CEE 551 - Traffic Science

Topic: Traffic Signal Control (2)

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Recap

- Fixed-time traffic signal control
  - Ring-and-barrier diagram & phase sequence
- Vehicle-actuated control
  - Max out & gap out

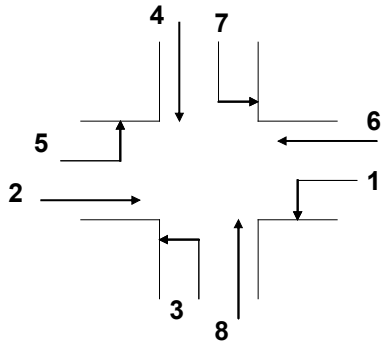
Outline: Traffic Signal Parameters

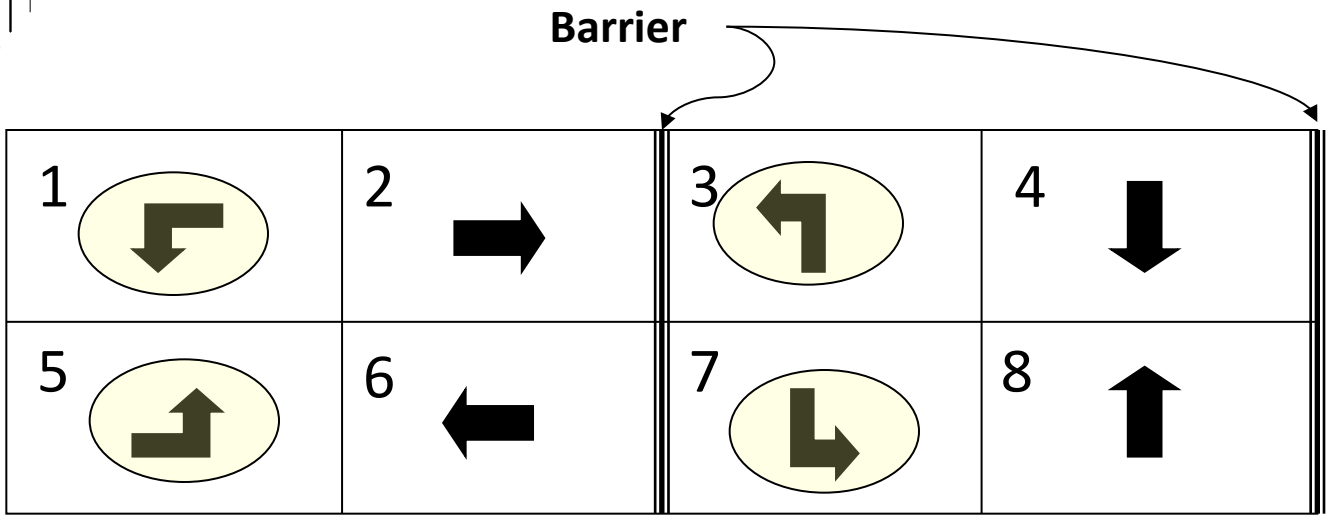
- Phase sequence
- Pedestrian walk time, leading pedestrian interval
- Minimum green, maximum green
- Yellow change interval: dilemma & option zone
- Unit extension

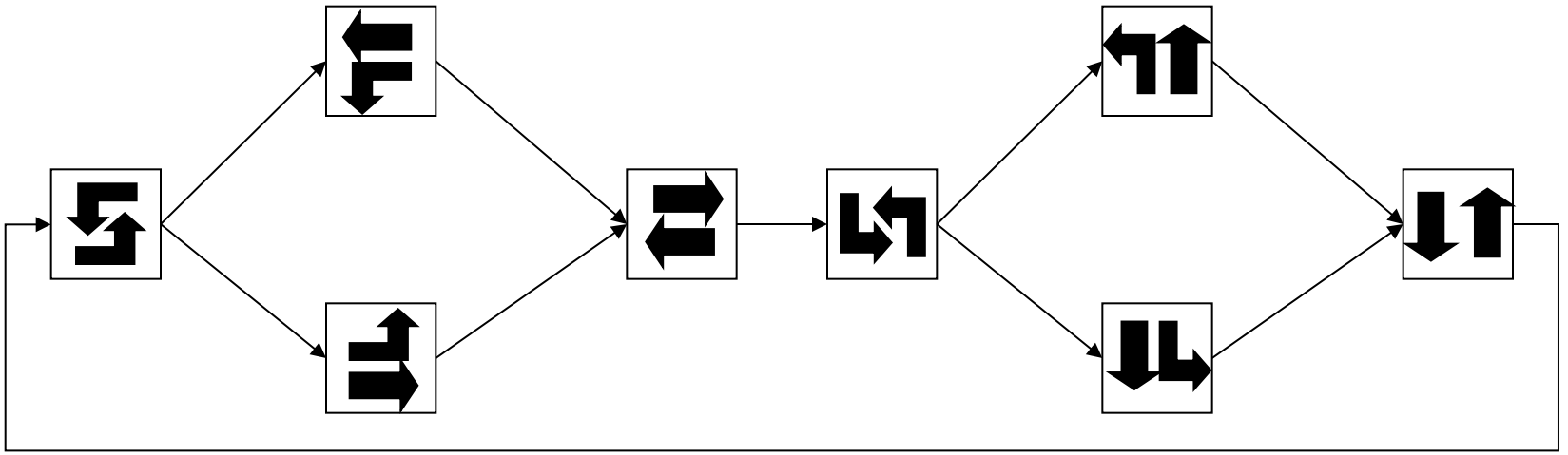
Timing Charts

Interval	Phase							
	1	2	3	4	5	6	7	8
Walk								
Ped Clearance (FDW)								
Initial (Min Green)								
Extension (Passage)								
Minimum Gap								
Time Before Reduce								
Time to Reduce								
Max Green								
Yellow								
Red Clearance								
Permit								
Lag Phase								

Lead – Lead, Lead – Lead Phasing







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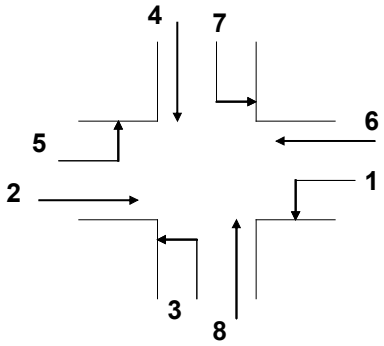
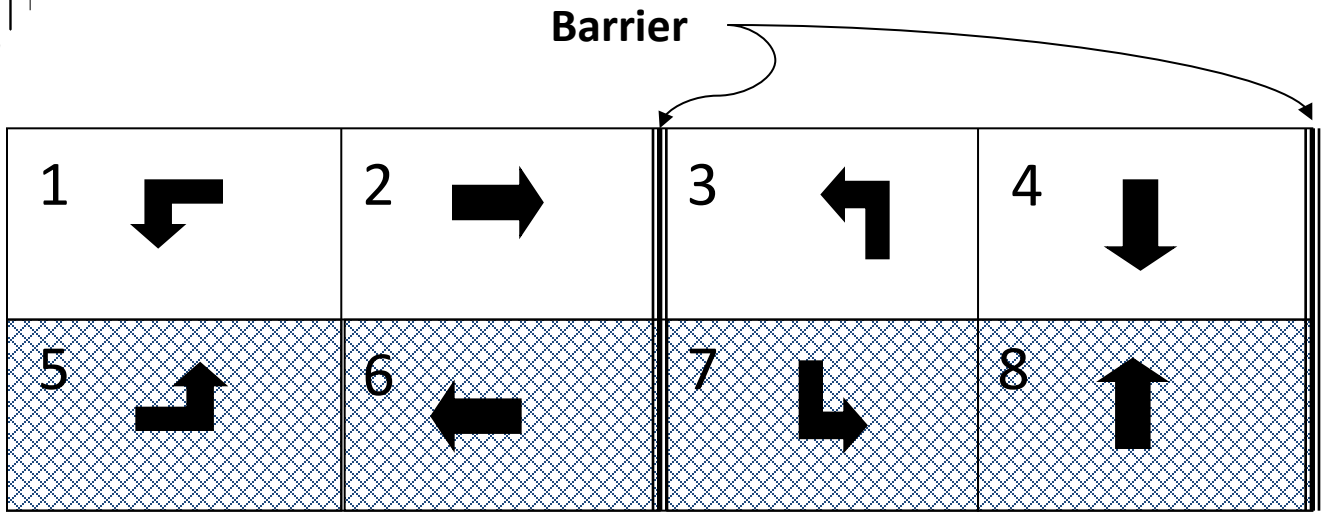
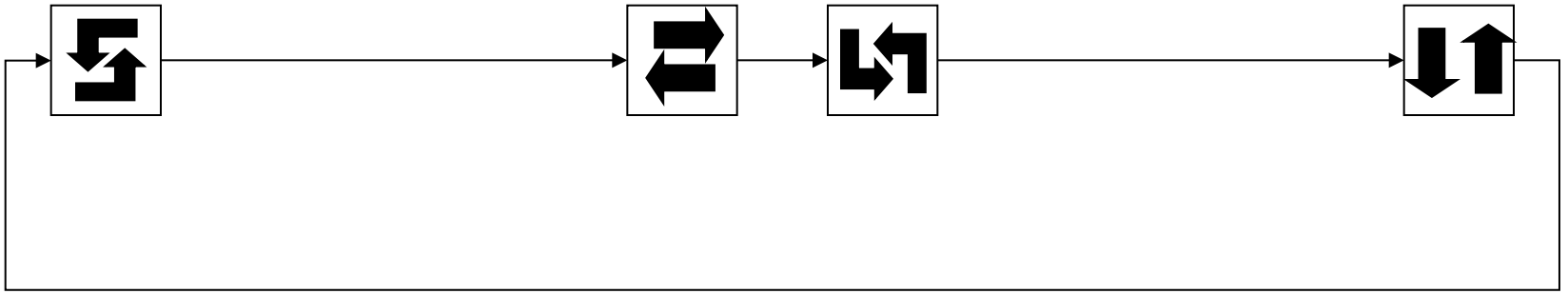
Red Clearance								
Permit	√	√	√	√	√	√	√	√
Lag Phase		√		√		√		√

4 Phase Single Ring Operation







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Yellow								
Red Clearance								
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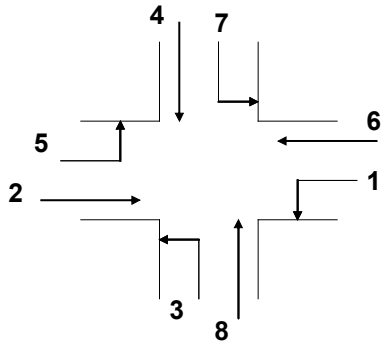
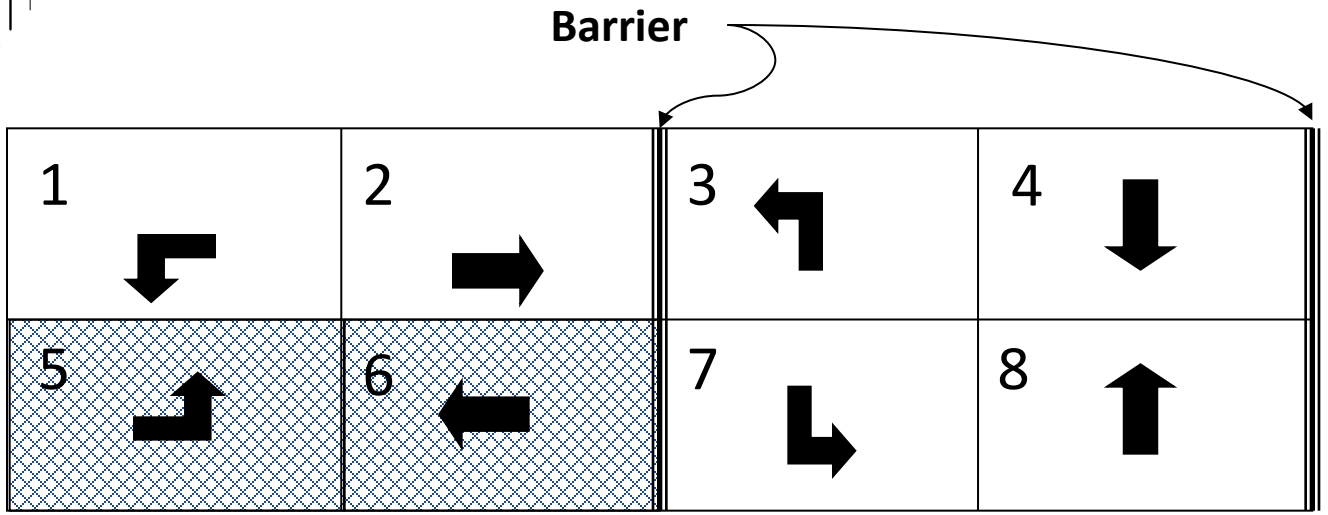
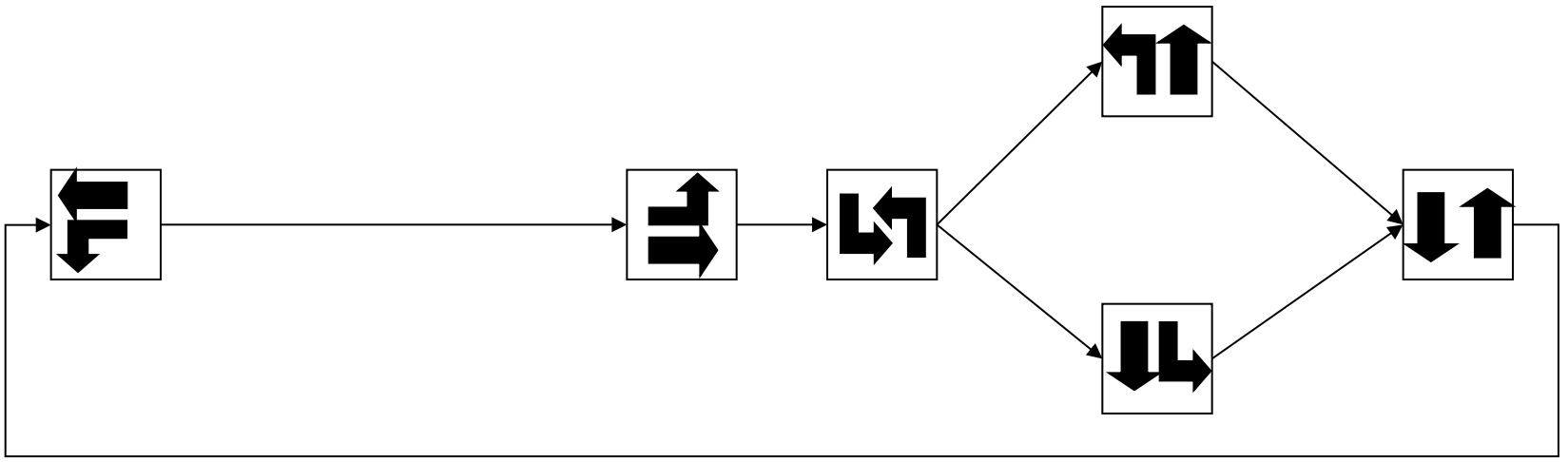
Lag Phase		√		√				

