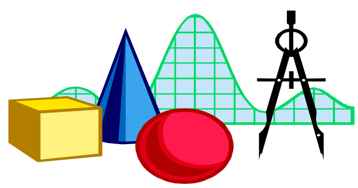
Texas Department of Transportation

Texas Transportation Institute

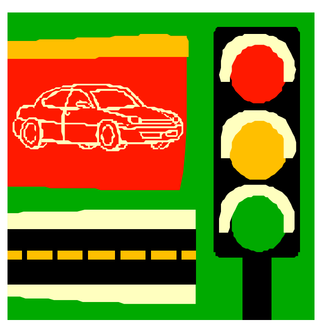
Traffic Signal Operations Workshop

An Engineer's Guide to Traffic Signal Timing and Design



Course Notes

Product 0-5629-P2



2008

TRAFFIC SIGNAL OPERATIONS WORKSHOP

Date: ______________________________
Location: ______________________________
Contacts: Jim Bonneson, (979) 845-9906, j-bonneson@tamu.edu

Agenda

(Agenda times to be determined based on workshop focus)

Introduction

Session 1: Signal Controller Timing

Session 2: Signal Coordination Timing

Session 3: Signal Phasing and Operation

Session 4: Advanced Signal Timing Settings

Session 5: Detection Design and Operation

Session 6: Diamond Interchange Operations

Course Materials: Course Notes
Traffic Signal Operations Handbook
Traffic Signal Coordination Optimizer Software (TSCO)

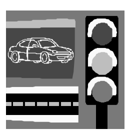
Traffic Signal Timing and Detection Design

Traffic Signal Operations Workshop

Texas Department of Transportation

Welcome

- Introductory Session
  - *Objective, outcome, scope*
  - *Background*
  - *Handbook and Workshop Organization*
  - *Agenda*



Objective & Outcome

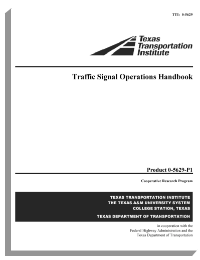
- Objective
  - *To inform participants about…*
    - Effective signal timing and design practices
    - Availability of tools to assist with timing and design
  - *To demonstrate how to apply these tools*
- Outcome
  - *Participants should be able to…*
    - Determine effective signal settings and detection layout
    - Apply the evaluation tools

Scope

- **Scope**
  - ***Workshop is intended to show engineers and technicians how various guidelines and tools can be used to develop effective signal timing and detection design***
  - ***Participant is assumed to have a working knowledge of traffic signal equipment and the authority to make, or recommend, changes to the operation of this equipment***

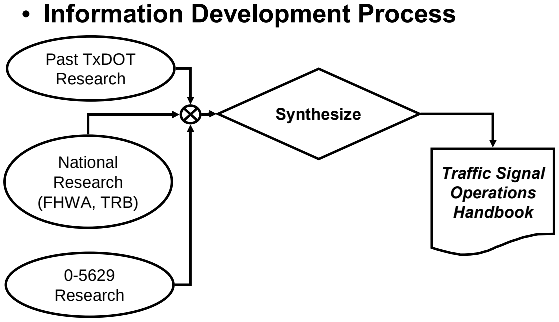
Background

- **Project 0-5629**
  - ***"Best TxDOT Practices for Signal Timing and Detection Design"***
  - ***Project Director:***
    - **Henry Wickes**
  - ***Key product:***
    - **Traffic Signal Operations Handbook**



Background

- **Information Development Process**



Handbook Organization

- Organization Objectives
  - *Quick-response*
    - Easy to find guidelines by locating in one location
    - Easy to use guidelines via table look-up and figures
- Chapters
  - *Overview*
  - *Concepts*
  - *Procedure*
  - *Guidelines*
- Appendices
  - *Overview*
  - *Concepts*
  - *Guidelines*

Handbook Organization

- Concepts
  - *Defines controller features and design terms*
  - *Something you read once*
  - *Experienced persons may not need this section*
- Procedure
  - *Describes typical steps in signal timing*
  - *Something you read once*
- Guidelines
  - *Information about where, when, what to use*
  - *Information you use all the time*

Workshop Organization

- Organization Objectives
  - *Chapter by chapter (appendix by appendix)*
  - *Within a chapter or appendix*
    - One topic at a time (e.g., minimum green)
    - Brief review of concepts
    - Detailed discussion of guidelines
    - Example application of guidelines
    - Exercises to practice use of guidelines
  - *Two items to note…*
    - Emphasis is on GUIDELINES
    - In the Handbook, concept material on a topic is not adjacent to guideline material on a topic

Agenda

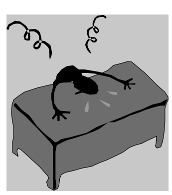
- Session 1:
  - *Signal Controller Timing*
- Session 2:
  - *Signal Coordination Timing*
- Session 3:
  - *Signal Phasing and Operation*
- Lunch Break

Agenda

- Session 4:
  - *Advanced Signal Timing Settings*
- Session 5:
  - *Detection Design and Operation*
- Session 6:
  - *Diamond Interchange Operations*

Policy on Questions

- Policy Points
  - *Questions are encouraged*
  - *Please ask them as they occur to you*



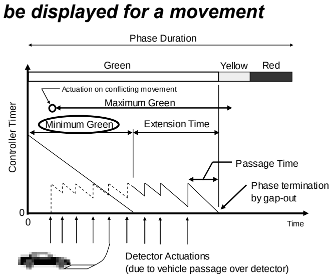
Questions?

1. Signal Controller Timing

- **Chapter 2 Guidelines**
  - ***Phase settings***
    - **Minimum green setting**
    - **Maximum green setting**
    - **Yellow change interval**
    - **Red clearance interval**
    - **Phase recall mode**
    - **Passage time**
  - ***Detector settings***
  - ***Pedestrian settings***

Minimum Green Setting

- **Concepts**
  - ***The least amount of time that a green indication will be displayed for a movement***



Minimum Green Setting

- Guidelines
  - *Considerations for selecting min. green*
    - Driver expectancy
    - Queue clearance
    - Pedestrian crossing time
  - *Each consideration has a different minimum green requirement*
  - *Consider all that apply and use the largest*

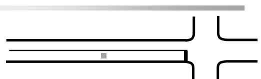
Minimum Green Setting

- Driver Expectancy
  - *Applies to every phase*

Phase	Approach Type	Minimum Green, s
Through	Major-road	8 to 15
Through	Minor-road	5 to 10
Left-turn	All	5 to 8

Minimum Green Setting

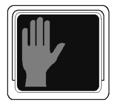
- Queue Clearance
  - *Applies when*
    - Advance-only detection is used
    - Variable initial is not used



Distance between Stop Line and Detector, ft	Minimum Green, s
0 to 25	5
26 to 50	7
51 to 75	9
76 to 100	11
101 to 125	13
126 to 150	15

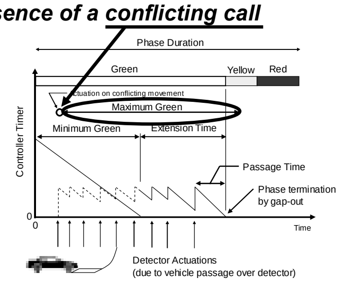
Minimum Green Setting

- **Pedestrian Crossing Time**
  - ***Applies when***
    - **Phase serves a through movement**
    - **Pedestrian push button not provided**
    - **Pedestrian demand is likely to exist**
  - ***Minimum Green (Gp)***
    - **Gp = W + PCI**
    - **where,**
      - **W = walk interval (4 to 7 s)**
      - **PCI = pedestrian change interval (10 to 30 s)**
    - **Variables discussed later in this session**



Maximum Green Setting

- **Concepts**
  - ***Maximum time of green display in the presence of a conflicting call***

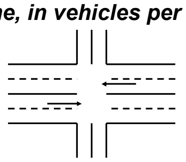


Maximum Green Setting

- **Guidelines**
  - ***Major-road through phase***
  - ***Minor-road through phase***
  - ***Left-turn movement phase***

Maximum Green Setting

- **Major-Road Through Phase**
  - ***1) At least 30 seconds***
  - ***2) At least 10 seconds longer than the minimum green setting***
  - ***3) At least as long, in seconds, as 1/10th the peak-period volume, in vehicles per hour per lane***

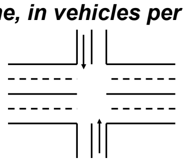


Maximum Green Setting

- **Major-Road Through Phase**
  - ***1) At least 30 seconds***
  - ***2) At least 10 seconds longer than the minimum green setting***
  - ***3) At least as long, in seconds, as 1/10th the peak-period volume, in vehicles per hour per lane***
- **Example:**
  - ***Vol. = 360 veh/h/ln, min. green = 12 s***
  - ***Max. green = larger of: (30, 12+10, 0.1 x 360)***
  - ***Max. green = 36 s***

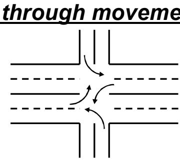
Maximum Green Setting

- **Minor-Road Through Phase**
  - ***1) At least <u>20</u> seconds***
  - ***2) At least 10 seconds longer than the minimum green setting***
  - ***3) At least as long, in seconds, as 1/10th the peak-period volume, in vehicles per hour per lane***



Maximum Green Setting

- **Left-Turn Movement Phase**
  1) ***At least 15 seconds***
  2) ***At least 10 seconds longer than the minimum green setting***
  3) ***At least half as long as the maximum green for the adjacent through movement***



Maximum Green Setting

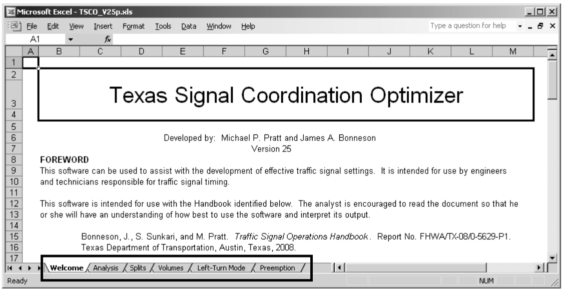
- **Left-Turn Movement Phase**
  1) ***At least 15 seconds***
  2) ***At least 10 seconds longer than the minimum green setting***
  3) ***At least half as long as the maximum green for the adjacent through movement***
- **Example**
  - ***Min. green = 6 s***
  - ***Max. green = larger of: (15, 6+10, 0.5 x 36)***
  - ***Max. green = 18 s***

Example Problem

- **Application**
  - ***Maximum green setting***
- **Calculation Tool**
  - ***Traffic Signal Coordination Optimizer (TSCO)***
- **Organization**
  - ***Introduce TSCO***
  - ***Work example problem using TSCO***

Introduction to TSCO

- **Signal Timing Toolbox**

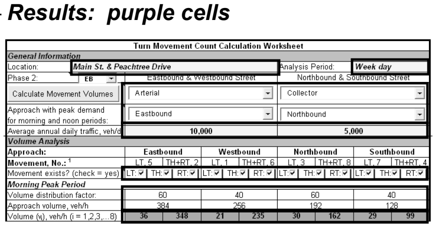


Introduction to TSCO

- **TSCO Tools**
  - ***Analysis***
    - **Timing plan evaluation and optimization**
  - ***Splits***
    - **Phase split calculation**
  - ***Volumes***
    - **Turn movement count estimation**
  - ***Left-Turn Mode***
    - **When to use protected left-turn phases**
  - ***Preemption***
    - **Preemption worksheet for highway-rail crossings**

Introduction to TSCO

- **TSCO Instructions** Click On: Volumes
  - ***Inputs: blue cells, drop-down, check boxes***
  - ***Intermediate calculations: white cells***
  - ***Results: purple cells***



Example 1: Maximum Green

- **Step 1: Collect Intersection Data**
  - ***Data needs:***
    - **Peak-period turn movement volume**
    - **Minimum green setting**
  - ***Traffic data collection alternatives***
    - **Conduct turn movement count**
    - **Use TSCO to estimate turn movement counts**

Example 1: Maximum Green

- **Step 2: Estimate Peak-Period Volume**
  - ***Enter data in Volumes worksheet*** Volumes
    - **Major (E/W): arterial, AADT = 10,000 veh/d**
    - **Minor (N/S): collector, AADT = 5,000 veh/d**
    - **Both: 2 through lanes, min. green = 10 s**

Turn Movement Count Calculation Worksheet								
General Information								
Location:	***Main St. & Peachtree Drive***				Analysis Period:		***Week day***	
Phase 2: EB	Eastbound & Westbound Street				Northbound & Southbound Street			
Calculate Movement Volumes	Arterial				Collector			
Approach with peak demand for morning and noon periods:	Eastbound				Northbound			
Average annual daily traffic, veh/d	**10,000**				**5,000**			
Volume Analysis								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Movement exists? (check = yes)	LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓	

Example 1: Maximum Green

- **Step 2: Estimate Peak-Period Volume**
  - ***Find the westbound peak-period volume***

Volume Analysis								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Movement exists? (check = yes)	LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓		LT: ✓ TH: ✓ RT: ✓	
Morning Peak Period								
Volume distribution factor:	60		40		60		40	
Approach volume, veh/h	384		2[illegible]6		192		128	
Volume (v_i), veh/h (i = 1,2,3,...8)	**36**	**348**	**21**	**235**	**30**	**162**	**29**	**99**
Mid-Morning Period								
Volume distribution factor:	50		50		50		50	
Approach volume, veh/h	250		250		125		125	
Volume (v_i), veh/h (i = 1,2,3,...8)	**22**	**228**	**22**	**228**	**24**	**101**	**24**	**101**
Noon Peak Period								
Volume distribution factor:	50		50		50		50	
Approach volume, veh/h	290		290		145		145	
Volume (v_i), veh/h (i = 1,2,3,...8)	**25**	**265**	**25**	**265**	**28**	**117**	**28**	**117**
Mid-Afternoon Period								
Volume distribution factor:	50		50		50		50	
Approach volume, veh/h	285		285		143		143	
Volume (v_i), veh/h (i = 1,2,3,...8)	**25**	**260**	**25**	**260**	**27**	**115**	**27**	**115**
Evening Peak Period								
Volume distribution factor:	40		60		40		60	
Approach volume, veh/h	316		474		158		237	
Volume (v_i), veh/h (i = 1,2,3,...8)	**26**	**290**	**44**	**430**	**36**	**122**	**38**	**199**

