL, 6-SBT
 - Cycle length: 100 s
 - Yellow: 4 sec
 - All-red: 1 sec
 - Lost time per phase: 4 s
 - No RTOR

Signal Timing

Lanes, Volumes, Timings

17: EW & NS

12/6/2004

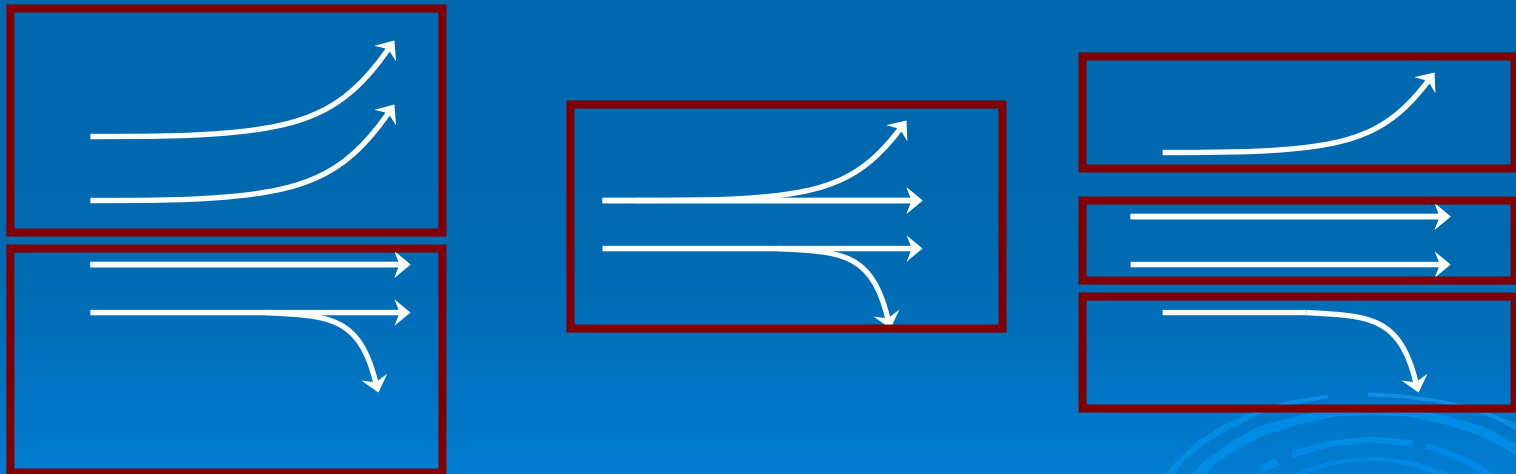


Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Lane Width (ft)	12	12	12	12	12	12	11	12	12	11	12	12
Grade (%)		0%			0%			2%			-2%	
Storage Length (ft)	0		0	0		0	150		300	150		300
Storage Lanes	0		0	0		0	1		1	1		0
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Turning Speed (mph)	15		9	15		9	15		9	15		9
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	0.95	0.95
Satd. Flow (perm)	0	1547	0	0	1535	0	1748	3617	1618	1784	3661	0
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)		31			7				126		8	
Volume (vph)	37	10	29	83	30	17	150	1435	120	19	526	31
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Heavy Vehicles (%)	2%	2%	2%	2%	2%	2%	4%	4%	4%	4%	4%	4%
Adj. Flow (vph)	39	11	31	87	32	18	158	1511	126	20	554	33
Lane Group Flow (vph)	0	81	0	0	137	0	158	1511	126	20	587	0
Turn Type	Perm			Perm			Prot		Perm	Prot		
Protected Phases		4			8		5	2		1	6	
Permitted Phases	4			8					2			
w/c Ratio		0.18			0.33		0.56	0.79	0.14	0.14	0.36	
Control Delay		19.7			30.3		47.5	22.8	2.5	45.3	18.5	
Queue Delay		0.0			0.0		0.0	0.0	0.0	0.0	0.0	
Total Delay		19.7			30.3		47.5	22.8	2.5	45.3	18.5	
LOS		B			C		D	C	A	D	B	

HCM Conceptual Framework

➤ Lane group

- Basic entity for starting the analysis (HCM 2000)
- Exclusive turn lane(s) is considered as a group
- Shared through/turn lanes are considered as a group



Saturation Flow Rate

- Saturation headway and Saturation flow rates
 - saturation headway, h_i
 - saturation flow rate, s_i

$$s = s_0 N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{RT} f_{LT} f_{Rpb} f_{Lpb}$$

Page 599 ~ 605

Signal Timing and Capacity

- v/s ratio as a measure of demand
- Signal timing: distribute green times among movements (phases)
- Capacity, c_i

$$c_i = s_i \left(\frac{g_i}{C} \right)$$

V/C Ratio, Delay, and LOS

- v/c ratio (degree of saturation), X_i

$$X_i = \frac{v_i}{c_i} = v_i \frac{C}{s_i g_i} = \frac{(v/s)_i}{(g/C)_i}$$

➤ LOS	Delay (sec/veh)
A	≤10
B	10-20
C	20-35
D	35-55
E	55-80
F	>80

Class Exercise

You can either work by yourself or with other members of your group to complete the class exercise. You are required to conduct the intersection LOS analyses for the example shown earlier in the lecture. You need to use both Synchro and TRAFFIX software to complete the analyses, and answer the following questions (assume *fixed time* signal control for your analyses).