Split Phasing on Arterial A







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Yellow								
Red Clearance								
Permit	√	√	√	√			√	√
Lag Phase		√		√				√

Timing Charts

Interval	Phase							
	1	2	3	4	5	6	7	8
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Minimum Gap								
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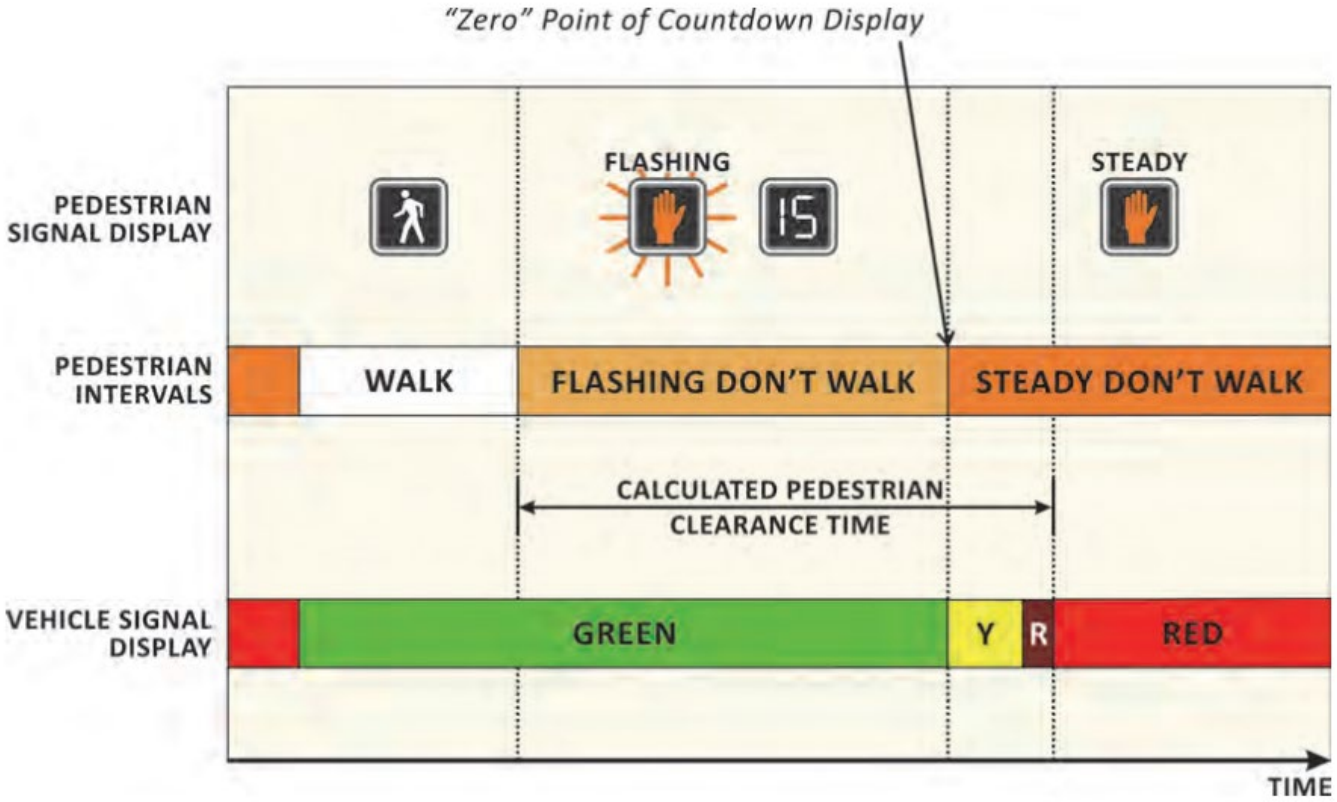
Pedestrian interval

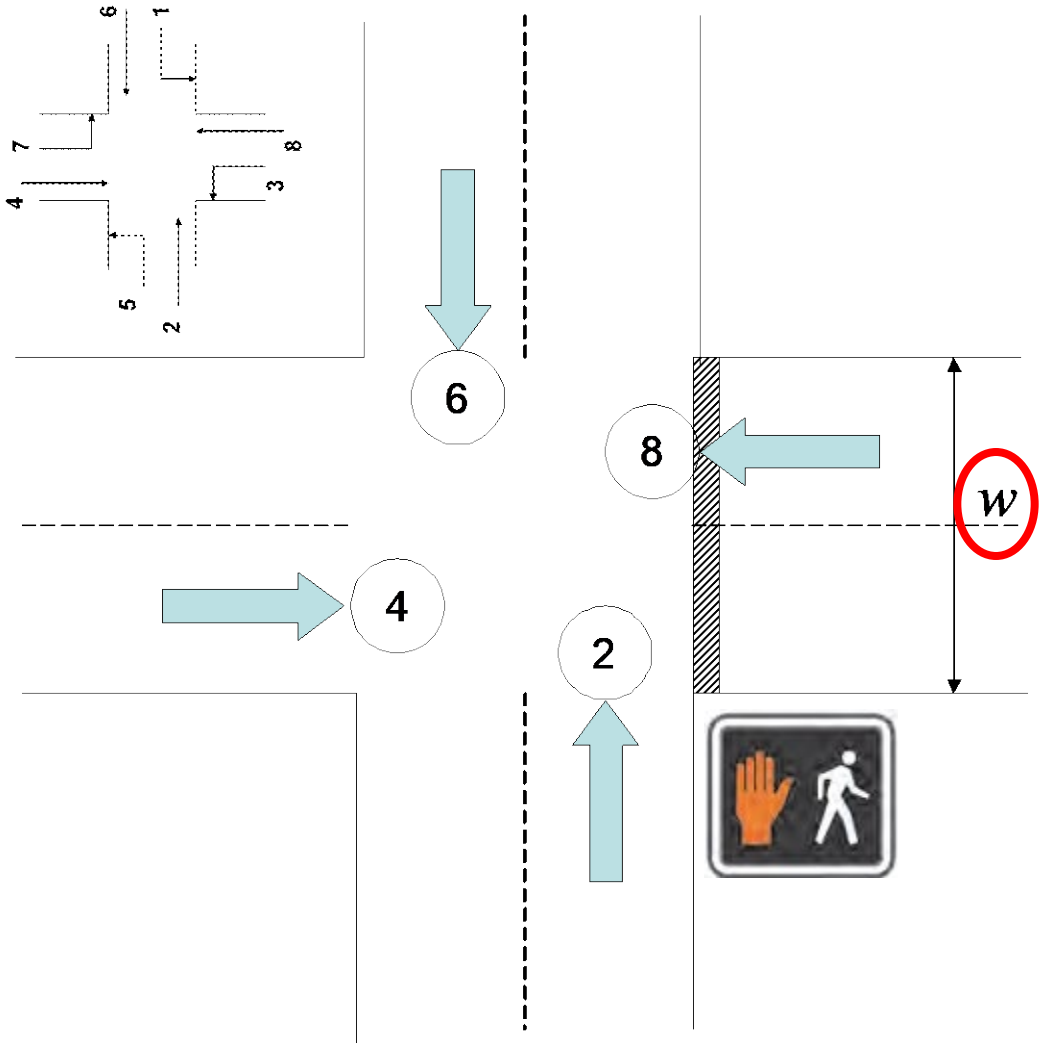


Walk time: 7 seconds minimum, can be reduced on certain condition
Flash don't walk (FDW): walk speed at 3.5 feet/s

Reference: MUTCD (Manual on Uniform Traffic Control Devices)

Walk and Flashing Don’t Walk (FDW)

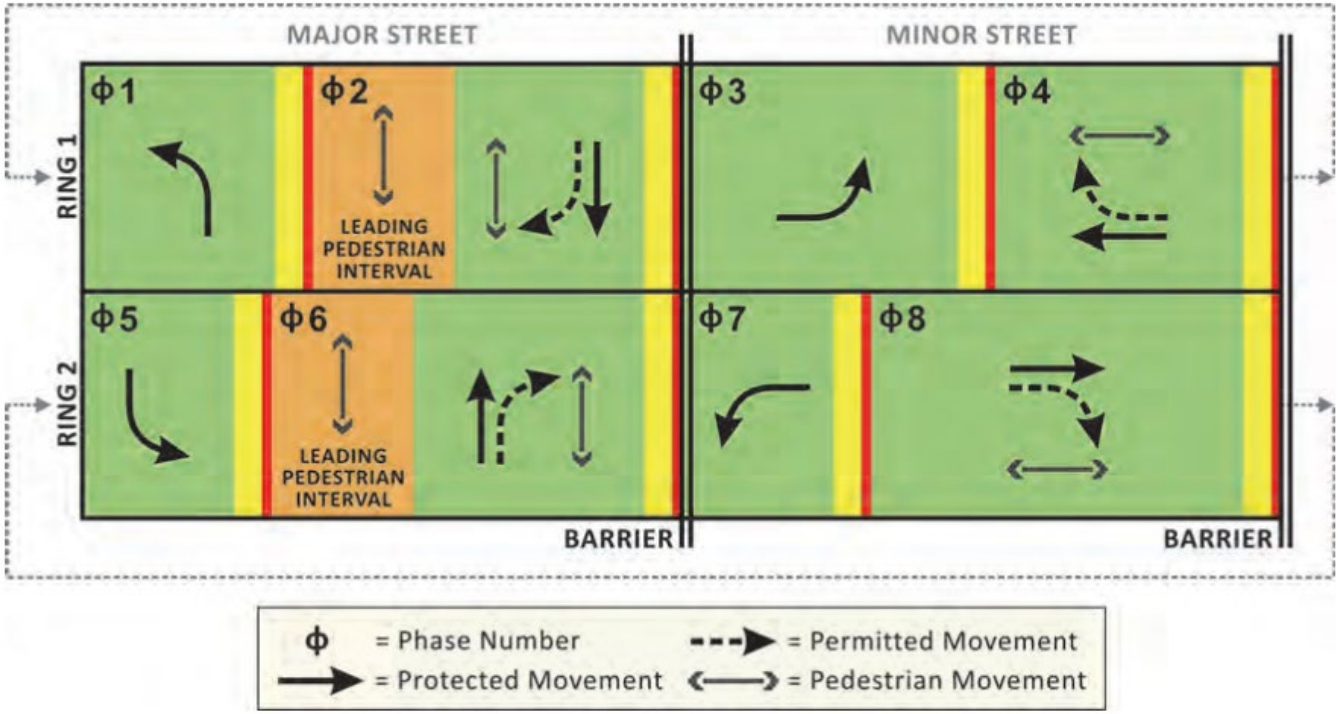
walk speed of about 3.5 ft/sec is usually assumed