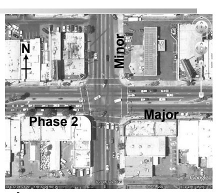
Example 1: Maximum Green

- **Step 3: Determine Maximum Green Setting**
  1) ***At least 30 seconds***
     G_{max} = **30 s**
  2) ***At least 10 seconds longer than the minimum green setting***
     $G_{max} = 10 + 10 = 20$ s
  3) ***At least as long, in seconds, as 1/10th the peak-period volume, in vehicles per hour per lane***
     V = 430/2 = 215 veh/h/ln
     $G_{max} = 0.1 \times 215 = 22$ s

Example 2: Maximum Green

- **Given**
  - ***AADTs for an intersection***
- **The Questions**
  - ***What is the peak-period through volume for each road?***
  - ***What is the maximum green setting for...***
    - **Major-road westbound through phase?**
    - **Minor-road northbound through phase?**
    - **Major-road eastbound left-turn phase?**

Example 2: Maximum Green



- **The Data**
  - ***AADT***
    - **Major (E/W): 15,500 veh/d**
    - **Minor (N/S): 7,500 veh/d**
  - ***Functional class***
    - **Both: arterial**
  - ***Configuration***
    - **Both: 2 through lanes per approach**
  - ***Minimum green settings***
    - **Major (E/W) left-turn phases: 6 s**
    - **Major (E/W) through phases: 12 s**
    - **Minor (N/S) through phases: 14 s**
- **Work for 5 minutes**

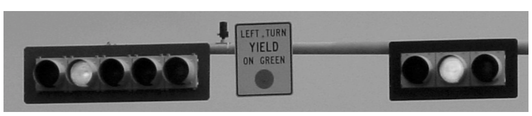
Example 2: Maximum Green

- The Answers
  - *Major through:*
  - *Minor through:*
  - *Major left:*
  - ***Use <u>File</u> → <u>Save As</u> to rename and save the TSCO file.***

Movement Phase	Peak-Period Volume, veh/h	Min. Green, s	Maximum Green, s Based on. . .		
			Shortest Value	Minimum Green+10	Volume
Major thru					
Minor thru					
Major left					

Yellow Change Interval

- Concepts
  - *Intended to alert a driver of an impending presentation of red indication*
  - *TMUTCD guidance*
    - Range: 3 to 6 s
    - Longer values used for higher speeds



Yellow Change Interval

- Guidelines
  - *ITE method*
    - Equation: $Y = 1.0 + \frac{1.47\ V}{20 + 64\ g}$
    - where,
      - Y = yellow change interval (3 to 6 s)
      - V = approach speed (mph)
      - g = approach grade (ft/ft)

Speed, mph	25	30	35	40	45	50	55	60
Yellow, s	3.0	3.2	3.6	3.9	4.3	4.7	5.0	<u>5.4</u>

Yellow Change Interval

- **Guidelines**
  - *Rounding to 5.0 s*
    - If Y > 5.0, many engineers round down to 5.0 s
    - If you do this…
      - Apply consistently at all intersections
      - Include the difference as a grace period when camera enforced

Speed, mph	25	30	35	40	45	50	55	60
Yellow, s	3.0	3.2	3.6	3.9	4.3	4.7	5.0	5.0

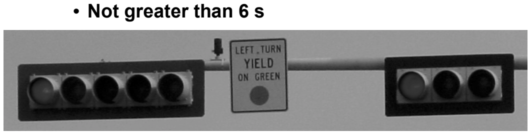
Yellow Change Interval

- **Guidelines**
  - *Approach speed*
    - Through movements
      - 85th percentile
      - Posted speed limit
      - Be consistent
    - Left-turn movements
      - Average of through speed and 20 mph

Through Speed, mph	Left-Turn Speed, mph
25 to 34	25
35 to 44	30
45 to 54	35
55 to 64	40
65 to 74	45

Red Clearance Interval

- **Concepts**
  - *A brief period of time after the yellow indication during which the ending phase and all conflicting phases display a red indication*
  - *TMUTCD guidance*
    - Optional
    - Not greater than 6 s

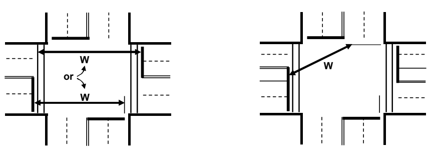


Red Clearance Interval

- Guidelines
  - *ITE method*
    - Equation: $Rc = \frac{W + L}{1.47\,V}$
    - where,
      - Rc = red clearance interval (6 s or less)
      - W = width of intersection (+ cross walk)
      - L = length of design vehicle (use 20 ft)
      - V = approach speed

Red Clearance Interval

- Guidelines
  - *Intersection width (W)*
    - Stop line to far edge of last conflicting lane
    - May extend to beyond crosswalk
  - *Left-turn movements*
    - Use a straight line approximation of path



Red Clearance Intervals

- Guidelines
  - *Typical values*
  - *Underlined values based on Y = 5.0 s*

Approach Speed, mph	Intersection Width, ft			
	50	70	90	110
30	1.6	2.0	2.5	3.0
40	1.2	1.5	1.9	2.2
50	1.0	1.2	1.5	1.8
60	<u>1.2</u>	<u>1.4</u>	<u>1.7</u>	<u>1.9</u>

Phase Recall Mode

- Concepts
  - *Recall causes the controller to place a call for a specified phase when the controller is serving a conflicting phase*
  - *Types*
    - Minimum recall
    - Maximum recall
    - Pedestrian recall
    - Soft recall

Phase Recall Mode

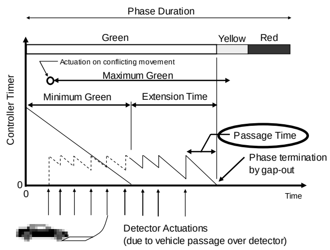
- Concepts
  - *Minimum recall*
    - Continuous call until the minimum green times out
  - *Maximum recall*
    - Continuous call until the maximum green times out
  - *Pedestrian recall*
    - Continuous call for pedestrian service until the pedestrian change interval times out
  - *Soft recall*
    - Call on a phase in the absence of any calls on a conflicting phase

Phase Recall Mode

- Guidelines
  - *Minimum recall*
    - Use on major-road through phases if no detection
  - *Maximum recall*
    - Use during detector failure
    - Use to emulate pretimed operation
  - *Pedestrian recall*
    - Use when pedestrians are present every cycle
  - *Soft recall*
    - Use on major-road through phases with detection

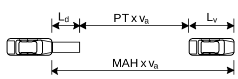
Passage Time

- **Concepts**
  - ***Maximum amount of time a vehicle actuation can extend the green interval***



Passage Time

- **Guidelines**
  - ***Duration based on three goals***
    - **Ensure queue clearance**
    - **Satisfy driver expectancy (no unneeded extension)**
    - **Reduce max-out frequency**
  - ***Equation***
    - **$PT = MAH - \frac{Lv + Ld}{1.47\ V}$**



  - ***where,***
    - **MAH = maximum allowable headway (3.0 s)**
    - **Lv = detected length of vehicle (17 ft)**
    - **Ld = length of detector (ft)**
    - **V = approach speed (mph)**

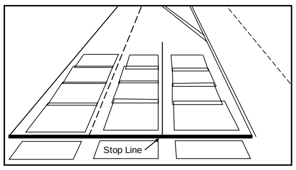
Passage Time

- **Guidelines**
  - ***Stop line presence detection***
  - ***Inductive Loop***
    - **Rule of thumb**
      - **PT = 85th % speed in mph / 20**

Detection Zone Length, ft	85th Percentile Speed, mph				
	20	25	30	35	40
	Passage Time (*PT*), s [1]				
20	1.5	2.0	2.0	2.0	2.5
40	1.0	1.0	1.5	1.5	2.0
60	0.0	0.5	1.0	1.5	1.5
80	0.0	0.0	0.5	1.0	1.0

Passage Time

- **Guidelines**
  - ***Stop line presence detection***
  - ***Video detection***
    - **PT = 0.0 s**
    - **Use long detection zone (discussed later)**

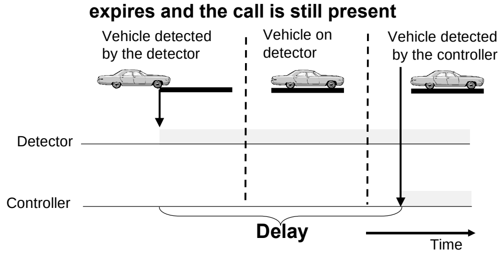


Detector Settings

- **Concepts**
  - ***Delay***
  - ***Extend***
  - ***Queue***

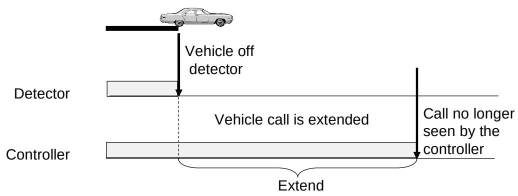
Detector Settings

- **Concepts**
  - ***Delay***
    - **Actuation is delayed until the delay timer expires and the call is still present**



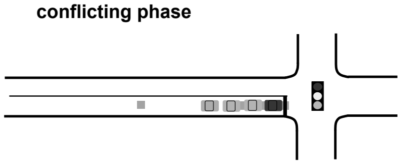
Detector Settings

- **Concepts**
  - ***Extend***
    - **Actuation is extended for a duration equal to the extension setting after the vehicle leaves the detection area**



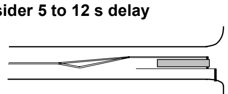
Detector Settings

- **Concepts**
  - ***Queue***
    - **Extends the phase until queue is serviced**
    - **It is then deactivated until the start of the next conflicting phase**



Detector Settings

- **Guidelines**
  - ***Delay***
    - **Use with stop line presence-mode detection serving turn movements from exclusive lanes**
    - **Right-turn movement**
      - **If opportunity for right-turn on red then,**
      - **Consider 8 to 14 s delay**
    - **Left-turn movement**
      - **If protected-permissive then,**
      - **Consider 5 to 12 s delay**



Pedestrian Settings

- Concepts
  - *Walk interval*
    - Time to alert pedestrian of opportunity to cross
    - WALK indication presented
  - *Pedestrian change interval*
    - Time to cross street
    - Flashing DON'T WALK indication presented

Pedestrian Settings

- Guidelines
  - *Walk interval*
    - TMUTCD guidance: 4 to 7 s

Conditions	Walk Interval Duration (*W*), s
High pedestrian volume areas (e.g., school, business district, etc.)	10 to 15
Typical pedestrian volume and longer cycle length	7 to 10
Typical pedestrian volume and shorter cycle length	7
Negligible pedestrian volume	4

Pedestrian Settings

- Guidelines
  - *Pedestrian change interval (PCI)*
    - Pedestrian walking speed
    - Pedestrian clearance time (PCT)


NYCDOT

Pedestrian Settings

- Guidelines
  - *Pedestrian walking speed*
    - TMUTCD – 4 fps
    - Other references – 3.5 fps
    - Children and elderly pedestrians – 3.0 fps
  - *Pedestrian clearance time (PCT)*
    - Equation: PCT = Dc/Vp
    - where,
      - Dc = curb to curb crossing distance (ft)
      - Vp = pedestrian walking speed (fps)
  - *Pedestrian change interval (PCI)*
    - Equation: PCI = PCT – (Y + Rc)

Pedestrian Settings

- Guidelines
  - *Pedestrian clearance time (PCT)*

Pedestrian Crossing Distance, ft	Walking Speed, ft/s		
	3.0	3.5	4.0
	Pedestrian Clearance Time (*PCT*), s		
20	7	6	5
30	10	9	8
40	13	11	10
50	17	14	13
60	20	17	15
70	23	20	18
80	27	23	20
90	30	26	23
100	33	29	25

Pedestrian Settings

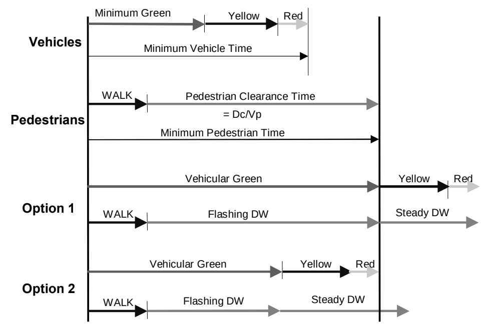
- Guidelines
  - *Pedestrian change interval*
  - *Option 1*
    - Display flashing DON'T WALK

$$PCI = PCT$$

  - *Option 2*
    - Display flashing DON'T WALK before Y+Rc
    - Display solid DON'T WALK during Y + Rc

$$PCI = PCT - (Y + R_c)$$

Pedestrian Settings

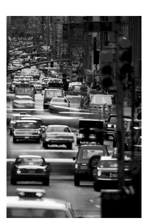


Summary

- Chapter 2 Guidelines
  - *Phase settings*
    - Minimum green setting
    - Maximum green setting
    - Yellow change interval
    - Red clearance interval
    - Phase recall mode
    - Passage time
  - *Detector settings*
  - *Pedestrian settings*
- Questions?