1. Compare and comment on the difference between software inputs. For example, lost time needs to be manually input in TRAFFIX, while Synchro provides defaults.
2. What are the optimal cycle lengths that both software recommend?
3. What are the LOS results from both software?
4. What are the signal timing results from both software?
5. What are the v/c ratios from both software? Can you identify the critical phases/movements from the software outputs? Which software do you believe uses Webster's methodology to derive the signal timing?
6. Does the software report delay, v/c, and LOS based on lane groups?
7. How can you obtain the saturation flow rates for each lane group based on the software outputs? Does both software yield similar saturation flow rates?
8. How can you obtain the capacities for each lane group or movement based on software outputs? How can you verify they are correct?

Adjustment Factors for Saturation Flow Rate

- f_w – lane width
- f_{HV} – heavy vehicles
- f_g – grade
- f_p – parking
- f_{bb} – bus stop and blockage
- f_a – area type (CBD or other)
- f_{LU} – lane utilization
- f_{RT} – right turn
- f_{LT} – left turn*
- f_{Rpb} – ped/bike interference with right turn
- f_{Lpb} – ped/bike interference with left-turn turn

Left-turn Adjustment Factor, f_{LT}

- *Case 1 – exclusive LT lane with protected control
- Case 2 – exclusive LT lane with permitted control
- Case 3 – exclusive LT lane with P/P control
- *Case 4 – shared lane with protected control
- Case 5 – shared lane with permitted control

* Protected LT

$$f_{LT} = 0.95 \quad \text{for exclusive lanes}$$

$$f_{LT} = \frac{1}{1.0 + 0.05P_{LT}} \quad \text{for shared lanes}$$

Example of f_{LT}

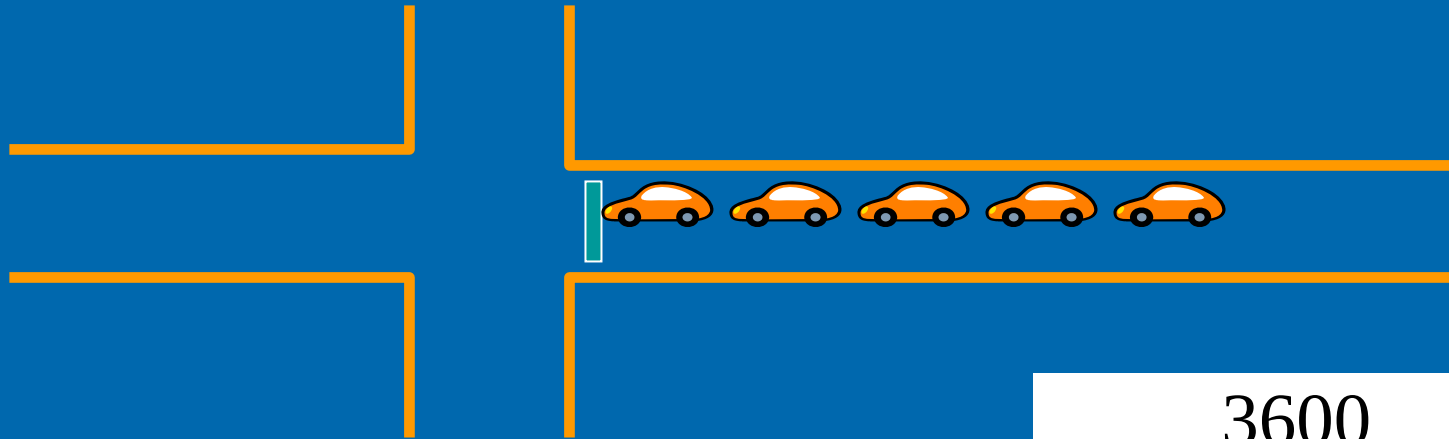
Assume the base saturation flow rate is 2000 vphpl.

- (a) What is the saturation flow rate for an exclusive left-turn lane with protected left-turn controls?
- (b) What is the saturation flow rate for a shared left/through lane on a one-way street?

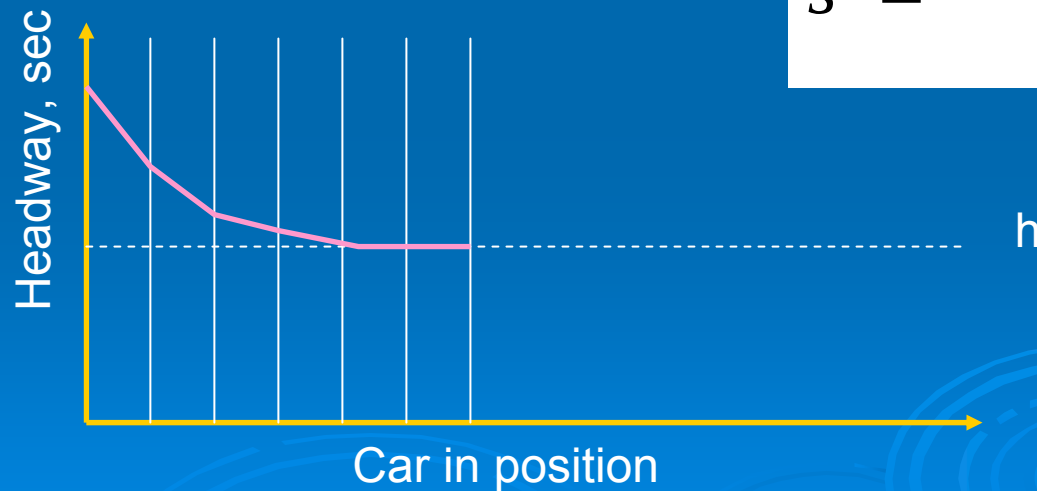
Complexities of f_{LT} with Permitted Control