FDW for NEMA Phase 2 should be greater than *w*/3.5 seconds

Leading Pedestrian Interval

Pedestrians enter the intersection before vehicles to establish the right-of-way



Leading pedestrian interval should be at least 3 seconds once it is used

Timing Charts

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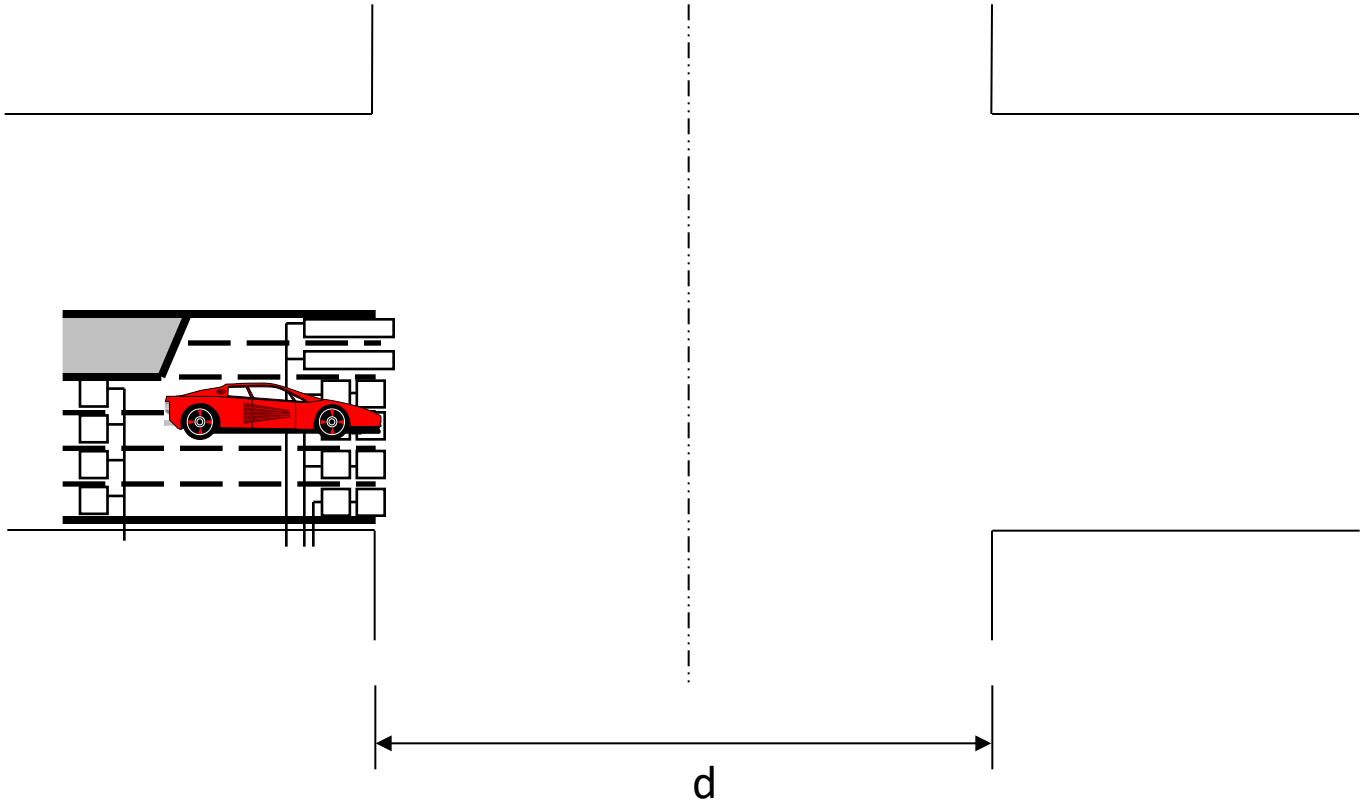
Minimum Green Time

- Purpose of minimum green: ensure safety
- Design guideline
  - It should be long enough for at least first vehicle to get to midpoint of intersection.
  - It should be long enough to meet motorists' expectations: Vehicles within about 400 ft of intersection when signal turns green "expect" to proceed through on green.
  - It should be long enough to clear "undetected" queued vehicles (without presence detector)
  - It should be long enough to match pedestrian timing

Minimum Green or Initial Green:

1. Long enough for at least first vehicle to get to midpoint of intersection



"Normal acceleration" $\approx 5\,\text{ft}/\text{sec}^2$

Conservative reaction time ≈ 2 sec

$$g_{\min} = \text{Minimum green time} \geq 2 \text{ sec} + \sqrt{\frac{2(d/2)}{5\,\text{ft}/\text{sec}^2}} = 2 \text{ sec} + 0.45\sqrt{d}$$

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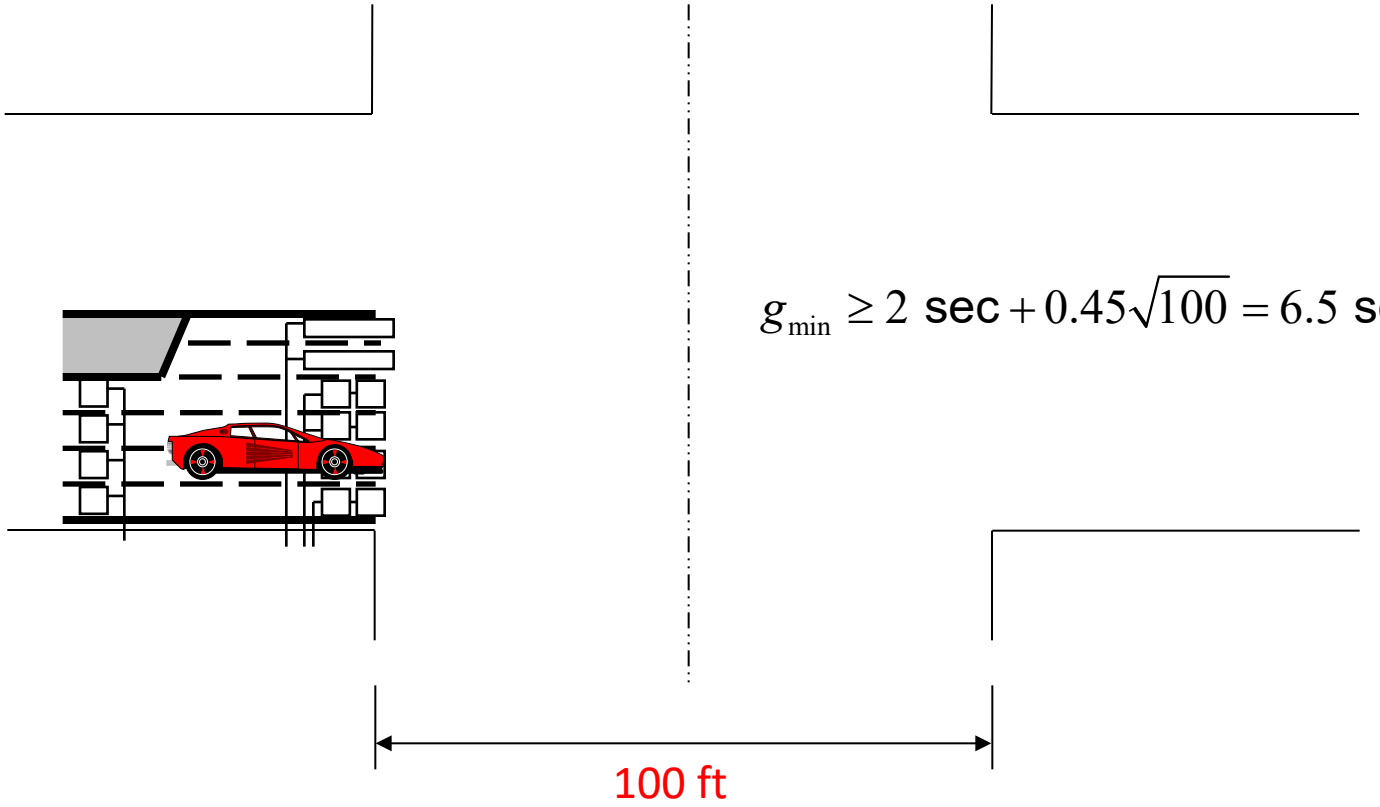

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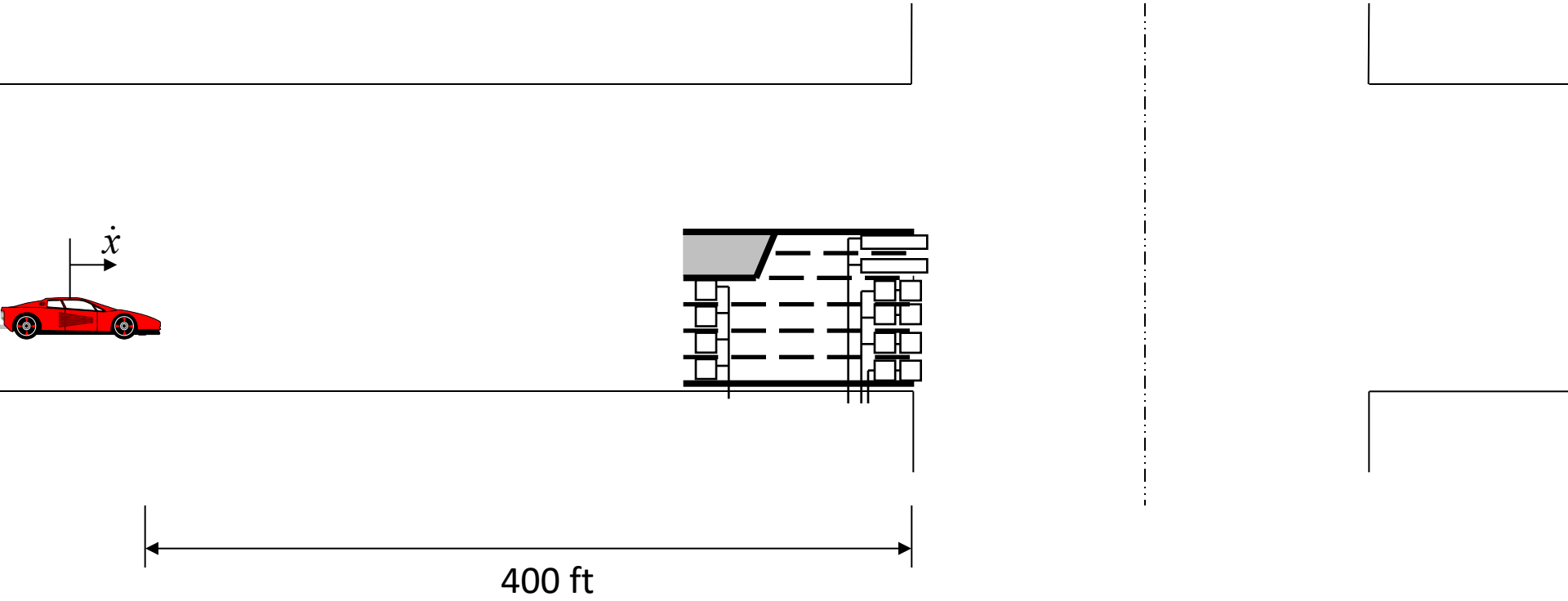
Minimum Green or Initial Green:

2. Long enough to meet motorists' expectations: Vehicles within about 400 ft of intersection when signal turns green "expect" to proceed through on green.

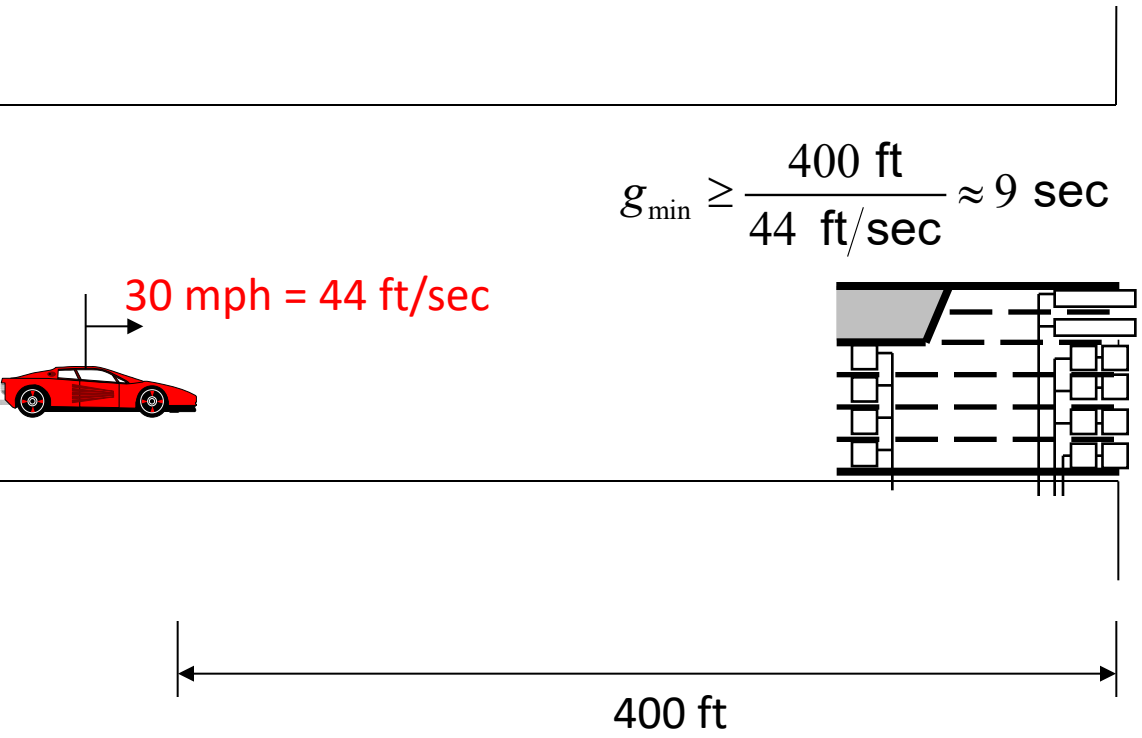


$$g_{\min} \geq \frac{400 \text{ ft}}{\dot{x}}$$

Minimum Green or Initial Green:

2. Long enough to meet motorists' expectations: Vehicles within about 400 ft of intersection when signal turns green "expect" to proceed through on green.