2. Signal Coordination Timing

- Chapter 3 Guidelines
  - *Coordination potential*
  - *System settings*
    - Cycle length
    - Offset
    - Phase sequence
    - Force mode
    - Transition mode
    - Coordination mode
  - *Phase settings*
    - Phase splits
    - Dynamic splits
    - Maximum green

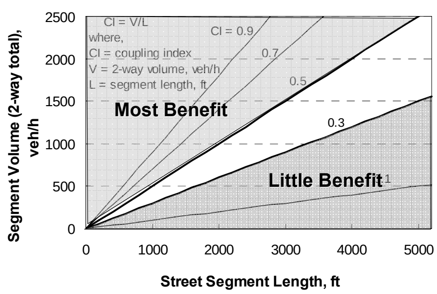


Coordination Potential

- **Concepts**
  - ***What intersections should be included in a coordinated signal system?***
  - ***Considerations***
    - **Traffic volume**
    - **Segment length (distance between signals)**
    - **Speed**
    - **Access point activity**
    - **Cycle length**
    - **Signal system infrastructure**

Coordination Potential

- **Guidelines**
  - ***Coupling index***



System Settings

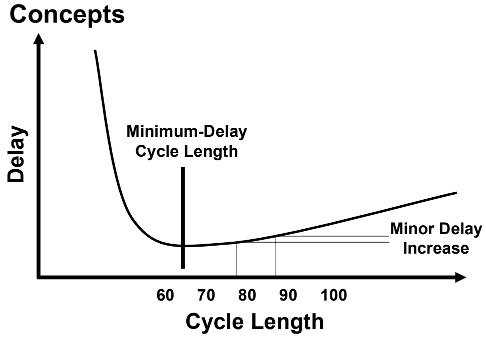
- **Settings Defining System Operation**
  - ***Cycle length***
  - ***Offset***
  - ***Phase sequence***
  - ***Force mode***
  - ***Transition mode***
  - ***Coordination mode***

Cycle Length

- Concepts
  - *Total time to complete one sequence of signalization of all movements at an intersection*
  - *Typical cycle length range*
    - Minor arterial streets: 60 to 120 s
    - Major arterial streets: 90 to 150 s
  - *Optimum cycle length based on…*
    - Traffic volume, speed,
    - Intersection capacity, phase sequence
    - Segment length

Cycle Length

- Concepts



Cycle Length

- Guidelines
  - *Longer cycle lengths*
    - Increase capacity (1 percent for 10 s increase)
    - More conducive to two-way progression
    - Increase queue length
  - *Shorter cycle length*
    - Reduce delay (if adequate capacity provided)
  - *Under-saturated intersections*
    - Use minimum delay cycle length
  - *Over-saturated intersections*
    - Use shorter cycle length to minimize spillback

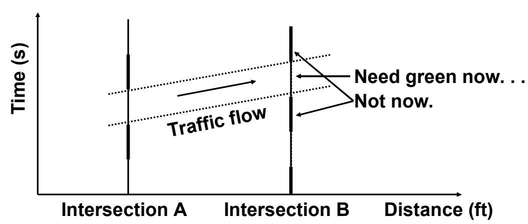
Cycle Length

- **Guidelines**

Average Segment Length, ft	Cycle Length by Street Class and Left-Turn Phasing, s					
	Major Arterial Street			Minor Arterial Street or Grid Network		
	No Left-Turn Phases	Left-Turn Phases on One Street	Left-Turn Phases on Both Streets	No Left-Turn Phases	Left-Turn Phases on One Street	Left-Turn Phases on Both Streets
250				50	50	50
500				60	90	100
1000				50	90	120
1500	90	120	150	60	80	120
2000	100	120	140	80	90	100
2500	90	140	150	100	100	120
3000	90	100	160			
3500	100	120	120			
4000	110	120	140			
4500	120	120	150			
5000	140	140	150			

Offset

- **Concepts**
  - ***Put green time where it is needed in the cycle to maximize flow***

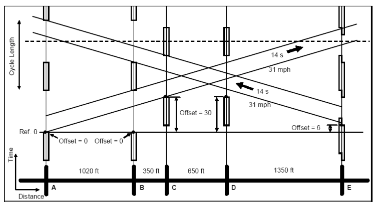


Offset

- **Guidelines**
  - ***When resources are available...***
    - **Use PASSER II or similar software tool**
  - ***When resources are not available...***
    - **Use "Kell Method" (in *Handbook* pp. 3-17 to 3-20)**
    - **Graphical solution for good two-way progression**
    - **Does not require traffic counts, just...**
      - **Progression speed**
      - **Splits**
      - **Signal spacing**

Offset

- **Guidelines**
  - ***Start with Intersection A, then B, ... etc.***
  - ***Center red or green on working line***
  - ***Automated in TSCO*** Analysis



Offset

- **TSCO Input Data**
  - ***Signal presence***
  - ***Signal location***
  - ***Offset***
  - ***Phase splits***
  - ***Change periods***
  - ***Phase sequence***

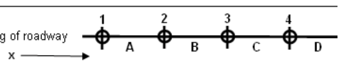
Signal Timing Data

	Data Description				
Search	Node Description:	1	2	3	4
	Signal present? (Check = yes):	1 ☑	0 ☐	3 ☑	0 ☐
Tweak	Distance coordinate (x), ft:	0		2260	
	Offset, s:	0		55	
	Phase split, % of cycle:	12%		33%	
Phase 1	Green interval, s:	4	0	19	0
Westbound	Change period (Y + RC), s:	4		4	
Left Turn	Phase sequence:	Lead	Lag	Lead	Lag
	Phase split, % of cycle:	52%		30%	
Phase 2	Green interval, s:	30	0	17	0
Eastbound	Change period (Y + RC), s:	6		4	

Offset

- **TSCO Input Data**
  - ***Segment speed***
    - **Speed of progressed traffic**
    - **TSCO can model mid-block speed changes**

Schematic drawing of roadway

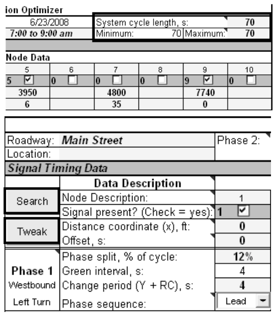


Segment Data

Segment:	A	B	C	D
Progression speed, mph:	40		40	

Offset

- **Worksheet Controls**
  - *Cycle length range*
    - Current
    - Minimum
    - Maximum
  - *"Search"*
    - Find optimal offsets & cycle length
  - *"Tweak"*
    - See if a small improvement in offsets is possible



Offset

- **Measures of Effectiveness**
  - *Bandwidth*
    - Larger is better
  - *Efficiency*
    - Larger is better
  - *Attainability*
    - Larger is better

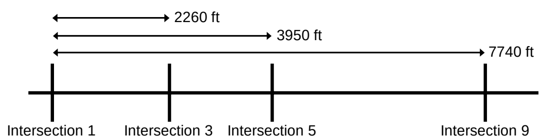
System Measures of Effectiveness		
Bandwidth, s:	27.0	
Weighted Efficiency:	19.3%	Fair
Weighted Attainability:	75.1%	Fine tune

Example 3: Offset

- **Goals**
  1) *Find the optimum timing plan (cycle length and offsets) for a coordinated signal system*
- **Steps**
  1) *Collect signal system data*
  2) *Identify the optimum timing plan (use TSCO)*

Example 3: Offset

- **Step 1: Collect Signal System Data**
  - ***Cycle length range: 60 to 80 s***



	Int. 1	**Int. 3**	**Int. 5**	**Int. 9**
Offset, s	0	55	6	0
Ph. 1 Split, %	12	33	18	15
Ph. 1 Y+RC, s	4	4	4	4
Ph. 1 Sequence	Lead	Lead	Lead	Lag

Example 3: Offset

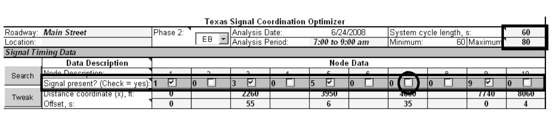
- **Step 1: Collect Signal System Data**

	Int. 1	**Int. 3**	**Int. 5**	**Int. 9**
Ph. 2 Split, %	52	30	44	41
Ph. 2 Y+RC, s	6	4	6	6
Ph. 5 Split, %	20	30	12	14
Ph. 5 Y+RC, s	3	4	3	3
Ph. 5 Sequence	Lead	Lag	Lag	Lead
Ph. 6 Split, %	44	33	50	42
Ph. 6 Y+RC, s	6	4	6	6

  - ***Progression speed: 40 mph***

Example 3: Offset

- **Step 2: Identify Optimal Timing Plan**
  - ***Enter input data***
    - **Enter cycle length range: 60 to 80 s**
    - **Uncheck the box for node 7**
      - **This data will be used later**
    - **Verify distance and offset data**



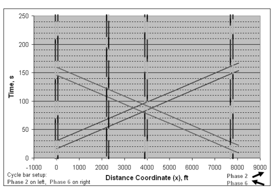
Example 3: Offset

- **Step 2: Identify Optimal Timing Plan**
  - *Enter input data*
    - **Verify phase and speed data**

		1	2	3	4	5	6	7	8	9	10
Phase 1 Westbound Left Turn	Phase split, % of cycle:	12%		33%		18%		15%		15%	
	Green interval, s:	4	0	19	0	9	0	7	0	7	0
	Change period (Y + RC), s:	4		4		4		4		4	
	Phase sequence:	Lead	Lag	Lead	Lag	Lead	Lead	Lag	Lead	Lag	Lag
Phase 2 Eastbound	Phase split, % of cycle:	52%		30%		44%		44%		41%	
	Green interval, s:	30	0	17	0	25	0	25	0	23	0
	Change period (Y + RC), s:	6		4		6		6		6	
Phase 5 Eastbound Left Turn	Phase split, % of cycle:	20%		30%		12%		15%		14%	
	Green interval, s:	11	0	17	0	5	0	8	0	7	0
	Change period (Y + RC), s:	3		4		3		3		3	
	Phase sequence:	Lead	Lead	Lag	Lead	Lag	Lag	Lead	Lag	Lead	Lag
Phase 6 Westbound	Phase split, % of cycle:	44%		33%		50%		44%		42%	
	Green interval, s:	24	0	19	0	30	0	25	0	24	0
	Change period (Y + RC), s:	6		4		6		6		6	
	Schematic drawing of roadway x →	1	2	3	4	5	6	7	8	9	10
Segment Data											
	Segment:	A	B	C	D	E	F	G	H	I	
	Progression speed, mph:	40		40		40		40		40	

Example 3: Offset

- **Step 2: Identify Optimum Timing Plan**
  - *Click the "Search" button*



	Int. 1	Int. 3	Int. 5	Int. 9
Offset (s)	0	55	12	69
Cycle length: 70 s		Bandwidth: 27.0 s		

Example 4: Offset

- **Given**
  - *The signal system from Example 3 and two alternative locations for a proposed new signal*
- **The Questions**
  - *What is the optimal offset for each alternative?*
  - *What is the optimal bandwidth for each alternative?*
  - *Which alternative is best?*

Example 4: Offset

- The Data
  - *Same data as for Example 3, except...*
  - *New signal (check the box for node # 7)*
    - Alternative 1
      - Distance (x): 4,800 ft from signal 1
      - Offset: 30 s
    - Alternative 2
      - Distance (x): 5,200 ft from signal 1
      - Offset: 30 s
- Work for 5 minutes
  - *Click "Tweak" to evaluate each option*

Example 4: Offset

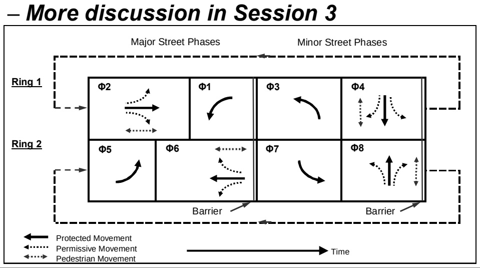
- The Answers
  - *Alternative 1 (4,800 ft)*

Example 4: Offset

- The Answers
  - *Alternative 2 (5,200 ft)*

Phase Sequence

- **Concepts**
  - ***Order by which the phases are presented***
  - ***Lead-lead, lag-lag, lead-lag***
  - ***More discussion in Session 3***



Phase Sequence

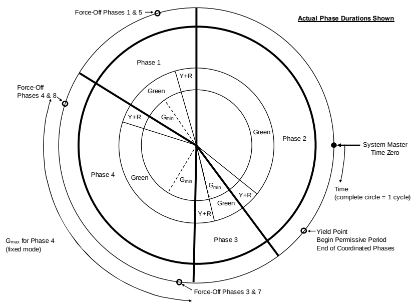
- **Guidelines**
  - ***Lead-lead***
    - **Most common**
  - ***Lag-lag***
    - **Some districts use to improve efficiency with protected-permitted operations**
    - **Watch out for yellow trap**
    - **Consider maximum recall for left-turn phase**
  - ***Lead-lag***
    - **Can improve the quality of progression**
    - **Watch out for yellow trap**
    - **Consider maximum recall for lagging left-turn**

Force Mode

- **Concepts**
  - ***Fixed mode***
    - **Excess time from an early non-coordinated phase available to a later non-coordinated phase**
    - **Usually more efficient than floating mode**
  - ***Floating mode***
    - **Excess time from all non-coordinated phases available to coordinated phase**
    - **Can be helpful IF an early return to the coordinated phase is desirable**

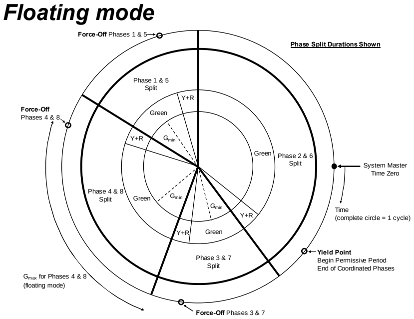
Force Mode

- **Concepts**
  - *Fixed mode*



Force Mode

- **Concepts**
  - *Floating mode*



Force Mode

- **Guidelines**
  - *Fixed mode should be used unless…*
    - **Extensive queues exist for the coordinated movements at the start of green and**
    - **Minor movement volumes are low**

Transition Mode

- **Concepts**
  - ***Used when a new timing plan is invoked***
  - ***Dictates how phase splits and offset are altered for the next few cycles to reflect new plan***
  - ***Modes***
    - **Short-way**
      - **Truncates or lengthens phases as needed**
      - **Change is incremental and spread over several cycles**
    - **Dwell**
      - **Dwells in the coordinated phase until synchronized**
      - **Change occurs in one cycle**

Transition Mode

- **Guidelines**
  - ***Choice of mode is based on…***
    - **Cycle length**
    - **Minor movement volume**

Minor Movement Volume	**1st Choice Transition Mode**	
	Short Cycle	**Long Cycle**
Low	Dwell	Short-way
High	Dwell or Short-way	Short-way

Coordination Mode

- **Concepts**
  - ***Modes vary among controller types***
  - ***Defines how and when minor movement calls received during coordinated phase are served***
  - ***Simple mode***
    - **Any call received before yield point terminates phase and is served in sequence**
  - ***Complicated mode***
    - **Only calls to next phase are considered just prior to their potential time period in sequence**

Coordination Mode

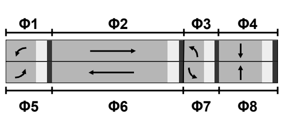
- Guidelines
  - *If pedestrian demand is significant then…*
    - Consider a mode that allows the coordinated phase to dwell in the WALK indication
  - *If volume on the cross street is light then…*
    - Consider a mode that yields only to the next phase during the permissive yield period (or previous phase)