- The discharge of left-turn vehicles depends on the opposing flow rate. With exclusive LT lanes, it can be modeled based on **gap-acceptance** theory.
- With shared lane(s), a left-turn vehicle waiting for making a turn can block the following through vehicles. Because of the random nature, it is difficult to accurately model.
- The factors considered in the HCM procedure include:
 - Time to clear the standing queue on the opposing approach
 - Time a left-turn vehicle arrived
 - The average flow rate

Field Measurement of Saturation Headway and Saturation Flow Rate



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



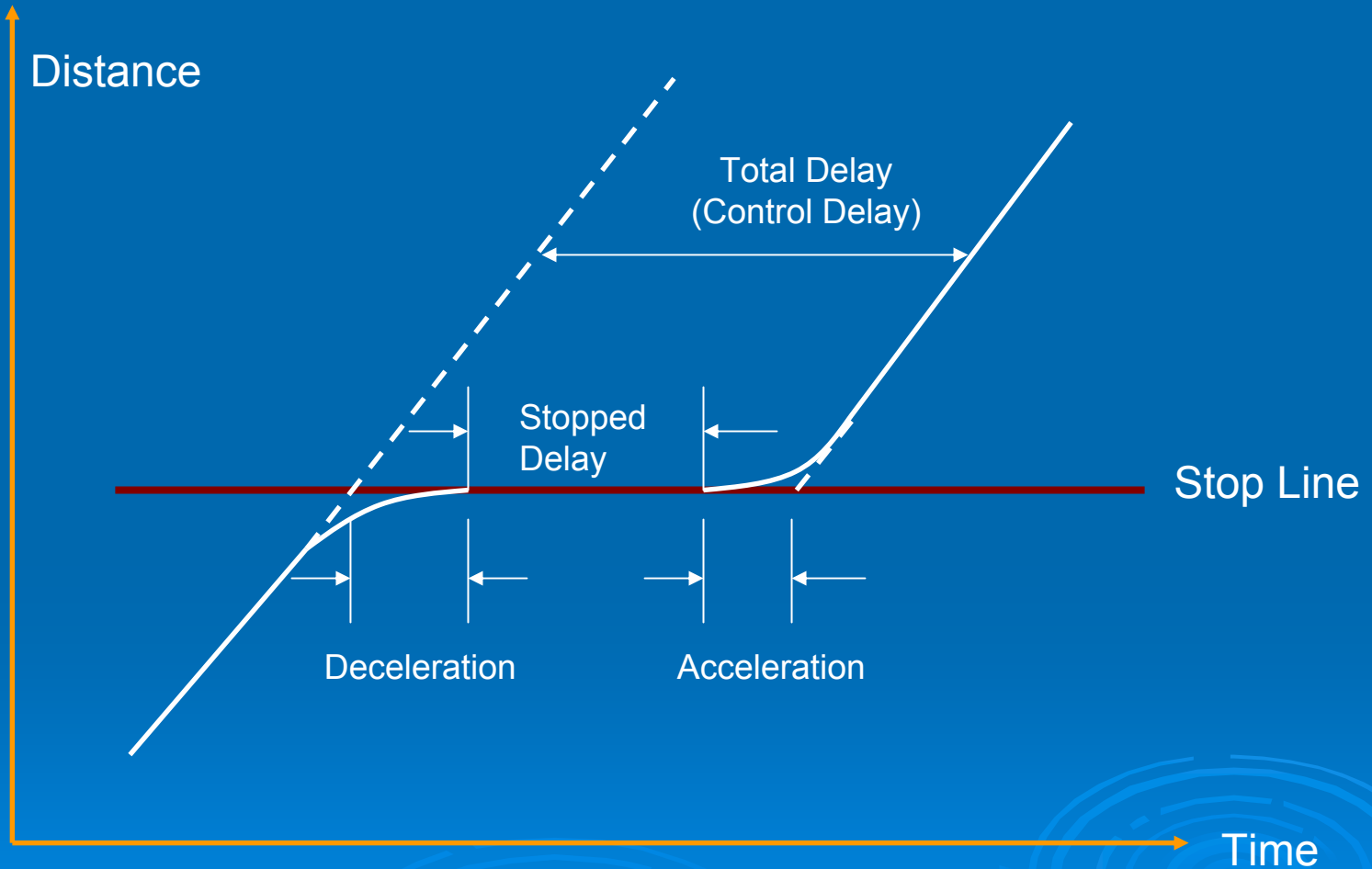
Field Measurement of Saturation Flow Rate