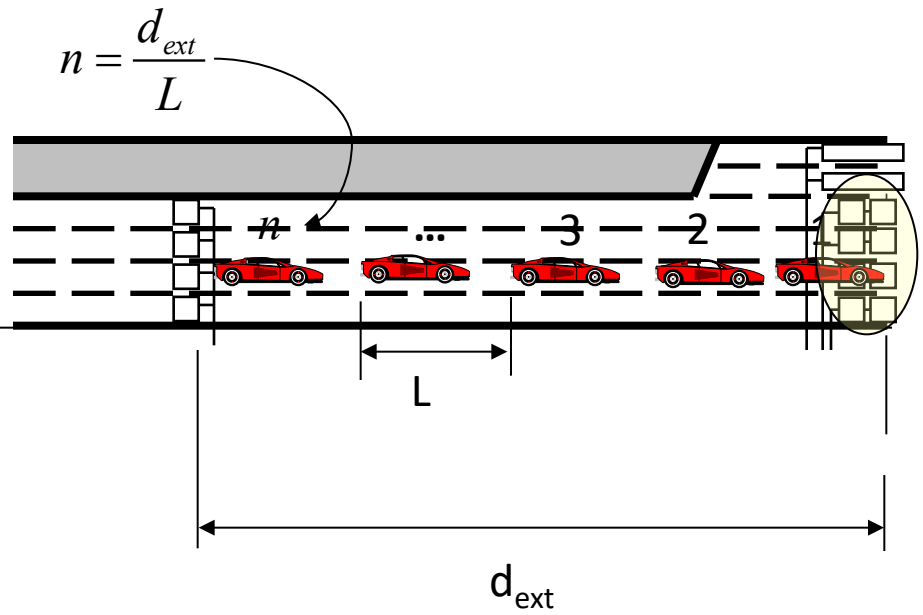
$$g_{\min} \geq \frac{400 \text{ ft}}{44 \text{ ft/sec}} \approx 9 \text{ sec}$$



$$g_{\min} \geq \frac{400 \text{ ft}}{\dot{x}}$$

Minimum Green or Initial Green:

3. Long enough to clear “undetected” queued vehicles



Minimum headway between vehicles ≈ 2 sec/veh

Conservative reaction time ≈ 2 sec

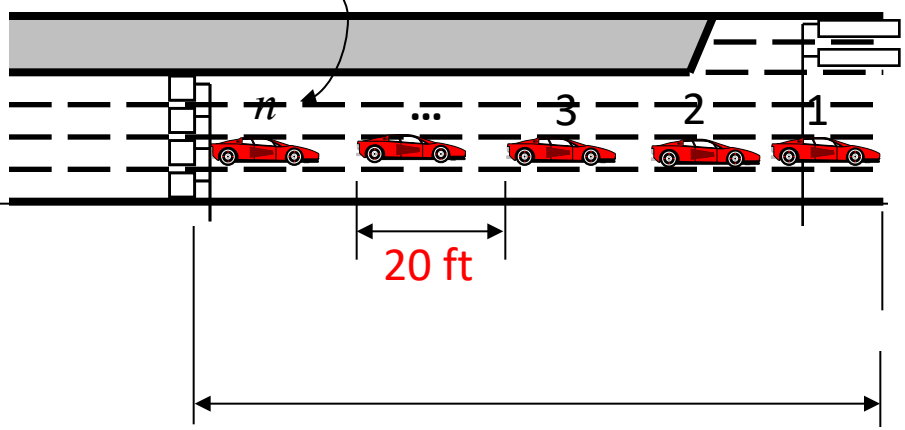
$$g_{\min} \geq 2 \text{ sec} + n \cdot 2 \text{ sec/veh} = 2 \text{ sec} + \frac{2d_{ext}}{L} \text{ sec}$$

Minimum Green or Initial Green:

3. Long enough to clear “undetected” queued vehicles

$$g_{\min} \geq 2 \text{ sec} + \frac{2(200\,\text{ft})}{20 \text{ ft}} \text{ sec} = 22 \text{ sec}$$

$$n = \frac{d_{ext}}{L}$$



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Conservative reaction time ≈ 2 sec

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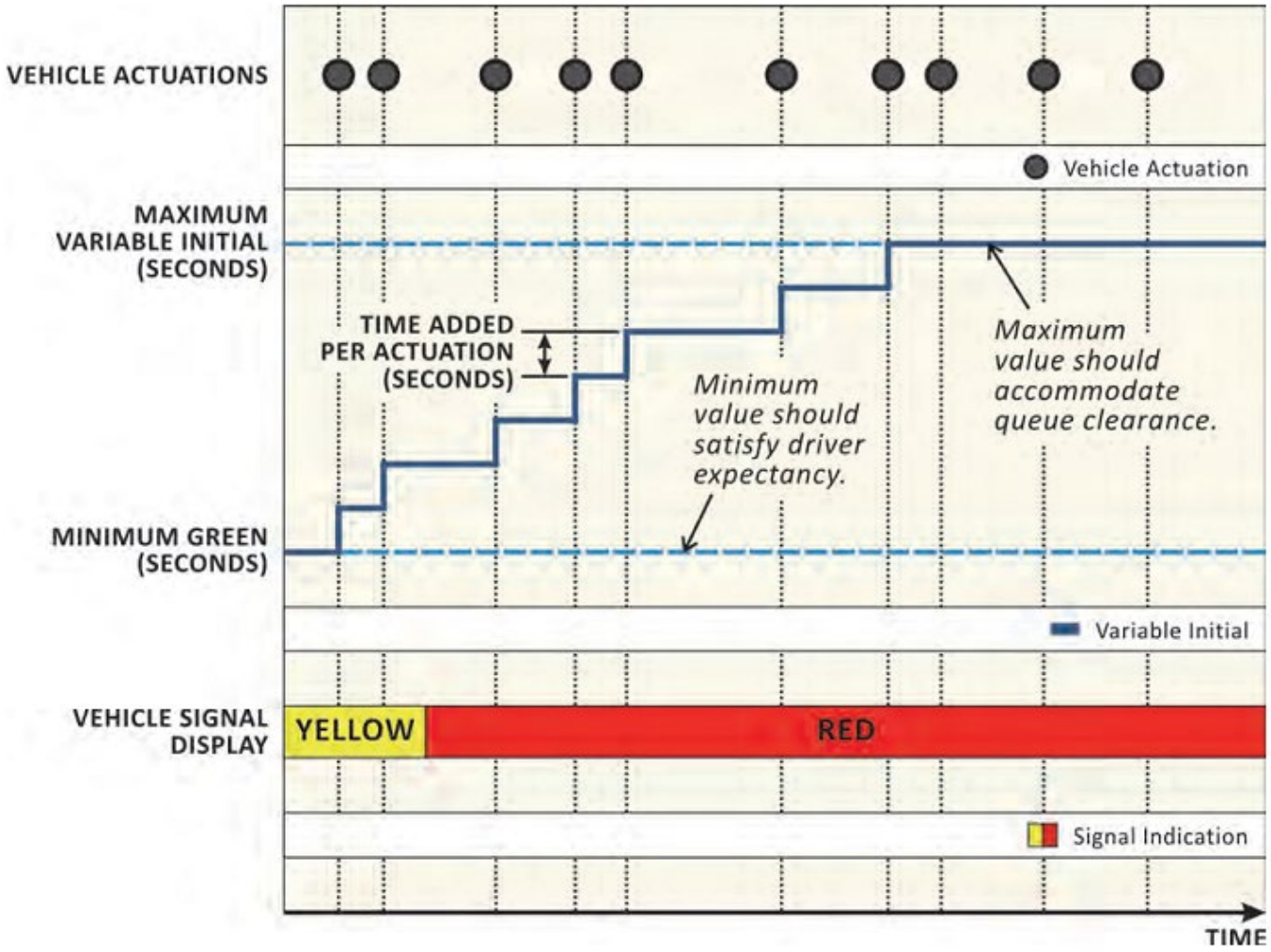
More Advanced Controller: Variable Initial



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Yellow								
Red Clearance								
Permit								
Lag Phase								

Maximum Green

- Too long: waste time at intersection (especially under detector failure)
- Too short: phase capacity may be inadequate for the traffic demand (phase failure)
- An appropriate setting: gap out most of the time, occasionally max out during peak hour
- Typical values:

Phase Type	Facility Type	Maximum Green (Seconds)
Through	Major Arterial (> 40 mph)	50 to 70
	Major Arterial (≤ 40 mph)	40 to 60
	Minor Arterial	30 to 50
	Collector, Local, or Driveway	20 to 40
Left Turn	Any	15 to 30

Timing Charts

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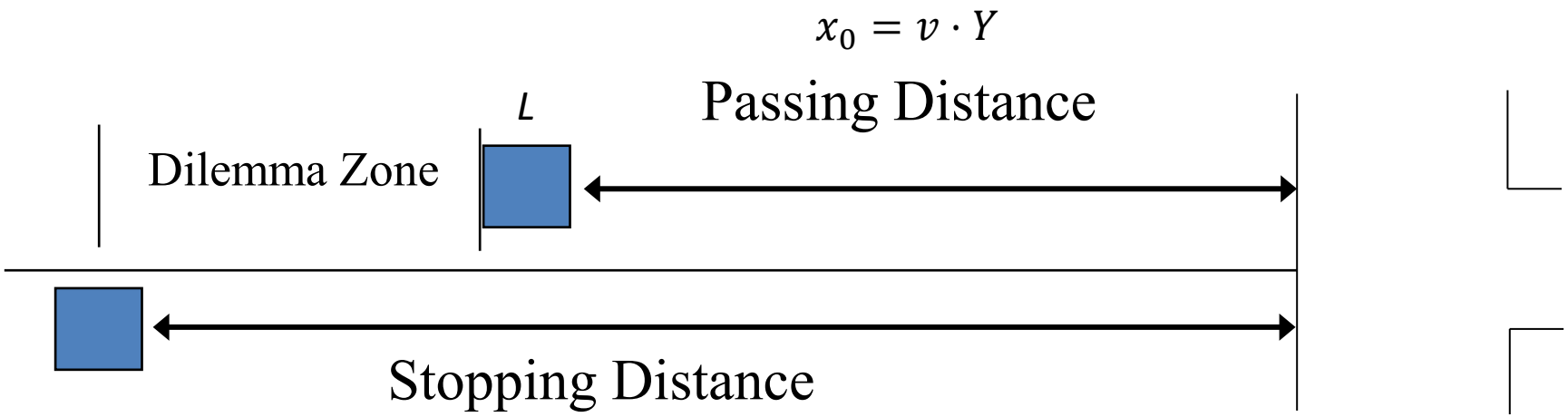
Dilemma Zone

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

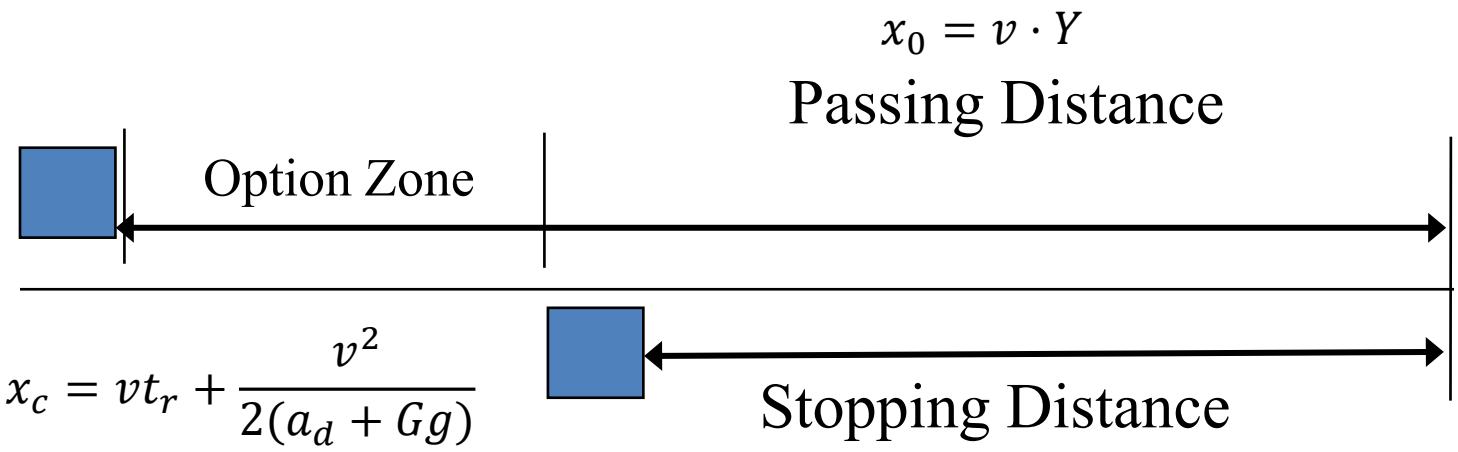


$$x_c = vt_r + \frac{v^2}{2(a_d + Gg)}$$

if $x_c > x_0$ => Dilemma Zone

Option Zone

- "Option Zone" -- driver can either stop safely or clear the intersection before the cross street green phase starts!