Phase Settings

- Settings Defining Phase Operation
  - *Phase splits*
  - *Dynamic splits*
  - *Maximum green*

Phase Splits

- Concepts
  - *Sum of green, yellow, and red clearance*
  - *Non-coordinated splits based on volume (average + random excess)*
  - *Allocate rest of cycle to coordinated phases*



Phase Splits

- **Guidelines**
  - ***Handbook worksheet (p. 3-24)***
    - **Collect volume and lane count data**
    - **Allocate green time and compute splits (critical movement analysis)**
  - ***Automated in TSCO***

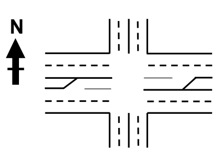
Phase Split Calculation Worksheet								
General Information								
Location: Main St. & Peachtree Drive			Cycle Length (C), s: 100		Analysis Period: ______ to ______			
Volume and Lane Geometry Input								
Approach:	Eastbound		Westbound		Northbound		Southbound	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Volume (v_i), veh/h i = 1, 2, 3, ... 8	*105*	*502*	*201*	*806*	*93*	*408*	*57*	*104*
Lanes (n_i)	*1*	*2*	*1*	*2*	*0*	*2*	*0*	*1*
Change Period and Minimum Green								
Yellow + red clearance (Y_i), s	*5*	*5*	*5*	*5*	--	*5*	--	*5*
Minimum green ($G_{m,i}$), s	*8*	*10*	*8*	*10*	--	*16*	--	*16*
Phase Sequence	LT & TH in Same Phase (prot TH & perm LT)				LT & TH in Same Phase (prot TH & perm LT)			
Opposing Volume ($v_{o,i}$), veh/h	v_6 =		v_2 =		v_4 = 104		v_8 = 408	
LT equivalence ($E_{L,i}$) (Fig. 3-7)		1.0		1.0	*1.5*	1.0	*2.1*	1.0
Sneakers (S_i), veh/h [=5400/C]		0.0		0.0	*54*	0.0	*54*	0.0
Adjusted volume (v^*_i) [= E_L (v_i - S_i) ≥ 0.0]					*59*	*408*	*6*	*104*
Without Bay								
Lane volume **without** bay ($v_{n,i}$) {see note 2}						*233*		*110*
Average Green ($G_{a,i}$), s [= larger of:($v_{n,i}$ C/1800/0.85, $G_{m,i}$]						*16*		*16*
Phase split (T_i), s {see note 3}						*21*		*21*
With Bay								
Lane volume **with** bay ($v_{n,i}$) [= v^*_i/ n_i], veh/h/ln								
Average Green ($G_{a,i}$), s [= larger of:($v_{n,i}$ C/1800/0.85, $G_{m,i}$]								
Phase split (T_i), s {see note 4}								
	LT Phase & TH Phase				LT Phase & TH Phase			
Lane volume **with** bay ($v_{n,i}$) [= v_i/ n_i], veh/h/ln	*105*	*251*	*201*	*403*				
Average Green ($G_{a,i}$), s [= larger of:($v_{n,i}$ C/1800/0.85, $G_{m,i}$]	*8*	*16*	*13*	*26*				
Phase split (T_i), s {see note 5}	*13*	*26*	*18*	*31*				
Phase Splits								
Phase split (T_i), s {see note 6}	*13*	*61*	*18*	*66*	--	*21*	--	*21*

Example 5: Phase Splits

- **Goals**
  1) ***Determine the turn movement counts for an intersection***
  2) ***Use these counts to compute reasonable evening peak-period phase splits***
- **Steps**
  1) ***Collect intersection data***
  2) ***Estimate the peak-period volume***
  3) ***Compute phase splits***

Example 5: Phase Splits

- **Step 1: Collect Intersection Data**
  - ***AADT***
    - **Major (E/W): 15,500 veh/d**
    - **Minor (N/S): 7,500 veh/d**
  - ***Functional class***
    - **Major (E/W): arterial**
    - **Minor (N/S): arterial**
  - ***Configuration***
    - **Major (E/W): 1 left-turn and 2 through lanes**
    - **Minor (N/S): 2 through lanes**



Example 5: Phase Splits

- **Step 1: Collect Intersection Data**
  - *Signal timing data*
    - Phasing
      - Major (E/W) left-turn phase on each approach
      - Major (E/W) through phase on each approach
      - Minor (N/S) through phase on each approach
    - Cycle length: 80 s
    - Yellow + red clearance settings
      - All phases: 5 s
    - Minimum green settings
      - Major (E/W) left-turn phase: 6 s
      - Major (E/W) through phase: 12 s
      - Minor (N/S) through phase: 14 s

Example 5: Phase Splits

- **Step 2: Estimate Peak-Period Volume**
  - *Same volume data from Example 2*

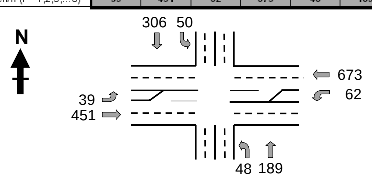
Turn Movement Count Calculation Worksheet

General Information								
Location:	*Main St. & Peachtree Drive*				Analysis Period:	*Week day*		
Phase 2: EB	Eastbound & Westbound Road				Northbound & Southbound Road			
Calculate Movement Volumes	Arterial				Arterial			
Approach with peak demand for morning and noon periods:	Eastbound				Northbound			
Average annual daily traffic, veh/d	15,500				7,500			
Volume Analysis								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Movement exists? (check = yes)	LT: ☑	TH: ☑ RT: ☑	LT: ☑	TH: ☑ RT: ☑	LT: ☑	TH: ☑ RT: ☑	LT: ☑	TH: ☑ RT: ☑

Example 5: Phase Splits

- **Step 2: Estimate Peak-Period Volume**
  - *Evening peak period was specified*

Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Evening Peak Period								
Volume distribution factor:	40		60		40		60	
Approach volume, veh/h	490		735		237		356	
Volume (v_i), veh/h (i = 1,2,3,...8)	**39**	**451**	**62**	**673**	**48**	**189**	**50**	**306**



Example 5: Phase Splits

- **Step 2: Estimate Peak-Period Volume**
  - *Transfer from "Volumes" tab into "Splits" tab*
    - Type each number using keyboard, or
    - Copy and paste the values

"Volumes" row 34:

Evening Peak Period								
Volume distribution factor:	40		60		40		60	
Approach volume, veh/h	490		735		237		356	
Volume (v_i), veh/h (i = 1,2,3,...8)	39	451	62	673	48	189	50	306

Copy

"Splits" row 11:

Volume and Lane Geometry Input								
Approach:	Eastbound		Westbound		Northbound		Southbound	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Volume (v_i), veh/h [i = 1,2,3,...8]	39	451	62	673	48	189	50	306
Lanes (n_i)	1	2	1	2	0	2	0	2

Paste Special → Values

Example 5: Phase Splits

- **Step 3: Compute Phase Splits**
  - *Cycle length: 80 s*
  - *Approach configuration:*
    - E/W: 1 left-turn + 2 through lanes, LT & TH phase
    - N/S: 2 through lanes, LT & TH in same phase

Splits

Phase Split Calculation Worksheet								
General Information								
Location:	*Main St. & Peachtree Drive*				Analysis Period:		*7:00 to 9:00 am*	
Cycle Length (C), s:	80	Eastbound & Westbound Phasing:			Northbound & Southbound Phasing:			
Phase 2:	EB	LT Phase & TH Phase			LT & TH in same phase			
Volume and Lane Geometry Input								
Approach:	Eastbound		Westbound		Northbound		Southbound	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Volume (v_i), veh/h [i = 1,2,3,...8]	39	451	62	673	48	189	50	306
Lanes (n_i)	1	2	1	2	0	2	0	2
Change Period and Minimum Green								
Yellow + red clearance (Y_i), s	5	5	5	5		5		5
Minimum green ($G_{m,i}$), s	6	12	6	12		14		14

Example 5: Phase Splits

- **Step 3: Compute Phase Splits**
  - *Yellow + red clearance settings*
    - All phases: 5 s
  - *Minimum green settings*
    - Major (E/W) left-turn phase: 6 s
    - Major (E/W) through phase: 12 s
    - Minor (N/S) through phase: 14 s

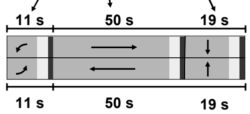
Phase Split Calculation Worksheet								
General Information								
Location:	*Main St. & Peachtree Drive*				Analysis Period:		*7:00 to 9:00 am*	
Cycle Length (C), s:	80	Eastbound & Westbound Phasing:			Northbound & Southbound Phasing:			
Phase 2:	EB	LT Phase & TH Phase			LT & TH in same phase			
Volume and Lane Geometry Input								
Approach:	Eastbound		Westbound		Northbound		Southbound	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Yellow + red clearance (Y_i), s	5	5	5	5		5		5
Minimum green ($G_{m,i}$), s	6	12	6	12		14		14

Example 5: Phase Splits

- **Step 3: Compute Phase Splits**
  - ***Results from "Splits" worksheet***
    - **63 percent of cycle available for phases 2 & 6**

Volume and Lane Geometry Input								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Computed Phase Splits								
Phase split (T_i), s {see note 6}	11	50	11	50	0	19	0	19
Phase split, % [= 100 T_i/C]	14	63	14	63	0	24	0	24

  - ***Equivalent ring structure***



Example 6: Phase Splits

- **Given**
  - ***AADTs, approach configurations, and phasing data for an intersection***
- **The Question**
  - ***What phase splits should be used for each movement phase?***

Example 6: Phase Splits

- **The Data**
  - ***Same data as for Example 5, except...***
    - **Phasing**
      - **Minor (N/S) left-turn phase on each approach**
    - **Cycle length: 70 s**
    - **Minor (N/S) left-turn lanes: 1 per approach**
    - **Minimum green settings:**
      - **Minor (N/S) left-turn phase: 6 s**
- **Work for 5 minutes**

Example 6: Phase Splits

- **The Answers**

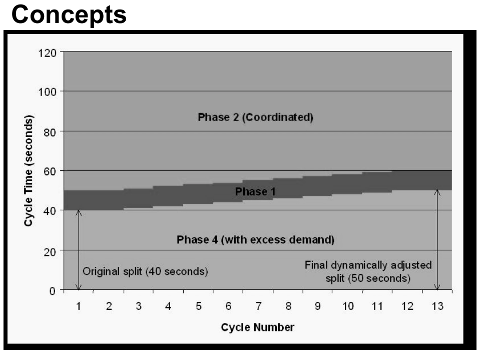
Phase Split Calculation Worksheet								
General Information								
Location:	***Main St. & Peachtree Drive***				Analysis Period:		***7:00 to 9:00 am***	
Cycle Length (C), s: **70**	Eastbound & Westbound Phasing:				Northbound & Southbound Phasing:			
Phase 2: EB	LT Phase & TH Phase				LT Phase & TH Phase			
Volume and Lane Geometry Input								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Volume (v_i), veh/h [i = 1,2,3,...8]	**39**	**451**	**62**	**673**	**48**	**189**	**50**	**306**
Lanes (n_i)	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Change Period and Minimum Green								
Yellow + red clearance (Y_i), s	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
Minimum green ($G_{m,i}$), s	**6**	**12**	**6**	**12**	**6**	**14**	**6**	**14**
Computed Phase Splits								
Phase split (T_i), s {see note 6}								
Phase split, % [= 100 T_i/C]								

Dynamic Splits

- **Concepts**
  - ***Controller automatically adjusts the phase splits on a cycle-by-cycle basis***
  - ***Takes time from a light non-coordinated phase (gapping out) to a heavier non-coordinated phase (being forced off)***
  - ***Works in coordinated mode***
  - ***Does not work if maximum recall is used***
    - **Lagging left-turn phases are often on maximum recall**

Dynamic Splits

- **Concepts**



Dynamic Splits

- **Guidelines**
  - ***Limited information on this setting***
  - ***Research indicates benefits obtained when…***
    - **Left-turn phases lead the through phases**
    - **Traffic volumes vary significantly and unpredictably**
  - ***May also be beneficial if resources limit the frequency of timing plan updates***

Maximum Green

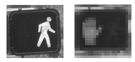
- **Guidelines**
  - ***Most controllers have the option to limit the split duration***
    - **Max 1**
    - **Max 2**
    - **Max inhibit**
  - ***Maximum green is redundant to force off***
  - ***Inhibit maximum green termination during coordinated operation***
    - **Maximum recall can still be used**

Summary

- **Chapter 3 Guidelines**
  - ***Coordination potential***
  - ***System settings***
  - ***Phase settings***
- **Questions?**

3. Signal Phasing & Operation

- **Appendix A Guidelines**
  - ***Left-turn operational mode***
  - ***Left-turn phasing***
  - ***Right-turn phasing***
  - ***Pedestrian phasing***



Left-Turn Operational Mode

- **Concepts**
  - ***Permissive***

    - **Left-turn drivers yield to oncoming vehicles**
  - ***Protected***

    - **Left-turn drivers have right-of-way**
  - ***Protected-permissive***

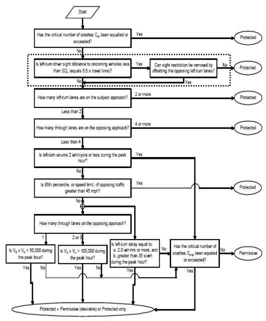
    - **Left-turn drivers have a protected phase**
    - **They can also turn during green ball, after yielding to oncoming vehicles**

Left-Turn Operational Mode

- **Guidelines**
  - ***Mode selection based on...***
    - **Left and opposing though volumes**
    - **Number of opposing through lanes**
    - **Cycle length**
    - **Opposing traffic speed**
    - **Sight distance**
    - **Crash history**

Left-Turn Operational Mode

- **Guidelines**
  - ***Flow chart from Handbook p. A-9***
    - **11 questions**
  - ***Consider each approach separately***
  - ***Automated in TSCO "Left-Turn Mode" worksheet***

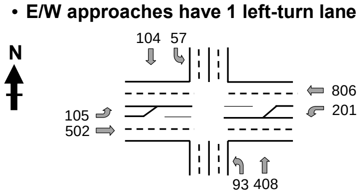


Example 7: Left-Turn Mode

- **Goals**
  1) ***Choose left-turn modes for each approach at an intersection***
- **Steps**
  1) ***Collect intersection data***
  2) ***Choose left-turn modes***