Queue Position	Observed Headways (s) in Cycle No.						Sum of Sat. Headways	No. of Sat. Headways
	1	2	3	4	5	6		
1	3.5	2.9	3.9	4.2H	2.9	3.2	0.0	0
2	3.2	3.0	3.3	3.6	3.5H	3.0	0.0	0
3	2.6	2.3	2.4	3.2H	2.7	2.5	0.0	0
4	2.8H	2.2	2.4	2.5	2.1	2.9H	0.0	0
5	2.5	2.3	2.1	2.1	2.2	2.5	13.7	6
6	2.3	2.1	2.4	2.2	2.0	2.3	13.3	6
7	3.2H	2.0	2.4	2.4	2.2	2.3	14.5	6
8	2.5	1.9	2.2	2.3	2.4	2.0	13.3	6
9	4.5	2.9H	2.7H	1.9	2.2	2.4	12.1	5
10	6.0	2.5	2.4	2.3	2.7H	2.1	12.0	5
11		2.8H	4.0	2.2	2.4	2.0	9.4	4
12		2.5	7.0	2.9H	5.0	2.3	7.7	3
13		5.0		4.1		6.0	0.0	0
14		7.5					0.0	0
15							0.0	0
Sum							96.0	41

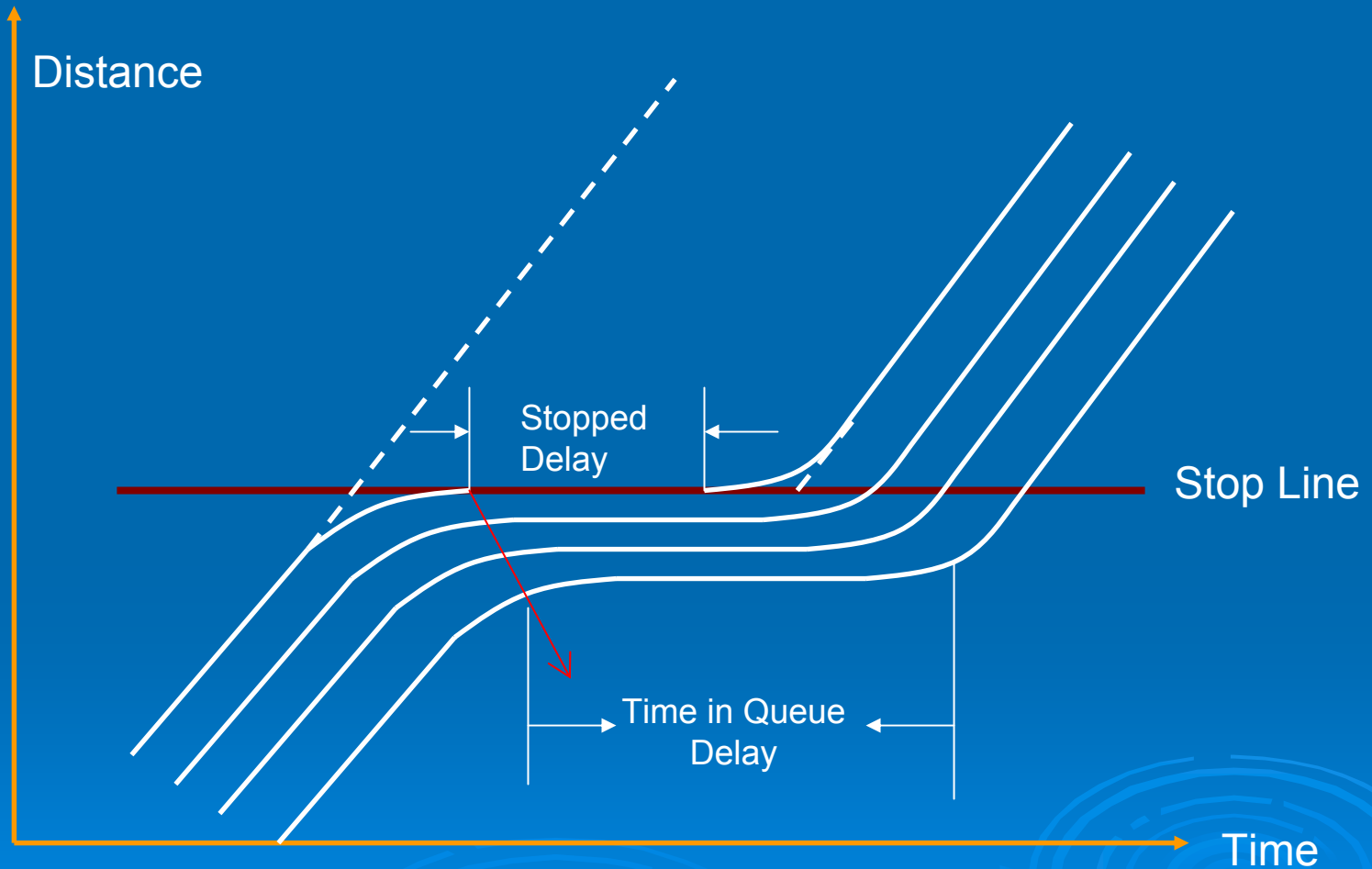
Delay

- **Delay**: the most commonly used performance measure
- Types of Intersection **Delays**
 - Stopped delay
 - Total delay (control delay)
 - Time in queue delay

Delay Studies



Time in Queue Delay



Control Delay Field Measurement

➤ Two observers:

- 1st person counts vehicles in queue based on 20-sec intervals, V_{iq}
- 2nd person counts arriving vehicles, V_T , and stopped vehicles, V_{STOP}

$$d = T_Q + (FVS * CF)$$

$$T_Q = \left(I_s * \frac{\sum V_{iq}}{V_T} \right) * 0.9$$

$$FVS = \frac{V_{STOP}}{V_T}$$

$$V_{SLC} = \frac{V_{STOP}}{N_C N_L}$$

* CF to obtain in Table 9.6 (page 232)