if $x_o > x_c$ => Option Zone

Yellow Change Interval

- Passing distance is equivalent to stopping distance

$$x_c = vt_r + \frac{v^2}{2(a_d + Gg)} = v \cdot Y = x_0 \quad \Rightarrow \quad Y = t_r + \frac{v}{2(a_d + Gg)}$$

  - Y: yellow change interval (sec)
  - a_d: deceleration rate (m/s²)
  - v: vehicle approaching speed (m/s)
  - t_r: perception-reaction time (sec)
  - g: gravity acceleration (m/s²)
  - G: slope (grade) of the approaching road (radian)

Dilemma Zone: Example

- A driver traveling at the speed limit of **35 mph** was cited for crossing an intersection on red. He claimed that he was innocent because the duration of the Yellow display was improper and, consequently, a dilemma zone exists at that location.
  - Using the following data, determine whether the driver's claim was correct.
  - Determine if the driver is innocent. Given he kept 37mph speed and he was 0.33 second into the red light when he crossed intersection.
- Yellow change interval = 3 s, perception/reaction time = 1.5 s, deceleration = 10 ft/s^2, road grade: $G = 0$

Dilemma Zone: Example

- Whether there is a dilemma zone
  - Yellow change interval = 3 s, perception/reaction time = 1.5 s, deceleration = 10 ft/s², road grade: $G = 0$

$$x_c = vt_r + \frac{v^2}{2(a_d + Gg)} = 35 \times 1.47 + \frac{(35 \times 1.47)^2}{2 \cdot 10} = 209.5 \text{ ft}$$

$$x_0 = Y \cdot v = 3 \times 35 \times 1.47 = 154.3 \text{ ft} \qquad 1 \text{ mph} = 1.47 \text{ ft/s}$$

$x_c > x_0$: there is a dilemma zone

- Whether the driver is within the dilemma zone
  - Location of the driver at the start of the yellow light

$$x = 35 \times 1.47 \times (3 + 0.33) = 181.1 \text{ ft} \qquad x_0 < x < x_c$$

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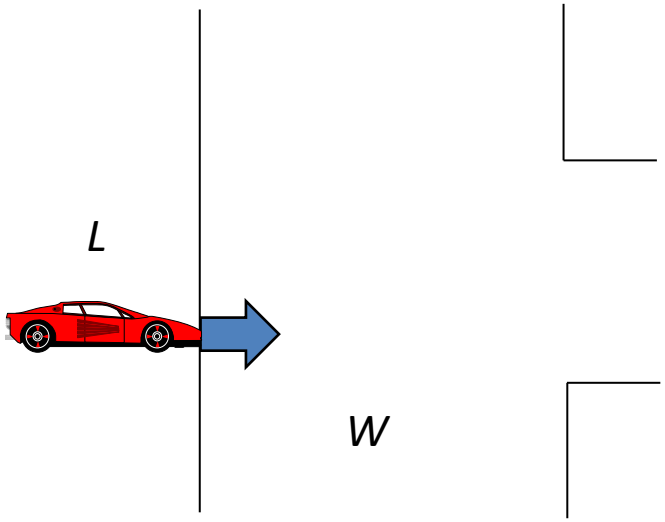
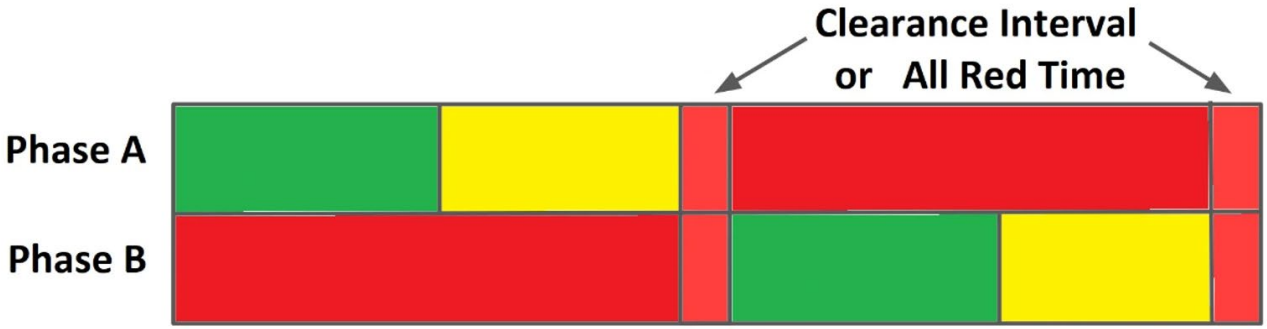
Permit								
Lag Phase								

Red Clearance (All-Red) Time



$$AR = \frac{L + W}{v}$$



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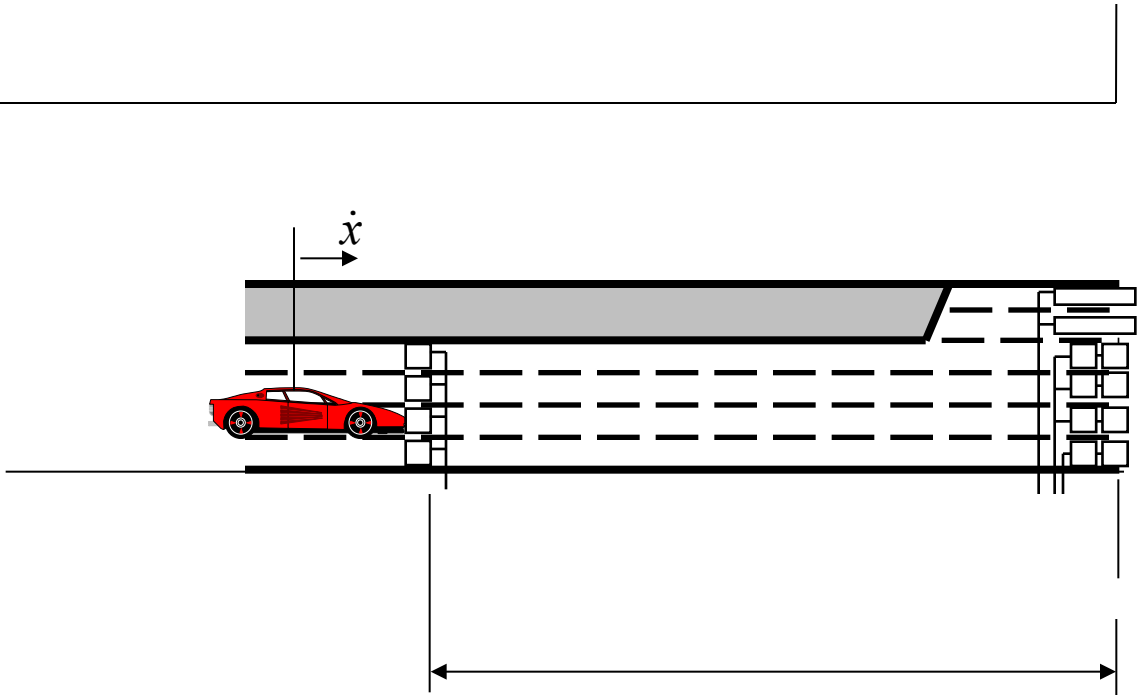
Permit								
Lag Phase								

Unit Extension or Passage Time:

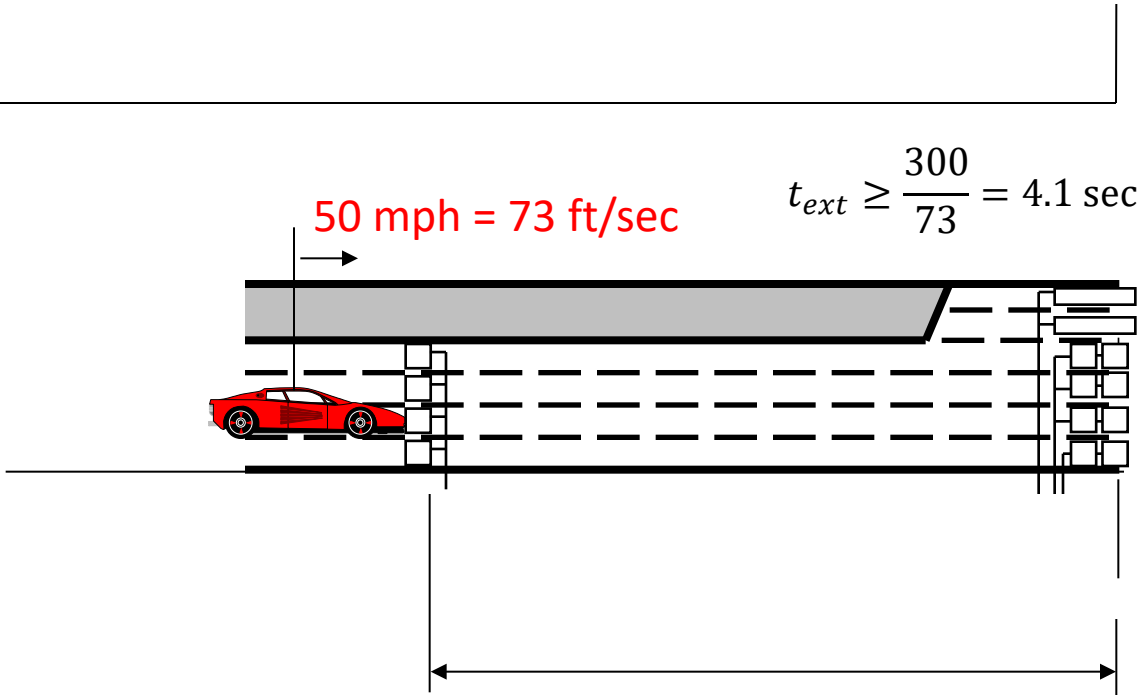
Long enough for vehicle to make it to stop line



$$t_{ext} \geq \frac{d_{ext}}{\dot{x}}$$

Unit Extension or Passage Time:

Long enough for vehicle to make it to stop line



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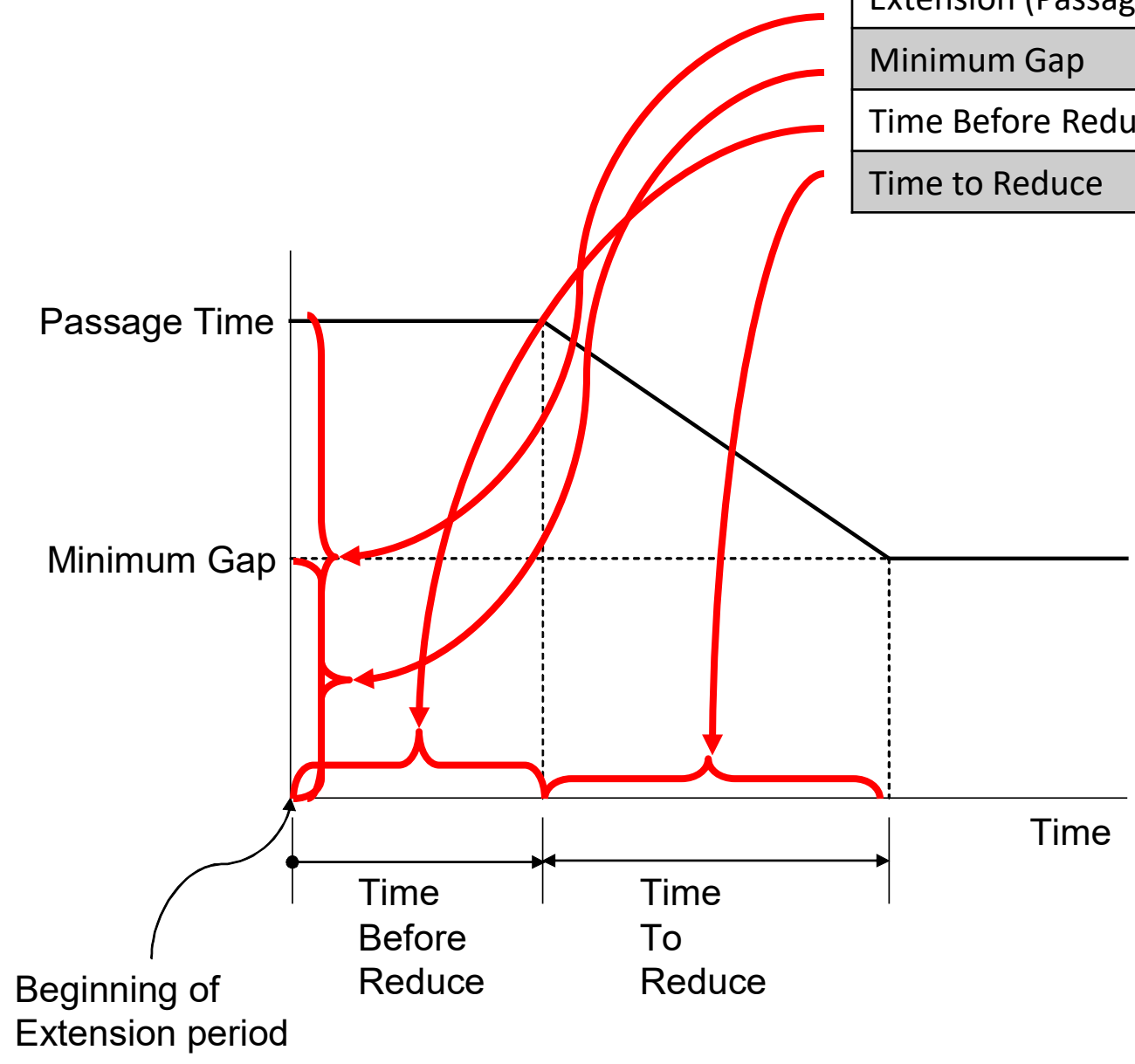
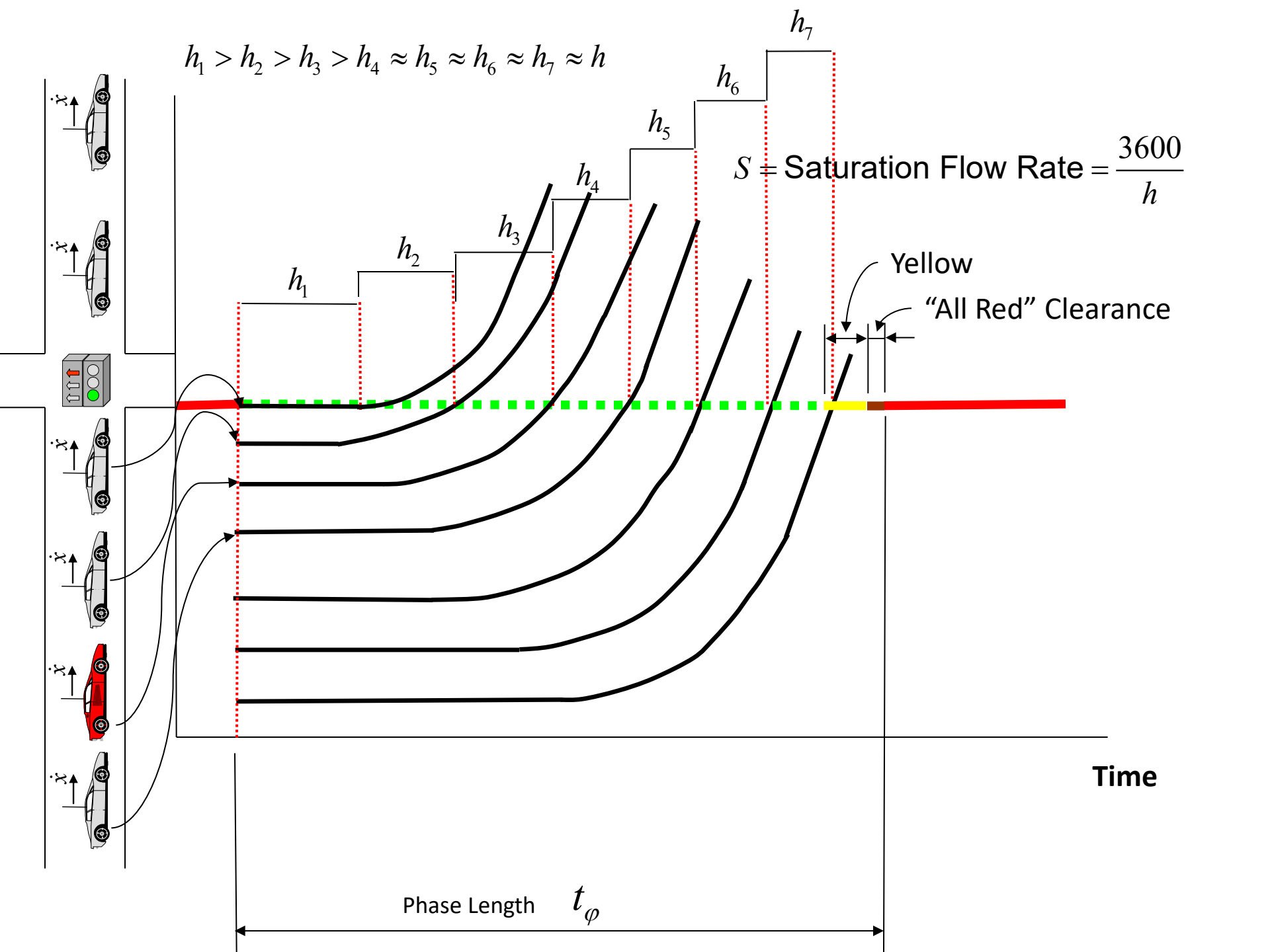
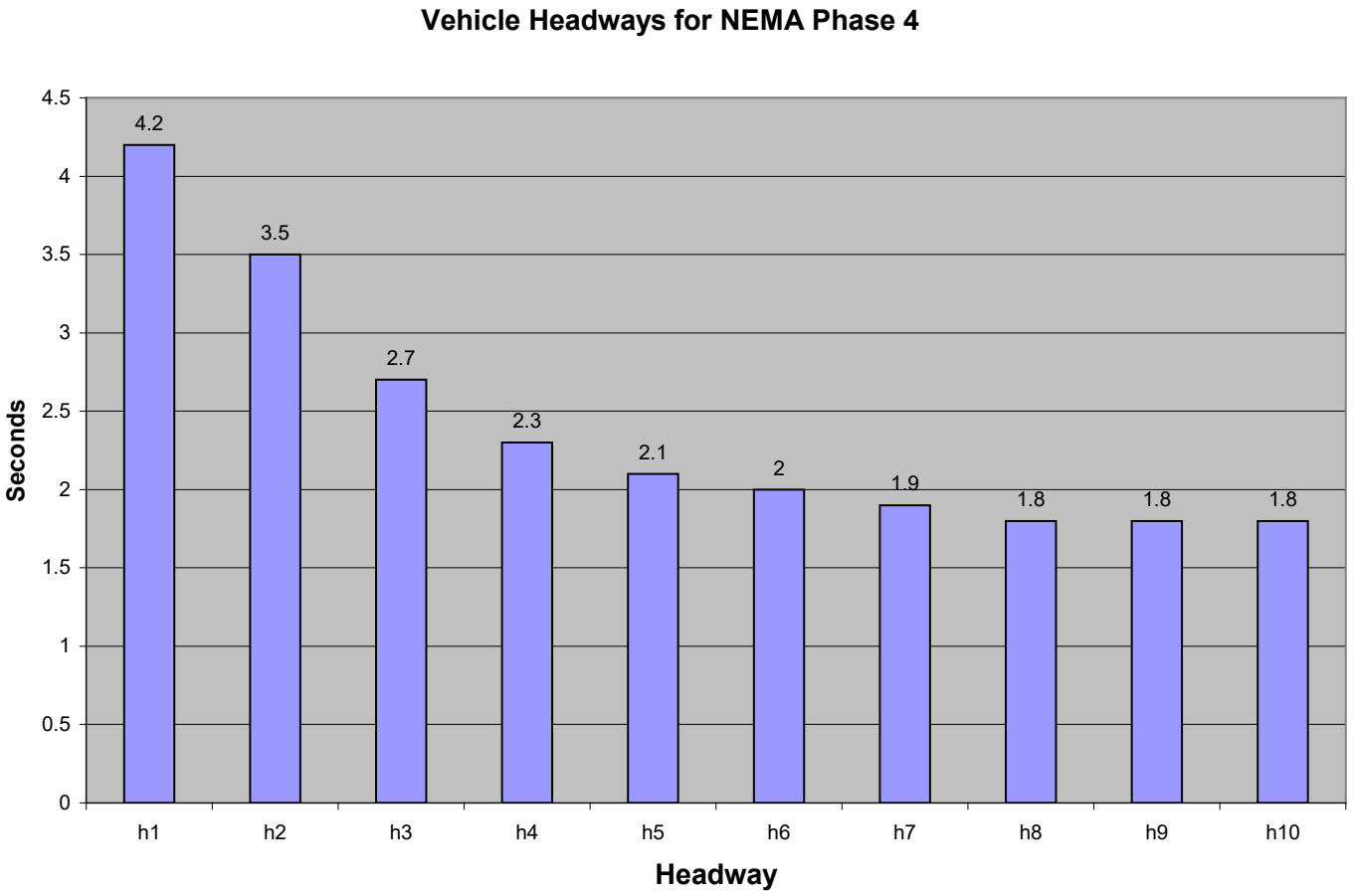


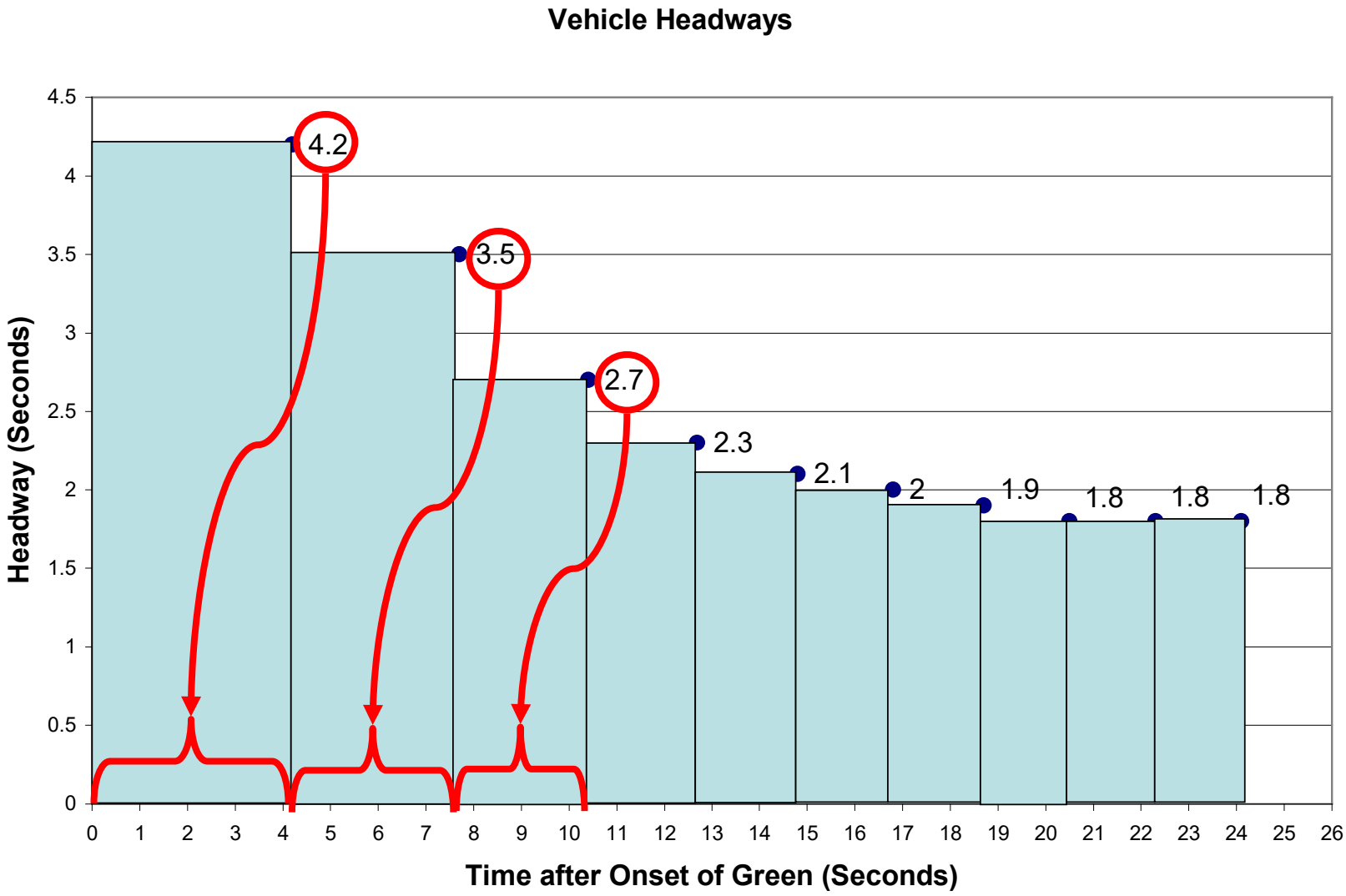

$h_1 > h_2 > h_3 > h_4 \approx h_5 \approx h_6 \approx h_7 \approx h$
h_1
h_2
h_3
h_4
h_5
h_6
h_7
S = Saturation Flow Rate = $\frac{3600}{h}$
Yellow
"All Red" Clearance
Time
Phase Length t_φ