Example 7: Left-Turn Mode

- **Step 1: Collect Intersection Data**
  - ***Cycle length: 100 s***
  - ***Volume and lane geometry***
    - **All approaches have 2 through lanes**
    - **E/W approaches have 1 left-turn lane**



Example 7: Left-Turn Mode

- Step 1: Collect Intersection Data
  - *Crash history*

Approach	EB	WB	NB	SB
Crashes	4	5	4	2

  - *Time period for crashes: 2 years*
  - *Approach speeds*
    - E/W: 45 mph
    - N/S: 35 mph
  - *Sight Distance*
    - Adequate for left-turn drivers

Example 7: Left-Turn Mode

- Step 2: Choose Left-Turn Modes
  - *Enter input data*
    - Verify volume, lane data
    - Enter crash history
    - Enter speed
    - Indicate whether sight distance is adequate

Volume and Lane Geometry Input								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Volume, veh/h	105	502	201	806	93	408	57	104
Lanes	1	2	1	2	0	2	0	2
Crash History								
Left-turn related crashes	4		5		4		2	
Time period for crashes, years:	2				2			
Speed and Sight Distance								
Approach speed, mph		45		45		35		35
Minimum sight distance (SDc), ft:	360		360		280		280	
Is sight distance for the left-turn driver adequate?	Yes		Yes		Yes		Yes	

Example 7: Left-Turn Mode

- Step 2: Choose Left-Turn Modes

Volume and Lane Geometry Input								
Approach:	**Eastbound**		**Westbound**		**Northbound**		**Southbound**	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Analysis Results								
Suggested left-turn mode:	Permissive		Protected-Permissive		Permissive		Permissive	
Has the critical number of crashes (Cpt) been equaled or exceeded?	No		No		No		No	
Is left-turn driver sight distance less than the minimum needed?	No		No		No		No	
Are there two or more left-turn lanes?	No		No		No		No	
Are there four or more through lanes on the opposing approach?	No		No		No		No	
Is the left-turn volume 2 veh/cycle or less?	No		No		No		[illegible]	
Is the speed of opposing traffic greater than 45 mph?	No		No		[illegible]		[illegible]	
How many through lanes on the opposing approach?	2		2		2		2	
Is Vlt x Vo > 50,000?	NA		NA		NA		NA	
Is Vlt x Vo > 100,000?	No		Yes		No		No	
Is left-turn delay > 2.0 veh-h or > 35 s/veh for permissive-only phasing?	No		No		No		No	
Has the critical number of crashes (Cp+p) been equaled or exceeded?	No		No		No		No	

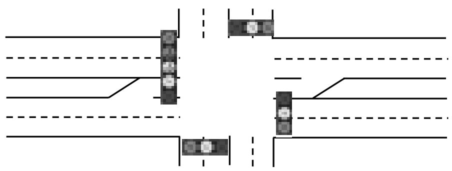
11 answers

High volumes of conflicting traffic

Example 7: Left-Turn Mode

- **Step 2: Choose Left-Turn Modes**

Volume and Lane Geometry Input								
Approach:	Eastbound		Westbound		Northbound		Southbound	
Movement, No.: [1]	LT, 5	TH+RT, 2	LT, 1	TH+RT, 6	LT, 3	TH+RT, 8	LT, 7	TH+RT, 4
Analysis Results								
Suggested left-turn mode:	Permissive		Protected-Permissive		Permissive		Permissive	

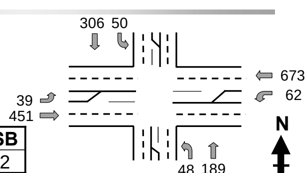


Example 8: Left-Turn Mode

- **Given**
  - *Volumes, lane counts, and operational data for an intersection*
- **The Question**
  - *What left-turn mode should be used for each intersection approach?*

Example 8: Left-Turn Mode

- **The Data**
  - *Cycle length: 100 s*
  - *Crash history*



Approach	EB	WB	NB	SB
Crashes	4	5	4	2

  - *Time period for crashes: 2 years*
  - *Approach speed*
    - E/W: 45 mph, N/S: 35 mph
  - *Sight distance*
    - E/W: 335 ft, N/S: 400 ft (compare with row 18 values)
- **Work for 5 minutes**

Example 8: Left-Turn Mode

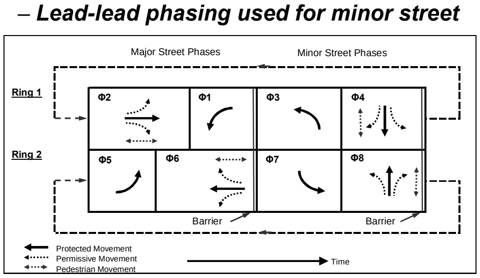
- The Answer

Left-Turn Phasing

- Concepts
  - *Sequence of service provided to left-turn phases, relative to other phases*
  - *Options*
    - Permissive-only (no left-turn phase)
    - Leading left-turn phase
    - Lagging left-turn phase
    - Split

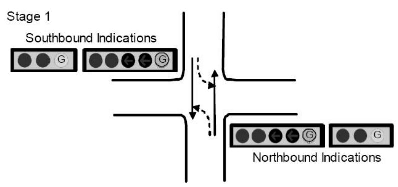
Left-Turn Phasing

- Concepts
  - *Lead-lag phasing used for major street*
  - *Lead-lead phasing used for minor street*



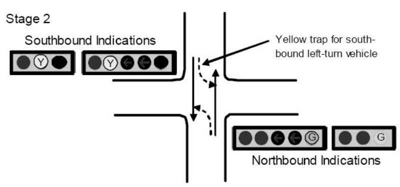
Left-Turn Phasing

- **Concepts**
  - *Yellow trap*
    - Can occur with lead-lag or lag-lag sequence and protected-permissive mode
    - Conflict between left-turn and oncoming vehicles at the end of the adjacent through phase
  - *Stage 1*



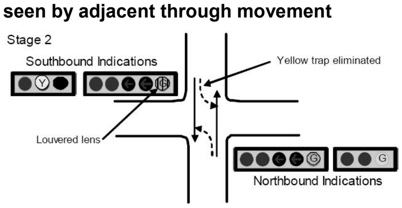
Left-Turn Phasing

- **Concepts**
  - *Trap occurs to the left-turn movement adjacent to the first though phase that ends*
  - *Stage 2 – change interval for southbound*



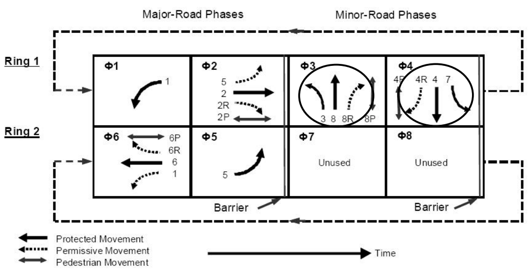
Left-Turn Phasing

- **Concepts**
  - *Dallas phasing solution to yellow trap problem*
    - Green ball in left-turn head is assigned to an overlap with adjacent and opposing through phases
    - Use louvers to prevent this indication from being seen by adjacent through movement



Left-Turn Phasing

- **Concepts**
  - ***Split phasing***



Left-Turn Phasing

- **Guidelines**
  - ***Lead-lead phasing***
    - **Consistent with driver expectation**
    - **Minimizes conflict between left turn and through vehicles by...**
      - **Clears left-turn vehicles during initial protected phase, leaving few permissive left-turns**
      - **Clears left-turn vehicles that may have spilled back into through lanes before the through phase starts**

Left-Turn Phasing

- **Guidelines**
  - ***Lag-lag phasing***
    - **Ensures both through phases start together**
    - **With protected-permissive mode...**
      - **Minimizes the need to call the left-turn phase**
      - **Reduces delay to left-turn movements that may arrive with the through platoon**
      - **Yellow trap problem can be created**

Left-Turn Phasing

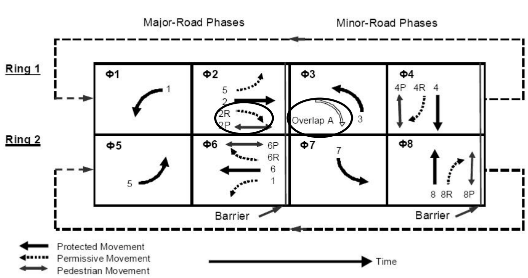
- **Guidelines**
  - ***Lead-lag phasing***
    - **Can improve progression**
    - **Can be used when leading left-turn phase serves left-turns from a shared lane**
    - **With protected-permissive mode...**
      - **Yellow trap can be a problem**

Left-Turn Phasing

- **Guidelines**
  - ***Split phasing***
    - **Less efficient than lead-lead, lead-lag, lag-lag**
    - **May be helpful if...**
      - **Travel paths of left-turns from opposing approaches cross within intersection**
      - **Left-turn and through must share a lane but left-turn phase is also required**
      - **Crash history of left-turn vehicles includes a large number of...**
        - » **Side swipe**
        - » **Head on**

Right-Turn Phasing

- **Concepts**
  - ***Typically using overlap with left-turn phase***



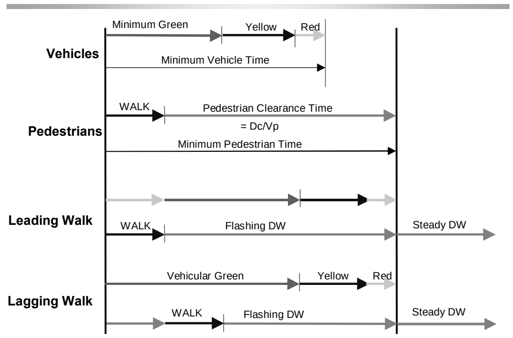
Right-Turn Phasing

- Guidelines
  - *All of the following should be satisfied...*
    - Exclusive right-turn lane is available
    - Right-turn volume is high (300 veh/h or more)
    - Left-turn phase is provided
    - U-turns are prohibited
  - *Operational mode*
    - If pedestrians are present, use protected-permissive mode
    - If no pedestrians, use protected mode during both the left-turn and adjacent through phases

Pedestrian Phasing

- Concepts
  - *Alternative pedestrian phasing*
    - Leading pedestrian walk
      - Concurrent with adjacent through movement phase
    - Lagging pedestrian walk
      - Concurrent with adjacent through movement phase
    - Exclusive
      - Additional phase for pedestrians

Pedestrian Phasing



Pedestrian Phasing

- Guidelines
  - *Leading pedestrian walk*
    - Use where there are significant pedestrian-vehicle conflicts
  - *Lagging pedestrian walk*
    - Use where the right-turn volume is high, and
      - There is an exclusive right-turn lane, or
      - The two streets serve one-way traffic
  - *Exclusive*
    - Use where there are high pedestrian volumes and significant conflicts with vehicles
    - Minimize impact to vehicle operation

Summary

- Appendix A Guidelines
  - *Left-turn operational mode*
  - *Left-turn phasing*
  - *Right-turn phasing*
  - *Pedestrian phasing*
- Questions?

4. Advanced Signal Timing Settings

- Appendix B Guidelines
  - *Dynamic maximum green settings*
  - *Variable initial settings*
  - *Gap reduction settings*
  - *Phase-sequence-related settings*
  - *Rail preemption settings*

Advanced Signal Timing Settings

- Overview
  - *Often used when conditions are unusual*
  - *Have influence on safety or operations*

Feature	Primary Influence of Feature	
	Operations	Safety
Dynamic maximum	Yes	
Variable initial	Yes	
Gap reduction	Yes	
Phase-sequence settings	Yes	Yes
Rail preemption		Yes

Dynamic Maximum Green

- Concepts
  - *Changes the maximum green in real time*
  - *Responds to phases that consistently max-out or gap-out*
  - *Responds in a gradual manner*
    - User defined
  - *Set on a phase-by-phase basis*

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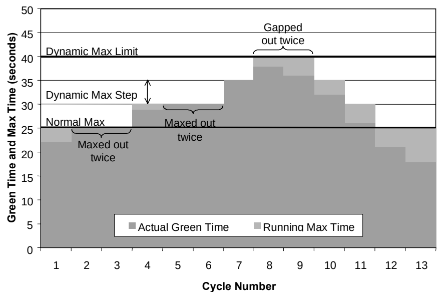
Dynamic Maximum Green

- Concepts
  - *Dynamic maximum limit*
    - The boundary within which the green interval can be varied
  - *Dynamic maximum step*
    - Amount of time added or subtracted during each adjustment

Dynamic Maximum Green

- **Concepts**



Dynamic Maximum Green

- **Guidelines**
  - ***Use for phases serving movements that are...***
    - **low-speed,**
    - **not coordinated, and**
    - **unpredictable in terms of traffic volume level**
      - **Special events or incidents**
  - ***Operation is based on phase max-out***
    - **Not desirable for high-speed approaches**
  - ***If traffic demand is predictable, use settings by time-of-day***

Dynamic Maximum Green

- **Guidelines**
  - ***Dynamic maximum limit***
    - **Larger than maximum green setting**
    - **Large enough to accommodate peak without creating damaging queues elsewhere**
  - ***Dynamic maximum step***
    - **Relatively short**
      - **Balance between responsiveness and efficiency**
    - **Value of 5 to 10 s**

Variable Initial Settings

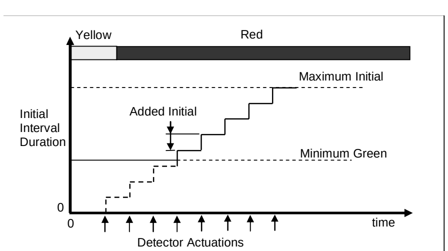
- **Concepts**
  - ***Used to ensure that vehicles queued between the stop line and the nearest upstream detector are served***
  - ***Typical application***
    - **Through movement with one or more upstream detectors present**
    - **No stop bar detector present**
  - ***Settings***
    - **Added initial**
    - **Maximum initial**

Variable Initial Settings

- **Concepts**
  - ***Computes the minimum green duration based on arrivals during red or yellow***
  - ***Added initial***
    - **Amount by which the variable initial time period increases for each vehicle actuation in yellow or red**
  - ***Maximum initial***
    - **Upper limit on the duration of variable initial timing period**