FFS, mph	V_{SLC}		
	≤ 7	8-19	20-30
≤ 37	5	2	-1
37 ~ 45	7	4	2
> 45	9	7	5

Example

Clock Time	Cycle Number	Number of vehicles in Queue, V_{iq}		
		+0 secs	+20 secs	+40 secs
5:00 PM	1	4	7	5
X	2	6	6	5
X	3	3	5	5
X	4	2	6	4
X	5	5	3	3
X	6	5	4	5
x	7	6	8	4
X	8	3	4	3
X	9	2	4	3
X	10	4	3	5
Total		40	50	42
$\Sigma V_{iq} = ??$	$V_T = 120$ vehs	$V_{STOP} = 75$	FFS = 35 mph	$N_L = 2$

The HCM Delay Equation

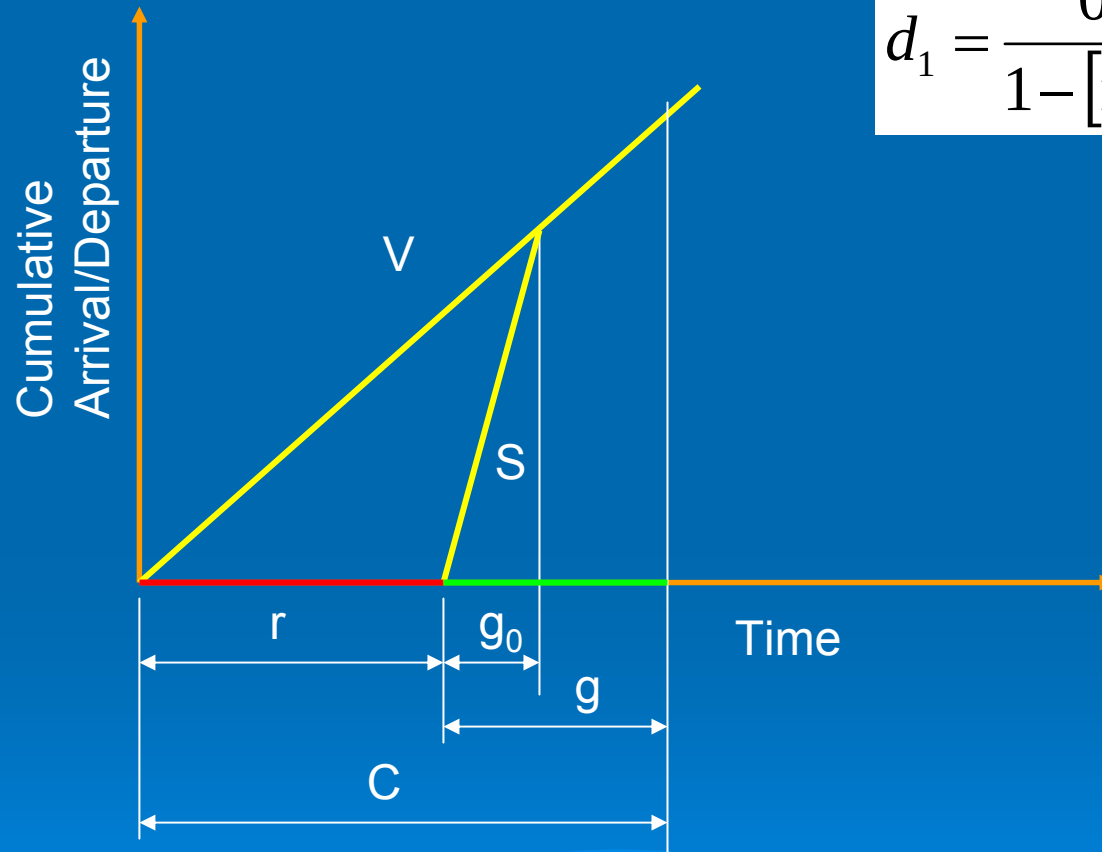
$$d = d_1 PF + d_2 + d_3$$

$$d_1 = \frac{0.5C[1 - g/C]^2}{1 - [\min(1, X) \times g/C]}$$

Uniform Delay

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