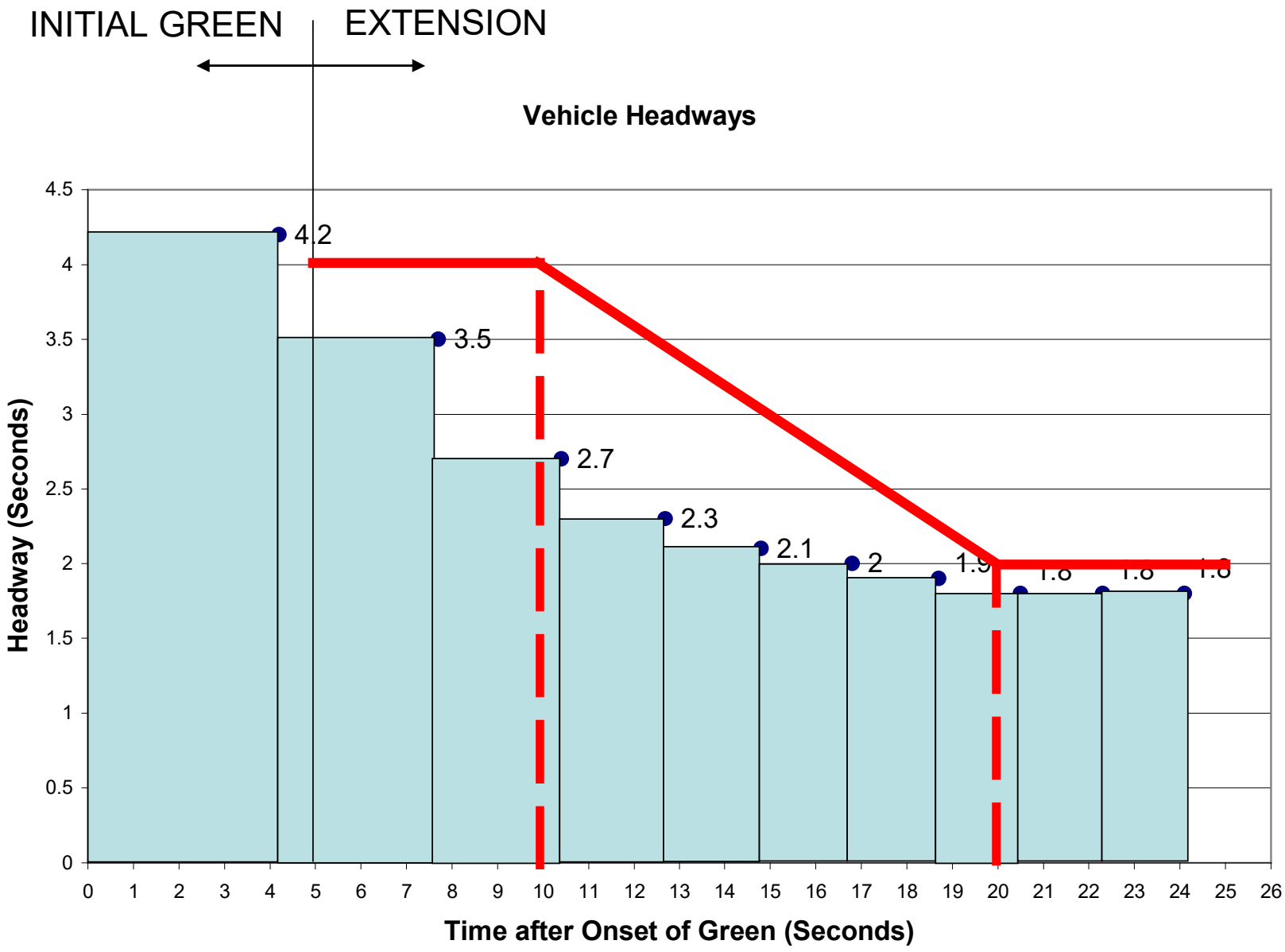
Recall

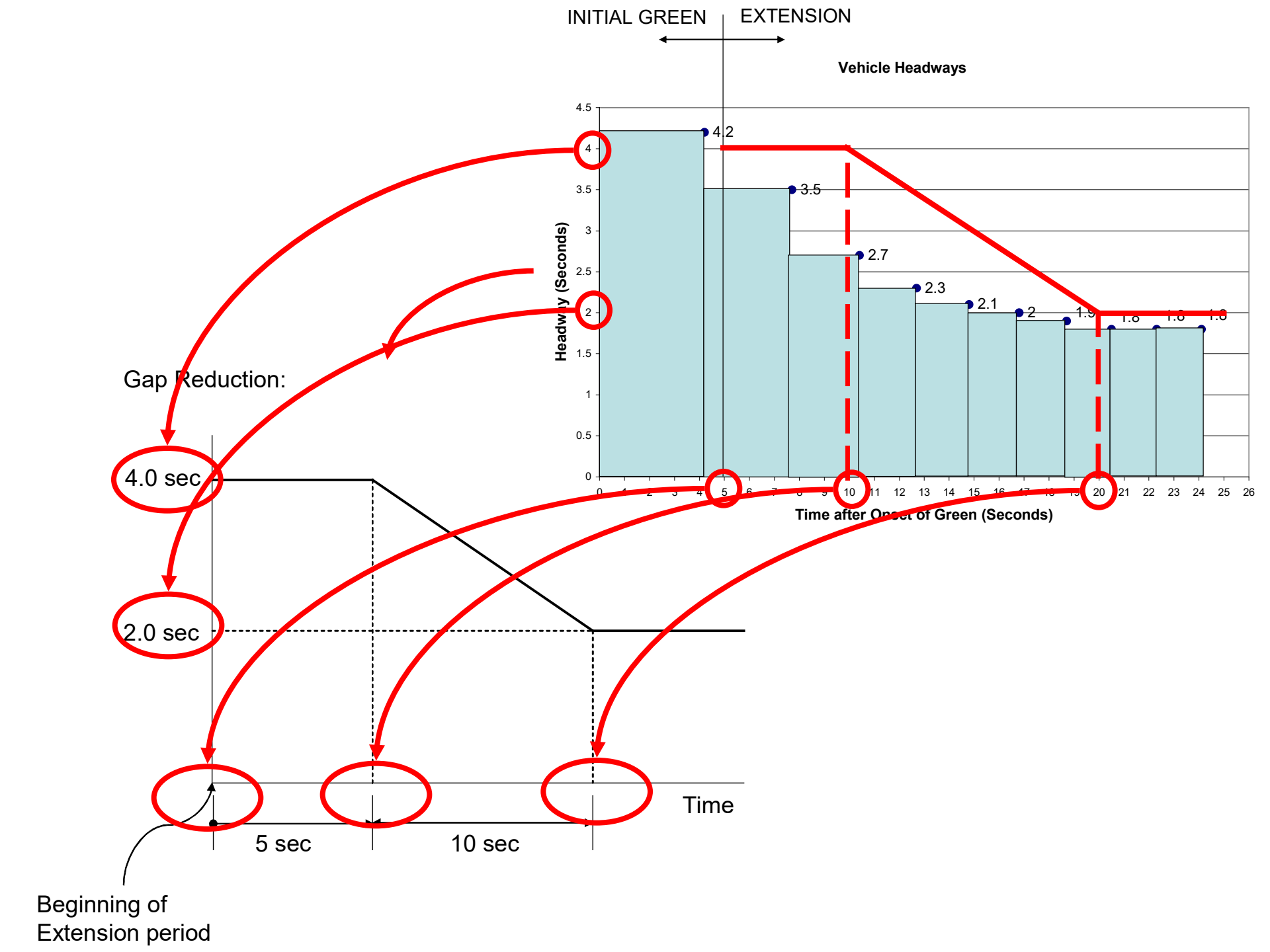
$$h_1 > h_2 > h_3 > h_4 \approx h_5 \approx h_6 \approx \ldots \approx h = \frac{3600}{S}$$

Results of a Study:



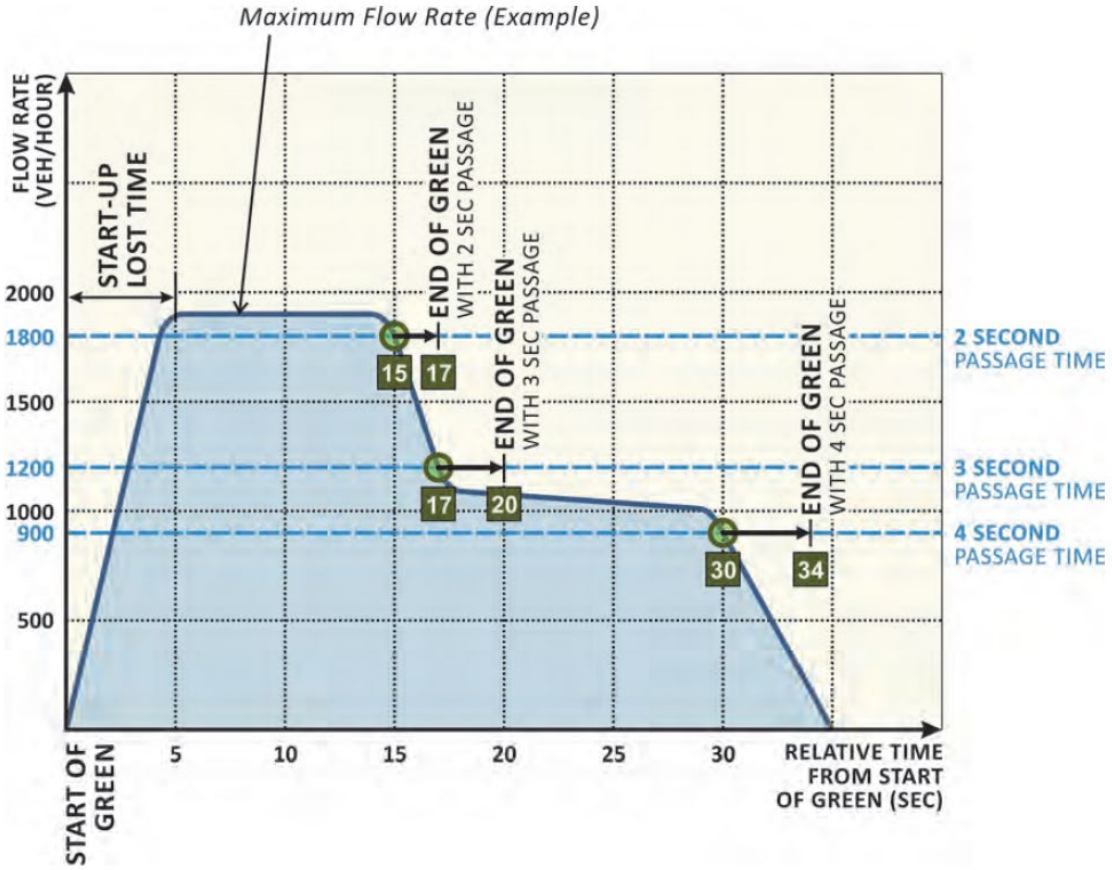

Vehicle Headways
Headway (Seconds)
Time after Onset of Green (Seconds)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
4.2
3.5
2.7
2.3
2.1
2
1.9
1.8
1.8
1.8


INITIAL GREEN
EXTENSION
Vehicle Headways
Headway (Seconds)
Time after Onset of Green (Seconds)
4.2
3.5
2.7
2.3
2.1
2
1.9
1.8
1.8
1.8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26


INITIAL GREEN
EXTENSION
Vehicle Headways
Headway (Seconds)
Time after Onset of Green (Seconds)
4.2
3.5
2.7
2.3
2.1
2
1.9
1.8
1.8
1.8
Gap Reduction:
4.0 sec
2.0 sec
Time
5 sec
10 sec
Beginning of
Extension period

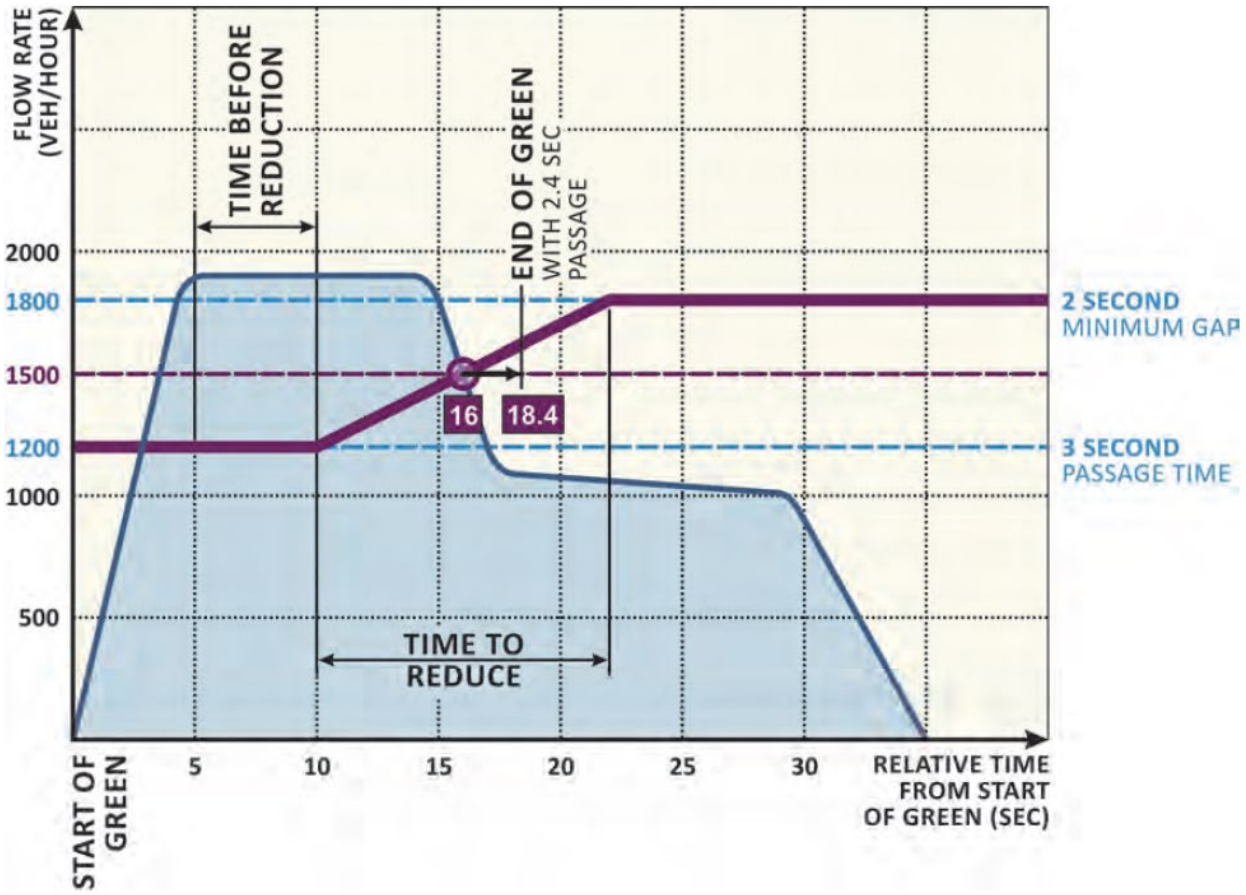
Flow Rate Perspective

- Flow rate is the inverse of headway
- Gap-out happens when the flow rate is less than the pre-determined flow rate given a certain passage time