Variable Initial Settings

- **Concepts**



Added Initial

- **Guidelines**

Right-turn on red significant | No right-turn on red

Number of Detectors[1]	Added Initial, s/actuation	
	Minimum	Desirable
1	2.0	2.5
2	1.3	1.5
3	0.8	1.0
4	0.6	0.8
5	0.5	0.6
6 or more	0.4	0.5

1 – Total number of advance detectors associated with the subject phase

Maximum Initial

- **Guidelines**
  - *Max. Initial (sec) = Distance (feet)/10*

Distance between Stop Line and Nearest Upstream Detector, ft	Maximum Initial, s
151 to 175	17
176 to 200	19
201 to 225	21
226 to 250	23
251 to 275	25
276 to 300	27
301 to 325	29
326 to 350	31

Gap Reduction Settings

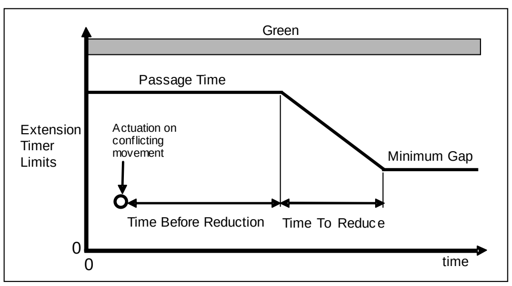
- **Concepts**
  - *Used to ensure queue clearance*
  - *Typical applications*
    - Phases serving high-volume movements
      - Provides queue clearance but less likely to extend to maximum green limit
      - Reduces delay to waiting movements
    - Phases serving high truck volumes
  - *Settings*
    - Passage time
    - Time before reduction
    - Time to reduce
    - Minimum gap

Gap Reduction Settings

- Concepts
  - *Reduces the extension time limit as the green interval duration increases*
  - *Time before reduction*
    - Initial portion of the green interval before the extension timer limit is reduced
  - *Time to reduce*
    - Portion of the green interval during which the extension timer limit is reduced
  - *Minimum gap*
    - Extension timer limit after the time-to-reduce period
    - Equal to the passage time setting

Gap Reduction Settings

- Concepts



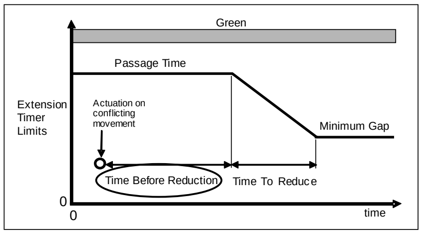
Passage Time

- Guidelines
  - *Single advance detector*
    - Use 3.5 s
  - *Stop line detection*
    - See table below
  - *Presence mode*

Detection Zone Length, ft	85th Percentile Speed, mph				
	25	30	35	40	45
	Passage Time (*PT*), s				
20	3.0	3.0	3.0	3.5	3.5
40	2.0	2.5	2.5	3.0	3.0
60	1.5	2.0	2.5	2.5	2.5
80	1.0	1.5	2.0	2.0	2.5

Time Before Reduction

- **Guidelines**
  - ***Use the larger of…***
    - **Minimum green or maximum initial, and**
    - **10 seconds**



Time To Reduce

- **Guidelines**
  - ***Equal to one half of the difference between the minimum and maximum green settings***
  - ***Equation TTR = $(G_{max} – G_{min})/2$***

Minimum Green Setting, s	Time Before Reduction, s	Maximum Green Setting, s							
		20	25	30	35	40	45	50	55
		Time To Reduce, s							
5	10	8	10	13	15	18	20	23	25
10	10	5	8	10	13	15	18	20	23
15	15	n.a.	5	8	10	13	15	18	20
20	20	n.a.	n.a.	5	8	10	13	15	18

Minimum Gap

- **Guidelines**
  - ***Presence mode***
    - **See table below**
  - ***Steep upgrade and heavy vehicles***
    - **Increase by up to 1.0 second**
  - ***Presence mode***

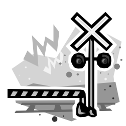
Detection Zone Length, ft	85th Percentile Speed, mph									
	25	30	35	40	45	50	55	60	65	70
	Minimum Gap, s									
6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
20	1.0	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
40	0.0	0.5	0.5	1.0	1.0	1.0	1.0	1.5	1.5	1.5
60	0.0	0.0	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0
80	0.0	0.0	0.0	0.0	0.5	0.5	0.5	1.0	1.0	1.0

Phase-Sequence Settings

- **Conditional Service**
  - ***Allow a previous phase in the ring to be serviced under certain conditions***
  - ***Sometimes used for left-turn phases***
- **Simultaneous Gap-Out**
  - ***Ensures that active phases in both rings are in agreement to terminate (gap-out, max-out, etc.)***
  - ***Typically used for all phases ending at barrier***
- **Dual Entry**
  - ***Ensures one phase in each ring served even if only one is called***
  - ***Typically used for through movement phases***

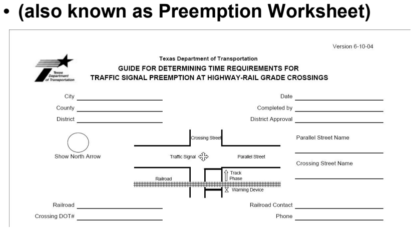
Rail Preemption Settings

- **Settings**
  - ***Right-of-way transfer***
    - **Priority status**
    - **Preempt delay**
    - **Preempt memory**
    - **Preempt minimum green and walk**
    - **Preempt pedestrian change**
  - ***Track clear***
    - **Track clear phases**
    - **Track green**
  - ***Dwell phases***
  - ***Exit phases***



Rail Preemption Settings

- **Primary Guidebook**
  - ***Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings (TxDOT 2003)***
    - **(also known as Preemption Worksheet)**


Version 6-10-04

Texas Department of Transportation

GUIDE FOR DETERMINING TIME REQUIREMENTS FOR
TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS

City ____________ Date ____________
County ____________ Completed by ____________
District ____________ District Approval ____________

Show North Arrow

Crossing Street
Traffic Signal
Parallel Street
Railroad
Track Phase
Warning Device

Parallel Street Name ____________
Crossing Street Name ____________

Railroad ____________ Railroad Contact ____________
Crossing DOT# ____________ Phone ____________

Right-of-Way Transfer

- Concepts
  - *Priority status*
    - Several preempts available
    - Priority determines which is used if several are called at the same time
  - *Preempt delay*
    - Time lag between detection and call for preempt
  - *Preempt memory*
    - With memory "on", a detection is retained after it is received and regardless if it subsequently dropped

Right-of-Way Transfer

- Concepts
  - *Minimum green and minimum walk*
    - Minimum length of the green interval of phase that is active prior to preempt
  - *Pedestrian change*
    - Minimum length of time provided for pedestrian change interval of a phase that is active prior to preempt
    - Follows the walk interval

Right-of-Way Transfer

- Guidelines
  - *Priority status*
    - Rail is assigned to Preempt 1
    - In special cases two preempts are used
  - *Preempt delay*
    - Normally 0.0 s
    - Some delay may be needed where rail switching occurs
  - *Preempt memory*
    - Should be operated with memory "on"
    - Exceptions
      - Phantom preempt calls occur
      - Multiple tracks with multiple preempts

Right-of-Way Transfer

- Guidelines
  - *Minimum green and minimum walk*
    - Should not be set to less than 2.0 s
    - A value less than 2.0 s may be used if needed to satisfy warning time requirements
  - *Pedestrian change*
    - Provide normal change interval if possible
    - TMUTCD permits truncation of this interval if needed to ensure preemption time does not exceed warning time
    - Check the truncation exposure for peds

Track Clear

- Concepts
  - *Track clear phases*
    - Phases that serve vehicles queued over the tracks during preempt sequence
  - *Track green*
    - Duration of green interval for track clear phase

Track Clear

- Guidelines
  - *Track clear phases*
    - Green indication should always be used
    - Flashing red or yellow is not recommended
  - *Track green*
    - Minimum duration is equal to the queue clearance time
    - Desirable duration is equal to APT + 15 s
      - This duration will avoid a preempt trap

Dwell and Exit Phases

- Concepts
  - *Dwell phases*
    - Follows the track clear phases
    - Cycles through phases that do not conflict with railroad crossing
  - *Exit phases*
    - Phases that are active during the exit period
    - One phase per ring

Dwell and Exit Phases

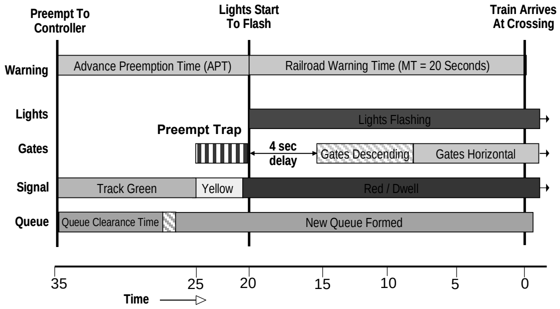
- Guidelines
  - *Dwell phases*
    - All phases serving movements not blocked by the train
    - All dwell phases should be served in sequence during dwell period
    - Signal operation in flash mode is not recommended
  - *Exit phases*
    - Typically the phases held in red (omitted) while the train is present

Preempt Trap

- Concepts
  - *Characteristics*
    - Train arrives when controller is serving the track clear phase
    - Right-of-way transfer time is short
    - Track clear phase ends before the gates go down
  - *More likely to occur with advance preemption time*

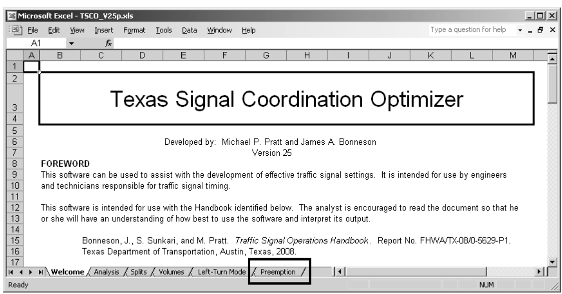
Preempt Trap

- **Concepts**



TSCO Demonstration

- **Preemption Worksheet**



TSCO Demonstration

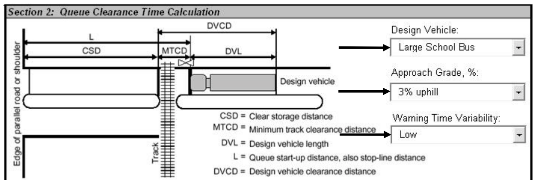
- **Right-of-Way Transfer**

Section 1: Right-of-Way Transfer Time Calculation				
Preempt Verification and Response Time				
1. Preempt delay time (seconds)		**0.0**	Usually 0.0 s	
2. Controller response time to preempt (seconds); get from manufacturer		**0.2**	Controller type	
3. Preempt verification and response time (seconds)				0.2
Worst-Case Conflicting Vehicle Time				
4. Worst-case conflicting vehicle phase number	**4**			
5. Minimum green time during right-of-way transfer (seconds)		**2.0**	2.0 s or more recommended	
6. Other green time during right-of-way transfer (seconds)		**0.0**	Usually 0.0 s	
7. Yellow change time (seconds)		**4.0**		
8. Red clearance time (seconds)		**1.0**		
9. Worst-case conflicting vehicle time (seconds)			7.0	
Worst-Case Conflicting Pedestrian Time				
10. Worst-case conflicting pedestrian phase number	**4**			
11. Minimum walk time during right-of-way transfer (seconds)		**2.0**	2.0 s or more recommended	
12. Pedestrian clearance time during right-of-way transfer (seconds)		**11.0**	o.k.	
13. Vehicle yellow change time (seconds)		**4.0**	Same as for normal operations.	
14. Vehicle red clearance time (seconds)		**1.0**	Same as for normal operations.	
15. Worst-case conflicting pedestrian time (seconds)			18.0	
Worst-Case Conflicting Vehicle or Pedestrian Time				
16. Worst-case conflicting vehicle or pedestrian time (seconds)				18.0
17. Right-of-way transfer time (seconds)				**18**

TSCO Demonstration

- **Queue Clearance Time**

Section 2: Queue Clearance Time Calculation



18. Clear storage distance, CSD (feet)	**25**			
19. Minimum track clearance distance, MTCD (feet)	**20**			
20. Design vehicle length, DVL (feet)	40			
21. Queue start-up distance, L (feet)		45		
22. Time required for design vehicle to start moving (seconds)			4.3	
23. Design vehicle clearance distance, DVCD (feet)		60		
24. Time for design vehicle to accelerate through the DVCD (seconds)			7.0	
25. Queue clearance time (seconds)				**11.3**

TSCO Demonstration

- **Maximum Preemption Time**
- **Warning Time Check**

Section 3: Maximum Preemption Time Calculation					
26. Right-of-way transfer time (seconds)		18.2			
27. Queue clearance time (seconds)		11.3			
28. Desired minimum separation time (seconds)		**4.0**	4.0 s recommended		
29. Maximum preemption time (seconds)				**33.5**	
Section 4: Sufficient Warning Time Check					
30. Required minimum time, MT (seconds); per regulations	**20.0**	20.0 s required by TMUTCD			
31. Clearance time, CT (seconds); get from railroad	**0.0**	AREMA requirement: 0.0 s			
32. Minimum warning time, MWT (seconds)		20.0	Excludes buffer time (BT)		
33. Advance preemption time, APT, if provided (seconds); get from railroad		**22.0**			
34. Warning time provided by the railroad (seconds)				42.0	
35. Additional warning time required from railroad (seconds)					**0**
Remarks:					

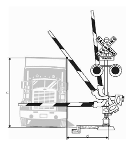
TSCO Demonstration

- **Track Clearance Green Time**
  - *Desirable track green duration (optional)*

Section 5: Track Clearance Green Time Calculation (Optional)						
Preempt Trap Check						
36. Advance preemption time, APT (seconds)	22.0	Typically, same value as in Line 33.				
37. Multiplier for maximum APT due to train handling	1.25	(based on entry in J51)				
Estimated maximum APT (seconds)		27.5				
38. Maximum APT (seconds)		**27.5**	May use estimate in row above.			
39. Minimum duration for the track clearance green interval (seconds)		**15.0**	For zero APT. 15 s or more required.			
40. Gates down after start of preemption (seconds)			42.5			
41. Preempt verification and response time (seconds)		0.2				
42. Best-case conflicting vehicle or pedestrian time (seconds)		**0.0**	Usually 0.0 s			
43. Minimum right-of-way transfer time (seconds)			0.2			
44. Minimum track clearance green time (seconds)				42.3		
Clearing of Clear Storage Distance						
45. Time required for design vehicle to start moving (seconds)			4.3			
46. Design vehicle clearance distance, DVCD (feet)	60					
47. Portion of CSD to clear during track clearance phase (feet)	**25**	CSD* in Figure 3 (see below); suggest using CSD				
48. Design vehicle relocation distance, DVRD (feet)		85				
49. Time required for design vehicle to accelerate through DVRD (seconds)			8.5			
50. Time to clear portion of clear storage distance (seconds)				12.8		
51. Track clearance green interval (seconds)					**43**	