Uniform Delay



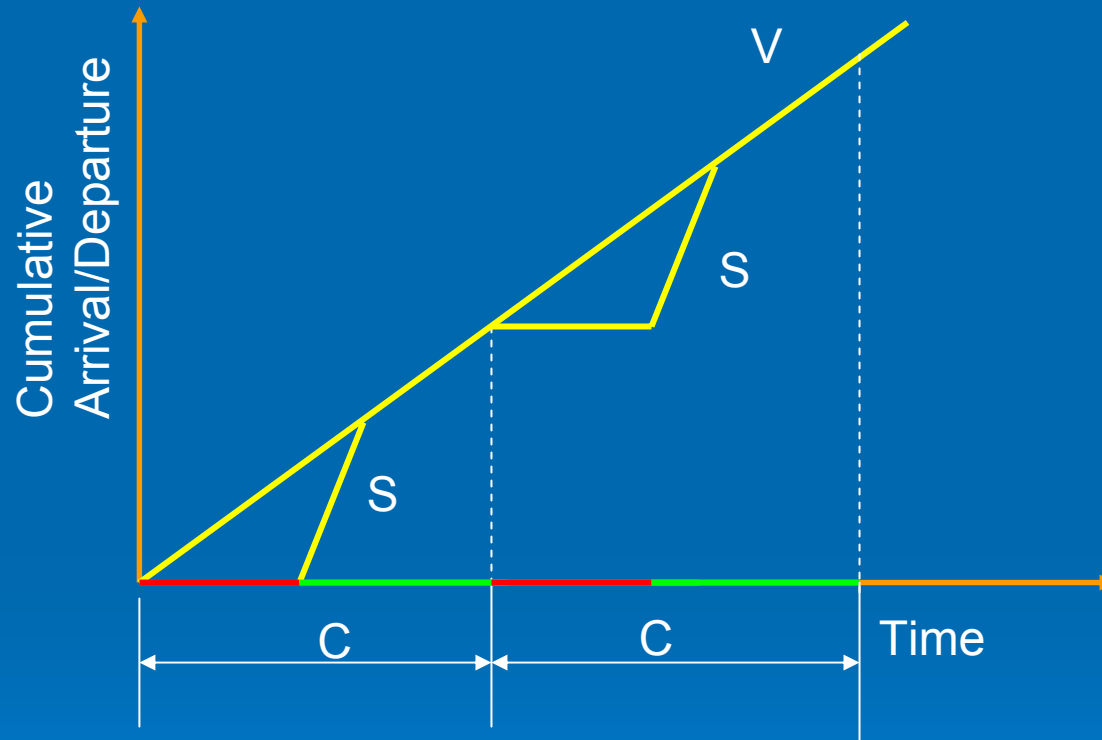
$$d_1 = \frac{0.5C[1 - g/C]^2}{1 - [\min(1, X) \times g/C]}$$

Questions

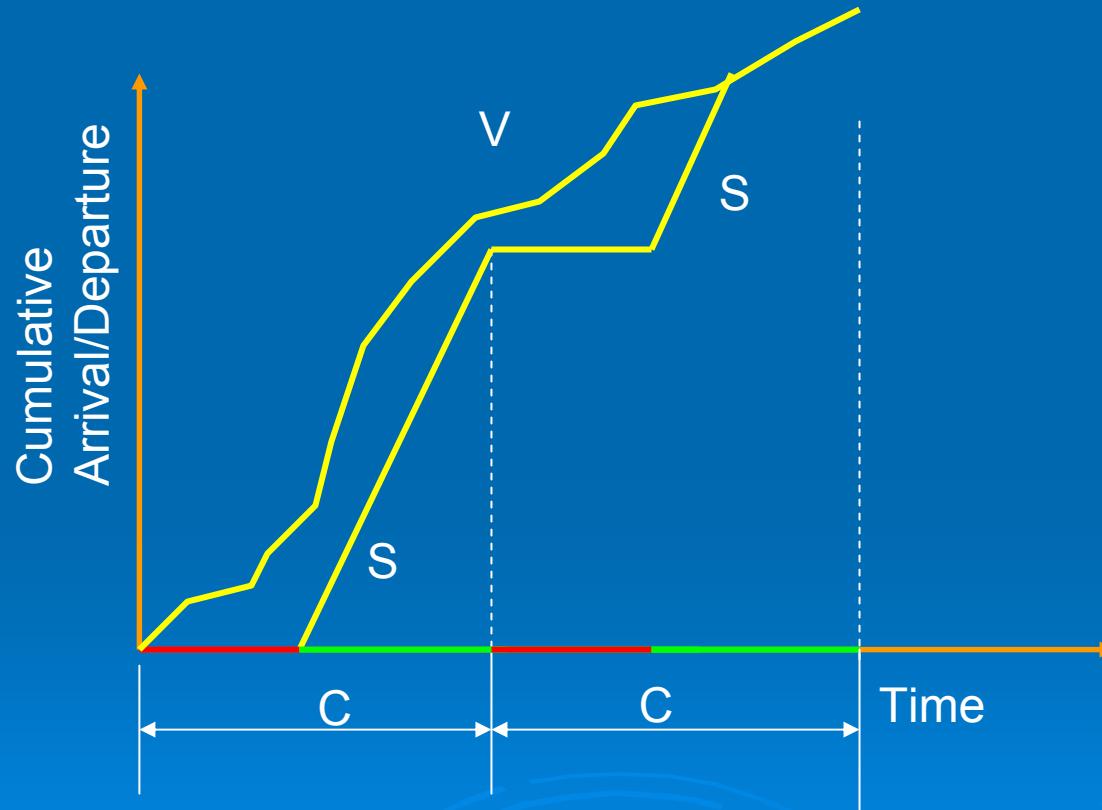
Suppose the cycle length is 100 sec, the effective green time is 40 sec, the uniform arrival flow rate is 400 vph, and the saturation flow rate is 2000 vph. Calculate:

- Average delay per vehicle
- Maximum queue length in vehicles
- Maximum backup queue in vehicles
- Fraction (%) of vehicles delayed
- Number of vehicles delayed per hour
- Maximum delay each individual vehicle experienced