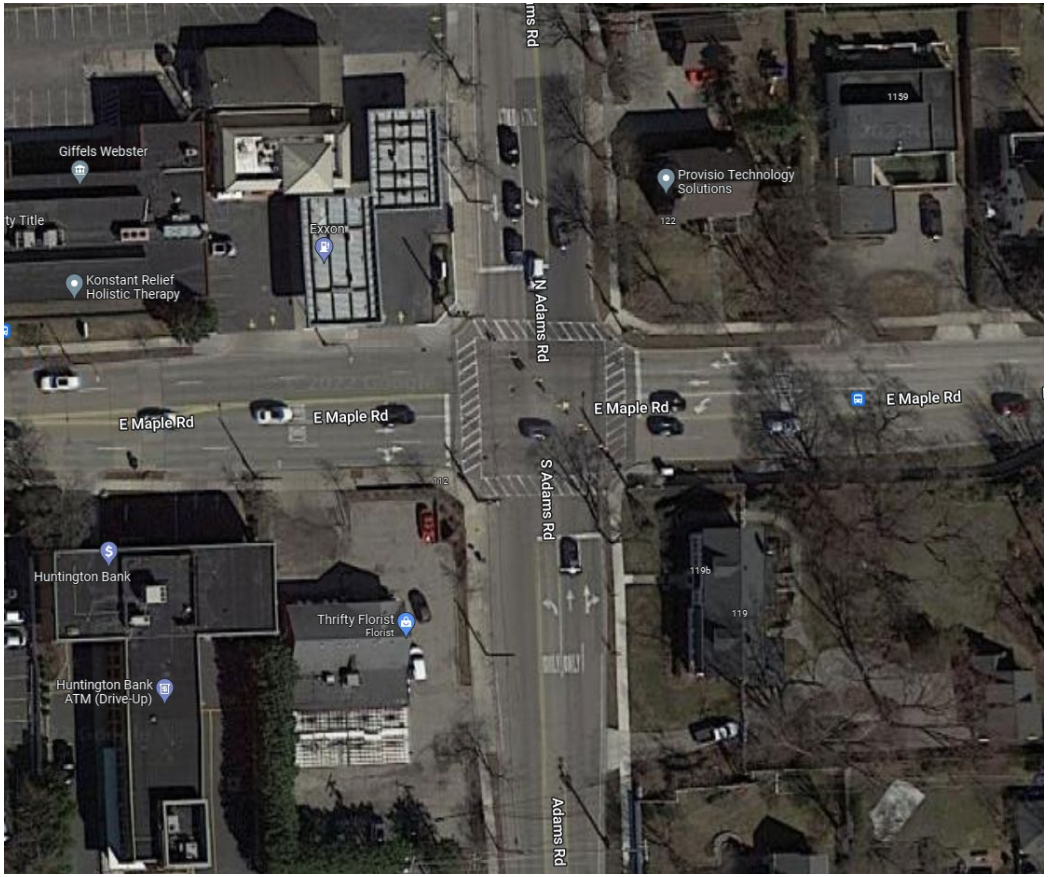
Flow Rate Perspective

- Gap reduction

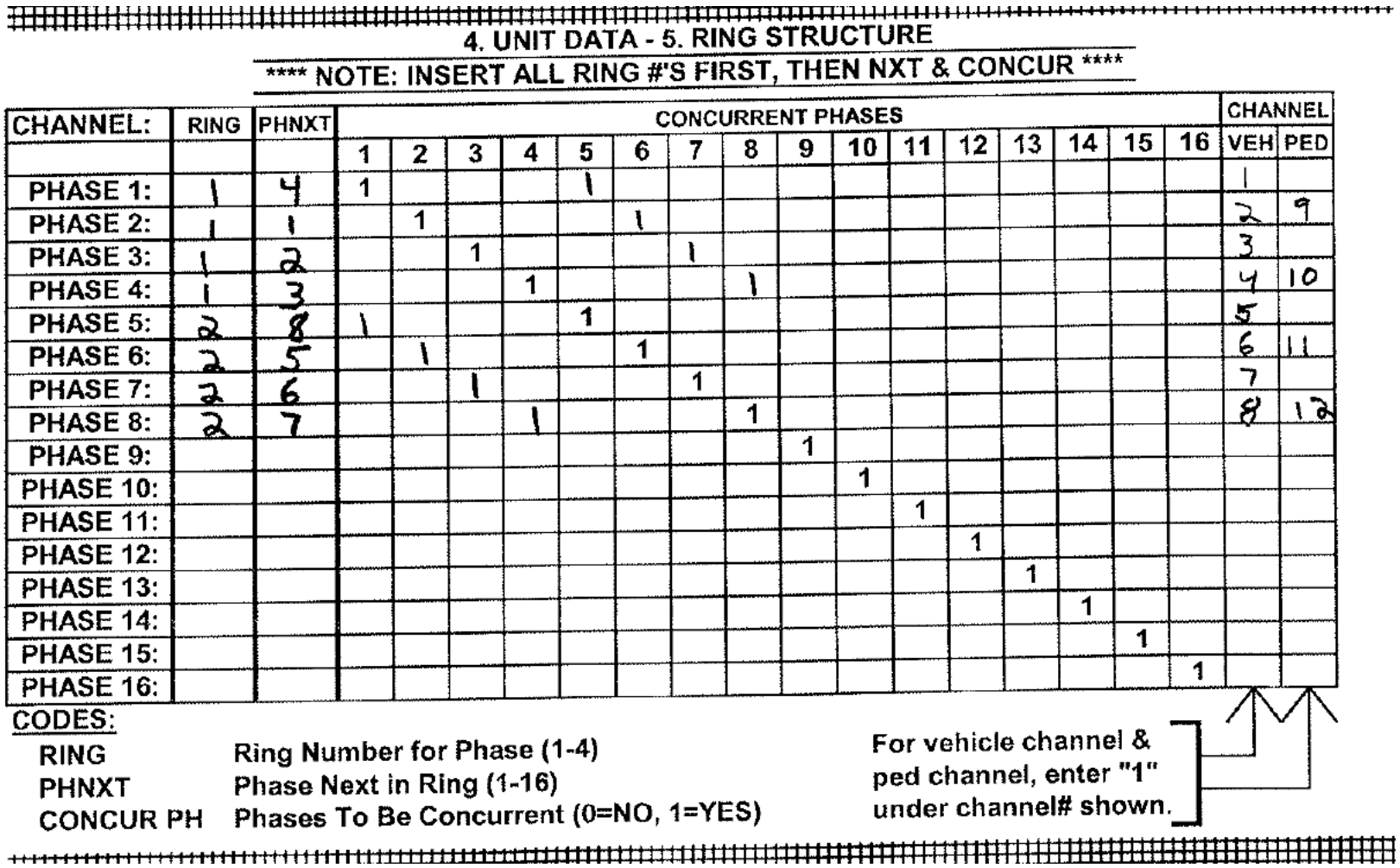


Real-World Example

- Adams & Maple Road, City of Birmingham, Michigan



Phase Structure



4. UNIT DATA - 5. RING STRUCTURE

**** NOTE: INSERT ALL RING #'S FIRST, THEN NXT & CONCUR ****

CHANNEL:	RING	PHNXT	CONCURRENT PHASES															CHANNEL	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	VEH	PED
PHASE 1:	1	4	1				1												1	
PHASE 2:	1	1		1				1											2	9
PHASE 3:	1	2			1				1										3	
PHASE 4:	1	3				1				1									4	10
PHASE 5:	2	8	1				1												5	
PHASE 6:	2	5		1				1											6	11
PHASE 7:	2	6			1				1										7	
PHASE 8:	2	7				1				1									8	12
PHASE 9:											1									
PHASE 10:												1								
PHASE 11:													1							
PHASE 12:														1						
PHASE 13:															1					
PHASE 14:																1				
PHASE 15:																	1			
PHASE 16:																		1		

CODES:

RING	Ring Number for Phase (1-4)
PHNXT	Phase Next in Ring (1-16)
CONCUR PH	Phases To Be Concurrent (0=NO, 1=YES)

For vehicle channel & ped channel, enter "1" under channel# shown.

Phase-Movement Mapping

SIGNAL PHASING

PHASE#	ROAD	PHASE	LOAD SW	FLASH
1	EB Maple LT	CL	1	R
2	WB Maple	A	2	R
3	NB Adams LT	DL	3	R
4	SB Adams	B	4	R
5	WB Maple LT	AL	5	R
6	EB Maple	C	6	R
7	SB Adams LT	BL	7	R
8	NB Adams	D	8	R
OLA				
OLB				
OLC				
OLD				
1PED				
2PED	Maple N Leg PED	WA	9	
3PED				
4PED	Adams W Leg PED	WB	10	
5PED				
6PED	Maple S Leg PED	WC	11	
7PED				
8PED	Adams N Leg PED	WD	12	

Phase Data

3. PHASE DATA - 1. BASIC TIMINGS

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	RANGE
Minimum Green	5	10	5	5	5	10	5	5									00-99
Passage																	0.0-9.9
Maximum #1	8	31	8	23	8	31	8	23									000-999
Maximum #2																	000-999
Yellow Clearance	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5									3.0-9.9
Red Clearance	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5									0.0-9.9

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ROAD COMMISSION FOR OAKLAND COUNTY, WATERFORD, MICHIGAN
PROGRAM LOG FOR EAGLE SIGNAL CONTROLLER - MOD 52 EPAC

3. PHASE DATA - 3. PEDESTRIAN TIMINGS

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	RANGE (SEC)
Walk		7		7		7		7									00-99
Pedest Clearance		13		13		13		13									00-99
Flashing Walk																	
Extend Ped Clear		0		0		0		0									(0-no, 1-Y+R, 2-Y)
Act Rest in Walk																	

Time of Day Plans

6. TIME BASE DATA - 3. TRAFFIC EVENTS

PRO DAY	TIME H H : M M	COORD PATRN		MAX 2 PHASE #S									OMIT PHASE #S							
* * *	* * * * *	D / S / O		*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*
01	00 : 00	1 / 1 / 1																		
02	00 : 00	1 / 1 / 1																		
02	07 : 00	2 / 1 / 1																		
02	10 : 00	1 / 1 / 1																		
02	15 : 00	3 / 1 / 1																		
02	19 : 00	1 / 1 / 1																		
	:	/ /																		
	:	/ /																		
	:	/ /																		
	:	/ /																		
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	:	/ /																		
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	:	/ /																		
	:	/ /																		
	:	/ /																		
	:	/ /																		
	:	/ /																		

REFERENCE DATA
PRO DAY = 01 - 99
(Program day)

HH:MM = 24 Hour clock

PATTERN: (D/S/O)
FLASH =5/5/
FREE =0/0/4

MAX2 & OMITS:
Call free, set pattern to 0/0/0.

D = DIAL #
S = SPLIT #
0 = OFFSET #

Cycle, Split, and Offsets

5. COORDINATION DATA - 3. DIAL/SPLIT DATA

LEVEL 2

DIAL 1 / SPLIT 1 CYCLE LENGTH: 90

PHASE	1	2	3	4	5	6	7	8
TIME	13	38	12	27	13	38	12	27
MODE	3	1	3	7	3	1	3	7

DIAL 1 / SPLIT 2 CYCLE LENGTH:

PHASE	1	2	3	4	5	6	7	8
TIME								
MODE								

DIAL 1 / SPLIT 3 CYCLE LENGTH:

PHASE	1	2	3	4	5	6	7	8
TIME								
MODE								

DIAL 1 / SPLIT 4 CYCLE LENGTH:

PHASE	1	2	3	4	5	6	7	8
TIME								
MODE								

LEVEL 1

OFFSET	1	2	3
TIME	37		
SEQUENCE			
RING 2 LAG			
RING 3 LAG			
RING 4 LAG			
OFFSET	1	2	3
TIME			
SEQUENCE			
RING 2 LAG			
RING 3 LAG			
RING 4 LAG			
OFFSET	1	2	3
TIME			
SEQUENCE			
RING 2 LAG			
RING 3 LAG			
RING 4 LAG			
OFFSET	1	2	3
TIME			
SEQUENCE			
RING 2 LAG			
RING 3 LAG			
RING 4 LAG			

Readings

- Signal Timing Manual (2nd Edition): Chapter 6