TSCO Demonstration

- **Vehicle-Gate Interaction Check**
  - *Minimum APT time to prevent gate from striking design vehicle*
  - *Compare result to APT (row 33)*
    - If less than APT, no problem
    - If greater than APT, gate strikes vehicle



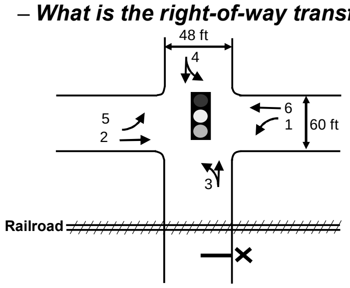
Section 6: Vehicle-Gate Interaction Check (Optional)				
52. Right-of-way transfer time (seconds)		18.2		
53. Time required for design vehicle to start moving (seconds)		4.3		
54. Time required for design vehicle to accelerate through DVL (seconds)		5.6		
55. Time required for design vehicle to clear descending gate (seconds)			28.1	
56. Duration of flashing lights before gate descent start (seconds); get from railroad		**4.0**	Typical: 3 to 5 s	
57. Full gate descent time (seconds); get from railroad	**7.5**	Typical: 6.5 to 8.5 s		
Distance from center of gate support post to nearest side of design vehicle, d (feet)	**12.0**	Figure 4 (see below)		
58. Proportion of non-interaction gate descent time	0.50			
59. Non-interaction gate descent time (seconds)		3.8		
60. Time available for design vehicle to clear descending gate (seconds)			7.8	
61. Advance preemption time (APT) required to avoid design vehicle-gate interaction (seconds)				**21**
APT Check: Vehicles should clear gates o.k.; APT is adequate.				

Example 9 - Preemption

- **Goals**
  - *Evaluate preemptions scenarios for an at-grade intersection*
- **Steps**
  - *Collect information*
    - Geometry
    - Phasing
  - *Enter all data in the worksheet*

Example 9 - Preemption

- **Right-of-Way Transfer**
  - *What is the pedestrian change interval (PCI)?*
  - *What is the right-of-way transfer time?*



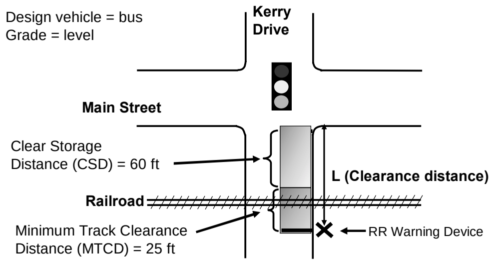
Yellow – 4 seconds
All-Red – 1 second

Track phase – 3
Dwell phases – 2, 5, 6
Exit phase – 3

PCI = Dc/Vp – (Y + Rc)
Walking speed = 4 fps

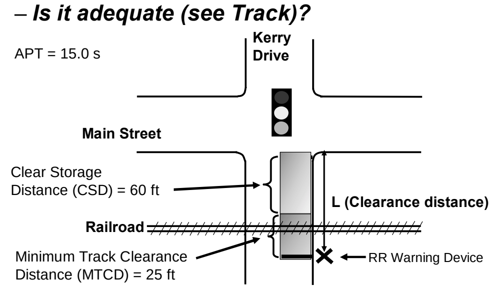
Example 9 - Preemption

- **Queue Clearance Time**
  - ***What is the queue clearance time?***
  - ***What is the max. preemption time?***



Example 9 - Preemption

- **Warning Time Check**
  - ***What is the available warning time?***
  - ***Is it adequate (see Track)?***



Example 9 - Preemption

- **Track Clearance Green Time**
  - ***Preempt trap check***
    - **What is the minimum track clearance green time?**
    - **Does the green extend beyond "gate down"?**
  - ***Clearing of clear storage distance***
    - **What is the time to clear the clear storage distance?**
- **Vehicle-Gate Interaction Check**
  - ***Distance from gate to vehicle (d) = 12 ft***
  - ***What APT is needed to avoid vehicle-gate interaction?***

Summary

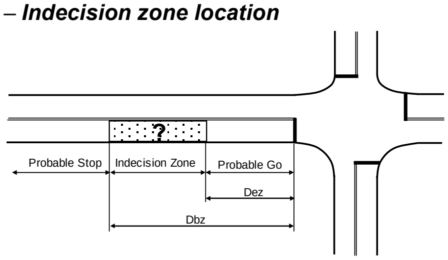
- **Appendix B Guidelines**
  - ***Dynamic maximum green settings***
  - ***Variable initial settings***
  - ***Gap reduction settings***
  - ***Phase-sequence-related settings***
  - ***Rail preemption settings***
- **Questions?**

5. Detection Design & Operation

- **Appendix C Concepts**
  - ***Indecision zone***
  - ***Detection-related control settings***
- **Appendix C Guidelines**
  - ***Loop detection layout for low speeds***
  - ***Loop detection layout for high speeds***
  - ***Video detection design***
  - ***Video detection layout for low speeds***

Indecision Zone

- **Concepts**
  - ***Indecision zone location***



Dbz = Distance to the beginning of the indecision zone
Dez = Distance to the end of the indecision zone

Indecision Zone

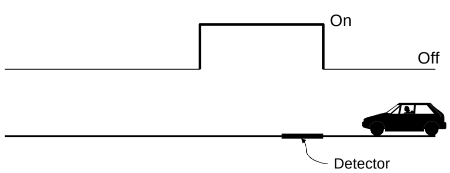
- Concepts
  - *Beginning of zone*
    - 5.5 seconds of travel time from the stop line
    - 90th percentile driver
  - *End of zone*
    - 2.5 seconds of travel time from the stop line
    - 10th percentile driver
  - *Exists every cycle after the onset of yellow*
  - *Advance detection*
    - Used to minimize instances where vehicles are caught in indecision zone at yellow onset

Detection-Related Settings

- Concepts
  - *Controller memory*
    - Locking
      - Actuations received on yellow or red are kept until served
      - Used for phases served by advance detection and no recall
    - Nonlocking
      - Actuations are dropped as soon as vehicle leaves the detector
      - Most appropriate for phases served by stop line detection

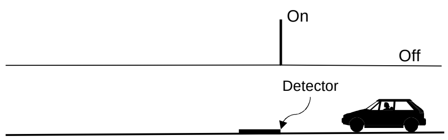
Detection-Related Settings

- Concepts
  - *Detection mode*
    - Presence mode
      - Detector on when vehicle enters detection zone
      - Detector off when vehicle leaves detection zone
    - Typically used with nonlocking memory



Detection-Related Settings

- **Concepts**
  - ***Detection mode***
    - **Pulse mode**
      - **Detector on when vehicle enters detection zone**
      - **Pulse immediately turns "off"**
    - **Not typically used for signal control**

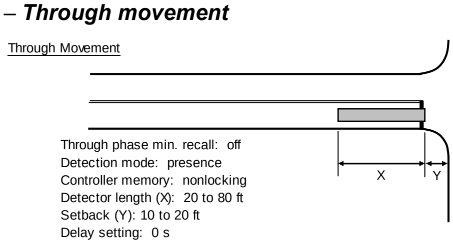


Loop Layout for Low Speeds

- **Guidelines**
  - ***85^{th} percentile speed of 40 mph or less***
  - ***Objectives***
    - **Inform the controller of waiting traffic**
    - **Serve the queue in each phase**
  - ***Detector location***
    - **Near stop line**
  - ***Applicable movements***
    - **Through**
    - **Left turn**
    - **Right turn**

Loop Layout for Low Speeds

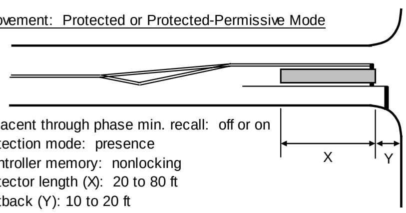
- **Guidelines**
  - ***Detection length***
    - **Longer lengths provide better information**
  - ***Through movement***



Loop Layout for Low Speeds

- **Guidelines**
  - ***Left-turn movement***
  - ***Protected or protected-permissive***

Left-Turn Movement: Protected or Protected-Permissive Mode

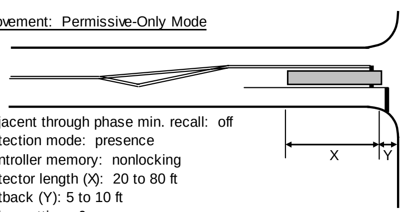


Adjacent through phase min. recall: off or on
Detection mode: presence
Controller memory: nonlocking
Detector length (X): 20 to 80 ft
Setback (Y): 10 to 20 ft
Delay setting: 0 s (desirably, 5 to 12 s if prot-perm. mode)

Loop Layout for Low Speeds

- **Guidelines**
  - ***Left-turn movement***
  - ***Permissive-only***

Left-Turn Movement: Permissive-Only Mode



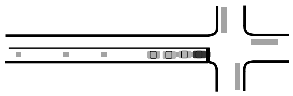
Adjacent through phase min. recall: off
Detection mode: presence
Controller memory: nonlocking
Detector length (X): 20 to 80 ft
Setback (Y): 5 to 10 ft
Delay setting: 0 s

Loop Layout for High Speeds

- **Guidelines**
  - ***85th percentile speed of 45 mph or more***
  - ***Objectives***
    - **Inform the controller of waiting traffic**
    - **Serve the queue in each phase**
    - **Provide safe termination of green interval**
  - ***Detector location***
    - **In advance of intersection**
    - **May be combined with stop line detection**
  - ***Applicable movements***
    - **Through**

Loop Layout for High Speeds

- **Guidelines**
  - ***Detection options***
  - ***Option 1***
    - **Advance detection and stop line detection**
    - **Stop line detection disabled after queue clears**
  - ***Option 2***
    - **Advance detection only**
    - **Need to use locking or recall features**
  - ***Option 3***
    - **Advance detection and stop line detection**
    - **Stop line detection always on**



Loop Layout for High Speeds

- **Guidelines**
  - ***Option 1***
    - **Most effective**
    - **Requires one lead-in for advance detection**
    - **Requires one lead-in for stop line detection**
  - ***Option 2***
    - **No stop line detection to maintain**
    - **Delay may be higher**
  - ***Option 3***
    - **Used when stop line and advance detection use common lead-in**
    - **Least effective**

Loop Layout for High Speeds

- **Guidelines**
  - ***Advance detectors are 6 ft in length***

Category	85th Percentile Speed, mph	Design Element	Design Values by Detection Option		
			Option 1	Option 2	Option 3
Detection layout	70	Distance from the stop line to the upstream edge of the advance detector, ft	600, 475, 350		
	65		540, 430, 320		
	60		475, 375, 275		
	55		415, 320, 225		
	50		350, 220		
	45		330, 210		
	45 to 70	Stop line detection zone length, ft	40	not used	40
	45 to 70	Advance detection lead-ins wired to channel separate from stop line detection	Yes	not used	Not necessary

Loop Layout for High Speeds

- **Guidelines**
  - *Controller settings*

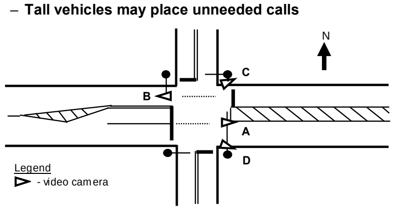
Category	85th Percentile Speed, mph	Design Element	Design Values by Detection Option		
			Option 1	Option 2	Option 3
Controller settings	70	Passage time, s	1.4 to 2.0	1.4 to 2.0	1.0 to 1.2
	65		1.6 to 2.0	1.6 to 2.0	1.0 to 1.2
	60		1.6 to 2.0	1.6 to 2.0	1.0 to 1.2
	55		1.4 to 2.0	1.4 to 2.0	1.0 to 1.2
	50		2.0	2.0	1.4 to 1.6
	45		2.0	2.0	1.4 to 1.6
	45 to 70	Detection mode	Presence	Presence	Presence
	45 to 70	Controller memory	Nonlocking	Varies	Nonlocking
	45 to 70	Stop line detection channel extend setting, s	2.0	not used	1.0
	45 to 70	Stop line detection operation	Deactivate after gap-out	not used	Contin-uously active

Video Detection Design

- **Guidelines**
  - *Camera location*
    - Camera offset
    - Camera height
  - *Field-of-view calibration*
  - *Application*
    - Low-speed movements
    - Other detection systems may be better suited to advance detection for high-speed movements

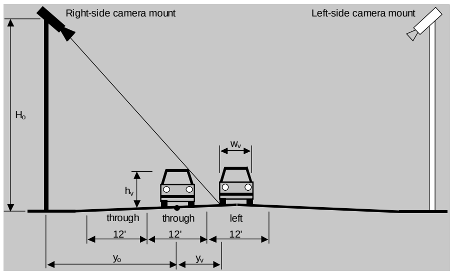
Video Detection Design

- **Guidelines**
  - *Camera offset*
    - When mast arms are used to support the signal heads, location A or B is recommended
      - It eliminates adjacent lane occlusion
    - When span wire is used, location C or D is recommended
      - Tall vehicles may place unneeded calls



Video Detection Design

- **Guidelines**
  - ***Camera height***
    - **Increase height to minimize adjacent lane occlusion**



Video Detection Design

- **Guidelines**
  - ***Camera height***
    - **Minimum heights to reduce occlusion**

Camera Location	Lateral Offset, ft	No Left-Turn Lanes			One Left-Turn Lane		
		Through+Right Lanes			Through+Right Lanes		
		1	2	3	1	2	3
		Minimum Camera Height and Typical Camera Mount, ft					
Left side of approach	-65			P,R 38			P,R,L42
	-55		P,R 35	P 30		P,R 39	
	-45		P 27		P,R 36	P 32	
	-35	P 24	P 20		P 29		
	-25	P 20			P 21		
	-15	P 20					
	-5				M 20	M 20	M 20
Center	0	M 20	M 20	M 20	M 20	M 20	M 20
Right side of approach	5	P 20	M 20	M 20	M 20	M 20	M 20
	15	P 20	P 20	P 20	P 20	P 20	M 23
	25	P 20	P 20	P 20	P 21	P 26	P 30
	35		P 20	P 20	P 29	P 33	P,R 38
	45						