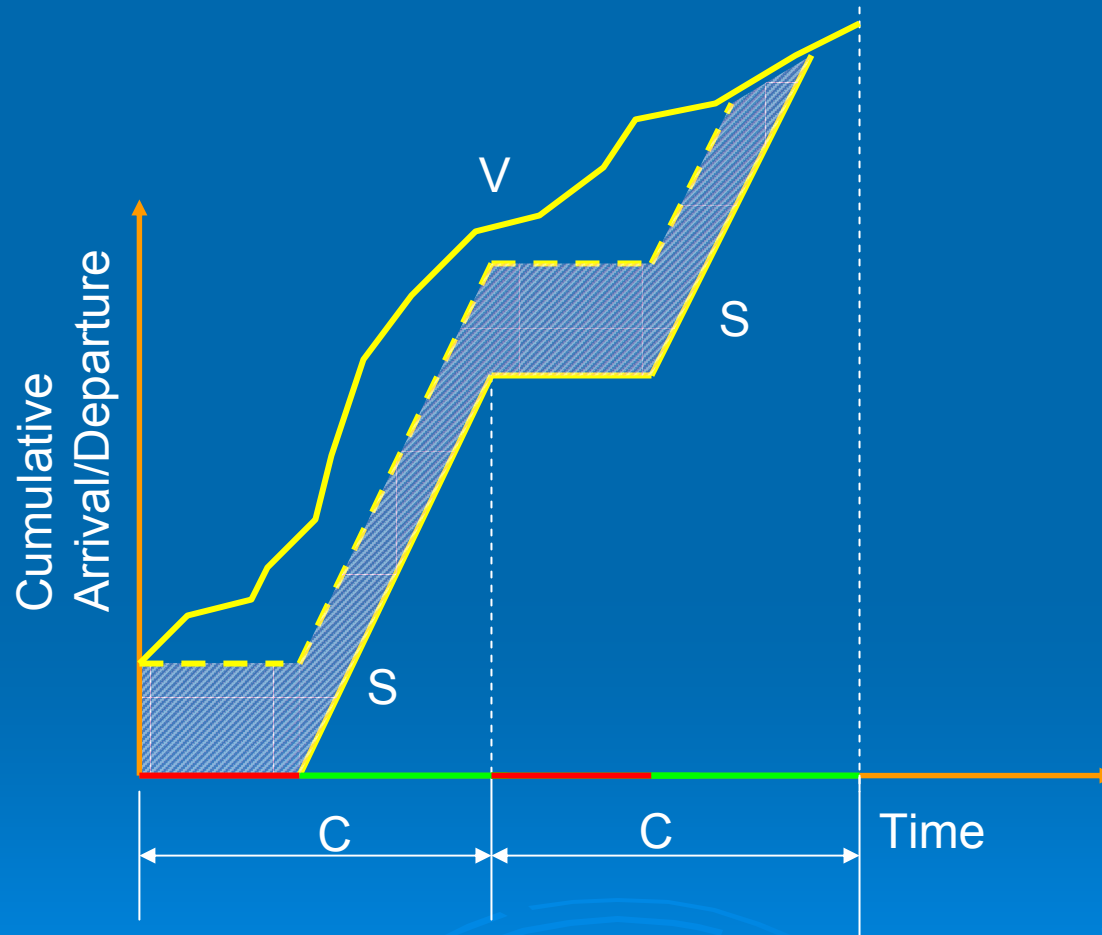
Uniform Delay



Random and Over-saturation Delay

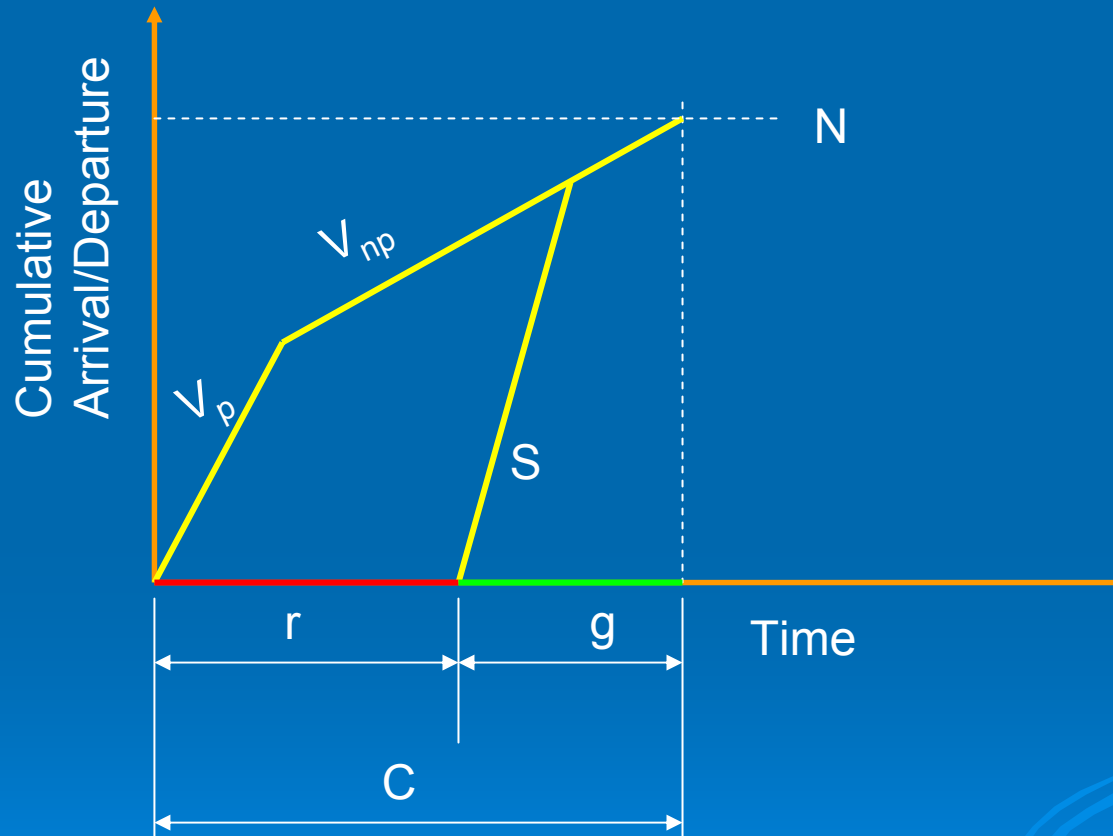


Delay with Initial Queue



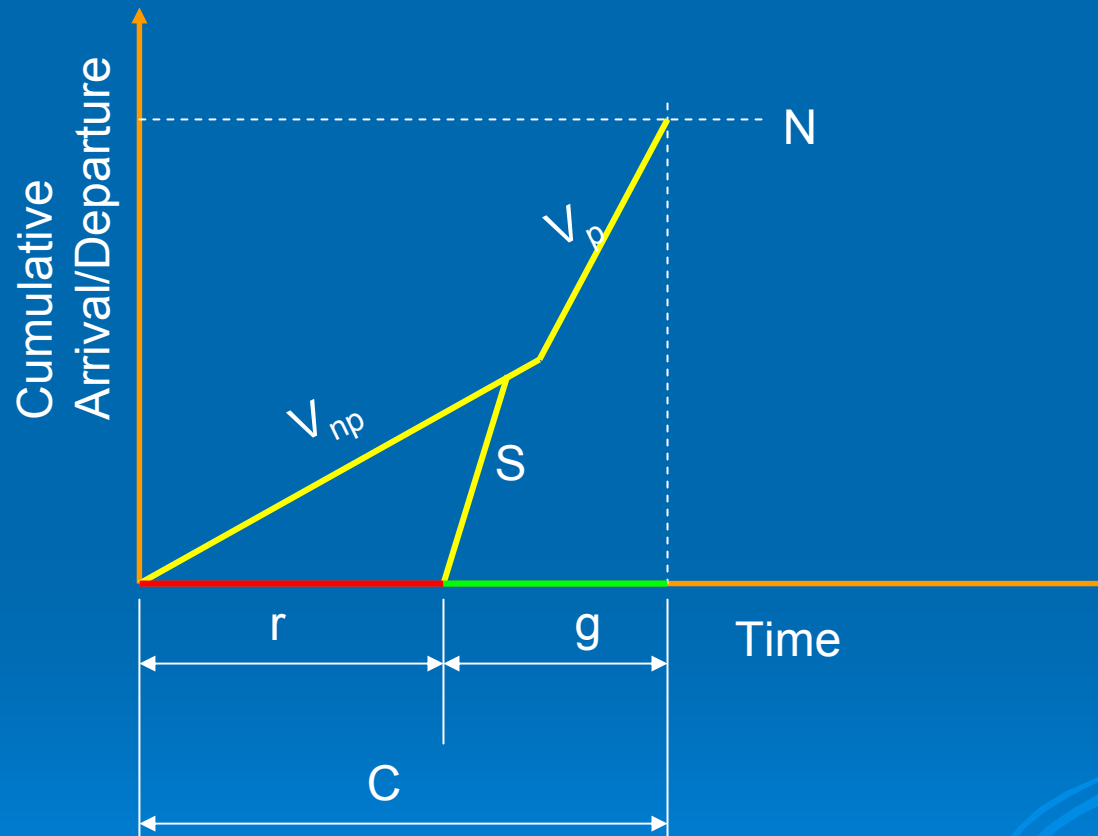
Uniform Delay with Platoon Arrival

(Platoon on Red)



Uniform Delay with Platoon Arrival

(Platoon on Green)



Areas Requiring Further Research

- Pedestrian effect (Tian and Xu)
- Protected/permitted control
- Short-lane/queue overflow (Tian and Wu)
- Actuated control

Assignment

You are asked to analyze the operations of N. Virginia/8th Street based on the data you collected for the weekday PM peak hour. You need to use the three capacity analysis software, HCS, TRAFFIX, and Synchro to do the analyses. Specific tasks and requirements of this assignment are as follows:

1. You can discuss and consult any questions with other members of your group, however, each person must submit an individual report.
2. You can make estimates or assumptions if certain data are not available, but you must provide the justifications of your estimates or assumptions. Furthermore, each group must come up with the same data inputs for conducting the analyses.
3. Based on the existing data you collected, conduct an operational analysis using the three software. Summarize the delay and LOS results from the three software (by lane group, approach, and intersection), compare and comment on the results. How do they compare with the delays you collected in the field? Discuss the results.
4. If the signal timings from the three software are different from Task 3, make them consistent and perform Task 3 again. Do you get identical results? Why?
5. Use the data from Task 4, change the signal timing from actuated control to fixed control, and report the delay results. What can you conclude from the results?
6. Select one of the software you prefer, run cycle length from 40 seconds to 100 seconds with a 10-sec increment. Plot the intersection delays vs. cycle length, and comment on the results.
7. Increase the demands by 60% for all the movements. If LOS D is the acceptable criteria for the intersection, and no lane group should have a v/c ratio greater than 1.0. Will the intersection still operate at acceptable LOS after the demand increase? If NOT, what mitigation measures would you recommend?