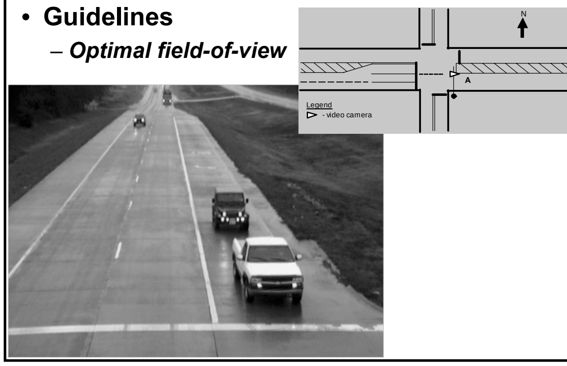
Legend
M = mast arm
P = strain pole
R = 5 ft riser
L = luminaire arm

Video Detection Design

- **Guidelines**
  - ***Field-of-view calibration***
    - **Stop line should be...**
      - **Parallel to the bottom edge of the view**
      - **In the bottom one-third of the view**
    - **Include all approach traffic lanes and one departing lane**
    - **Approach width at the stop line is...**
      - **90 percent of the horizontal width for head-on view**
      - **40 to 60 percent for offset view**
    - **View must exclude horizon**

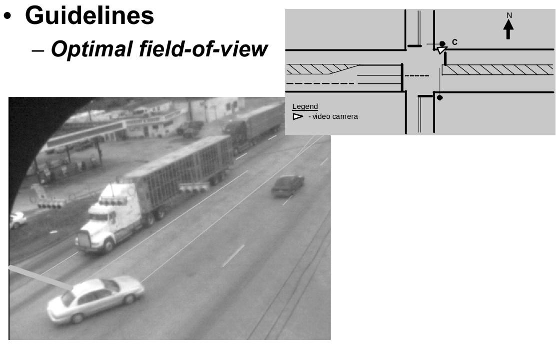
Video Detection Design

- **Guidelines**
  - *Optimal field-of-view*



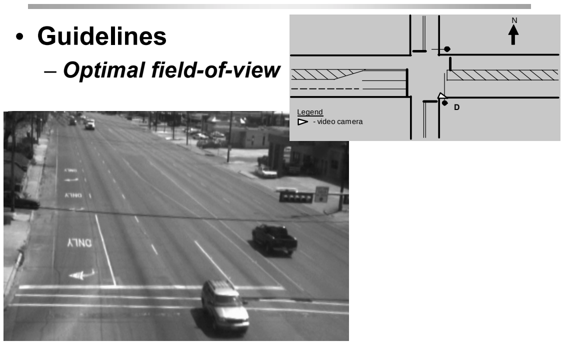
Video Detection Design

- **Guidelines**
  - *Optimal field-of-view*



Video Detection Design

- **Guidelines**
  - *Optimal field-of-view*



Video Detection Design

- Guidelines
  - *Field-of-view*
    - Adjustments to minimize sun glare
      - Use a visor
      - Tilt the camera downward
      - Minimum pitch of 3 degrees from the horizontal
    - Adjustments to minimize lighting glare
      - Avoid bright lights in the evening hours
      - Avoid lights that flash or vary in intensity
    - Use a video recorder to check nighttime operation

Video Detection Layout

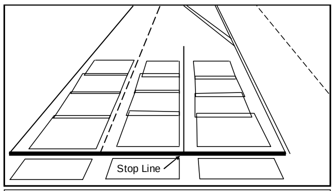
- Guidelines
  - *Low-speed movements*
    - 85^{th} percentile speed of 40 mph or less
  - *Objectives*
    - Inform the controller of waiting traffic
    - Serve the queue in each phase
  - *Detector location*
    - Near stop line
  - *Applicable movements*
    - Through
    - Left turn
    - Right turn

Video Detection Layout

- Guidelines
  - *Detection zone location and length*
  - *Detection mode and settings*

Video Detection Layout

- Guidelines
  - *Detection zone location*
    - Typically use several detectors in zone
    - Locate one zone beyond stop line



Rule-of-Thumb: The detection zone should consist of one or more detectors, with each detector about the size of a car. Detectors may be overlapping. Those beyond the stop line also detect headlights.

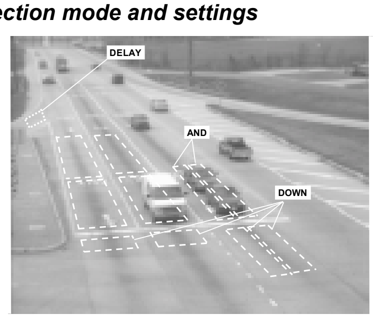
Video Detection Layout

- Guidelines
  - *Detection zone length*
    - Use passage time of 0.0 s
    - Use zone length (in ft) = 3 x 85^{th} % speed in mph

85^{th} Percentile Speed, mph	Distance between Camera and Stop Line, ft	Camera Height, ft			
		20	24	28	32
		Stop Line Detection Zone Length, ft			
20	50	55	55	55	60
	100	45	45	50	50
	150	30	35	40	45
30	50	95	95	95	95
	100	80	85	90	90
	150	70	75	80	85
40	50	130	135	135	135
	100	120	125	125	130
	150	110	115	120	120

Video Detection Layout

- Guidelines
  - *Detection mode and settings*



Summary

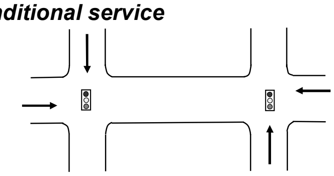
- **Appendix C Guidelines**
  - *Loop detection layout for low speeds*
  - *Loop detection layout for high speeds*
  - *Video detection design*
  - *Video detection layout for low speeds*
- **Questions?**

6. Diamond Interchange Operations

- **Appendix D Concepts**
- **Appendix D Guidelines**

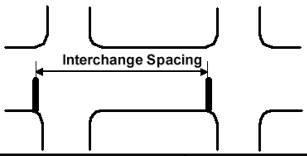
Diamond Interchange Operations

- **Concepts**
  - *Interchange spacing*
  - *Traffic patterns*
  - *Types of traffic signal control*
  - *Phase sequence*
  - *Conditional service*



Interchange Spacing

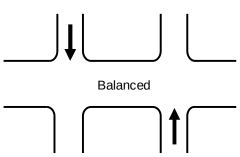
- **Concepts**
  - ***Three interchange spacing categories***

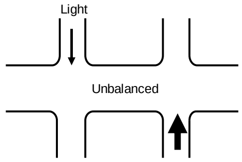


Interchange Category	Spacing
Narrow	< 400 ft
Intermediate	400 to 800 ft
Wide	> 800 ft

Traffic Patterns

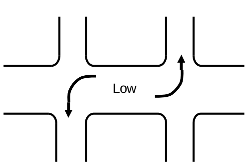
- **Concepts**
  - ***Frontage road traffic***
    - **Balanced**
    - **Unbalanced**

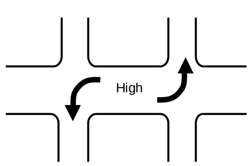




Traffic Patterns

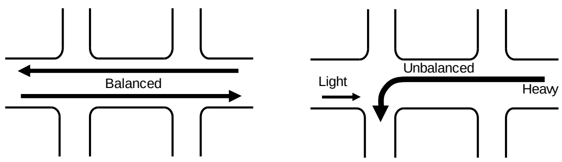
- **Concepts**
  - ***Internal left-turn traffic***
    - **Low**
    - **High**





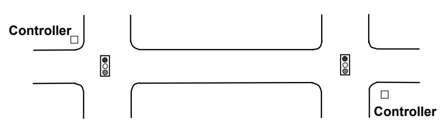
Traffic Patterns

- Concepts
  - *Arterial through traffic*
    - Balanced
    - Unbalanced

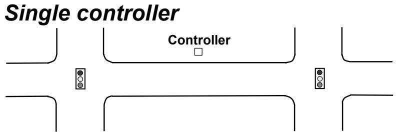


Types of Traffic Signal Control

- Concepts
  - *Two controllers*

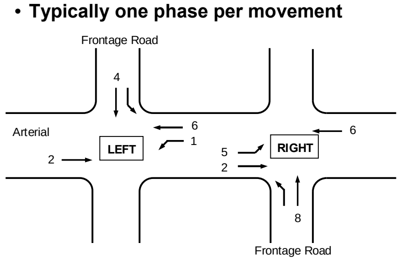


  - *Single controller*



Phase Sequence

- Concepts
  - *Movement numbers*
    - Eight basic movements
    - Typically one phase per movement

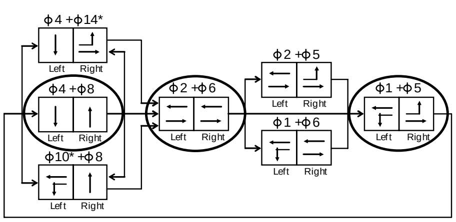


Phase Sequence

- Concepts
  - *Three phase*
  - *Four phase*
  - *Separate intersection*
  - *Two-phase*

Phase Sequence

- Concepts
  - *Three-phase sequence*
    - Frontage road phases start and end together
    - Arterial lefts lag (usually)

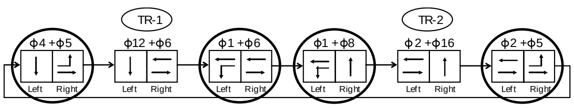


Phase Sequence

- Concepts
  - *Three-phase characteristics*
    - Arterial through traffic typically has good progression through the interchange
      - Can have coordination with adjacent signals
    - Adequate interior storage is needed when serving frontage road phases
    - Frontage road volumes should be reasonably balanced

Phase Sequence

- **Concepts**
  - *Four-phase sequence*
    - Four external phases
    - Each external movement served in sequence
    - Includes two fixed transition intervals

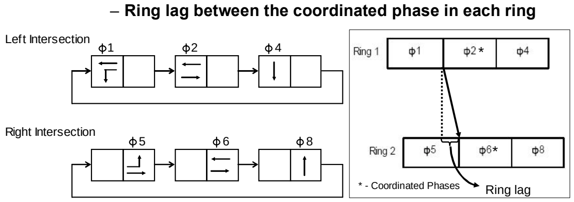


Phase Sequence

- **Concepts**
  - *Four-phase characteristics*
    - Arterial traffic has good progression through the interchange
      - Coordination with adjacent signals is difficult
    - External phases are fully actuated
      - Can adjust to variations in traffic demand
    - Internal movements always clear the interior of the interchange
    - Two transition intervals improve throughput during high-volume conditions
      - Can be inefficient during low-volume conditions

Phase Sequence

- **Concepts**
  - *Separate intersection sequence*
    - Assigns one ring to control each intersection
    - Coordination is achieved by specifying
      - Common cycle length for each ring
      - Ring lag between the coordinated phase in each ring

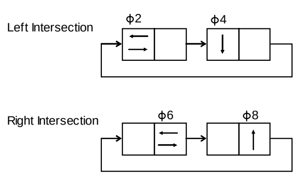


Phase Sequence

- **Concepts**
  - *Separate intersection characteristics*
    - Offers some flexibility in phasing that was available with two controllers
      - Uses only lead-lead phasing sequence
    - Can operate fully actuated
      - Each ring fully actuated and isolated
    - Can be used to provide good coordination between the two intersections

Phase Sequence

- **Concepts**
  - *Two-phase sequence*
    - Assigns one ring to control each intersection
    - Omits the internal left-turn phases
    - These left-turn movements are served permissively



Phase Sequence

- **Concepts**
  - *Two-phase characteristics*
    - Used at locations with protected-permissive internal left-turn phases
    - Can reduce the delay for all major movements
    - Most effective when…
      - Interior left turn movements are very light
      - Overall volumes are low (e.g., nighttime)
    - Implemented after placing the controller in the separate intersection

Conditional Service

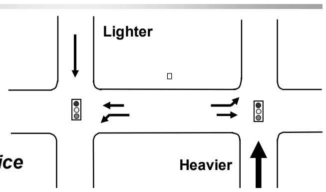
- **Concepts**
  - *Controller will invoke if...*
    - Conditional service is enabled
    - One of the frontage road phases gaps out
    - There is a call on the internal left-turn phase
    - There is sufficient time to serve the minimum green of the internal left-turn phase

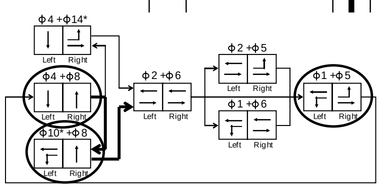
Ring Structure

10	4	2	1
14	8	6	5

Conditional Service

- **Concepts**
  - *Application*
    - Three-phase sequence
  - *Internal left-turn phase served twice*





Diamond Interchange Operations

- **Appendix D Guidelines**
  - *Selection of phase sequence*
  - *Actuated phase settings*
  - *Loop detection layout for low speeds*
  - *Loop detection layout for high speeds*
  - *Configuration of video detection outputs*
  - *Conditional service*

Selection of Phase Sequence

- **Guidelines**
  - *Selection of phase sequence*
    - Narrow interchanges (< 400 ft)

Interchange Spacing	Arterial Through Traffic Volume	Frontage Road Traffic Pattern	Internal Left-Turn Traffic Volume	Typical Phase Sequence
Less than 400 ft (narrow)	Unbalanced	Balanced	Low	Four
			High	
		Unbalanced	Low	
			High	
	Balanced	Balanced	Low	Four or three
			High	Four
		Unbalanced	Low	Four or three
			High	Four

Selection of Phase Sequence

- **Guidelines**
  - *Selection of phase sequence*
    - Intermediate interchanges (400 ft to 800 ft)

Interchange Spacing	Arterial Through Traffic Volume	Frontage Road Traffic Pattern	Internal Left-Turn Traffic Volume	Typical Phase Sequence
Between 400 and 800 ft (intermediate)	Unbalanced	Balanced	Low	Three
			High	Three or separate
		Unbalanced	Low	Separate
			High	
	Balanced	Balanced	Low	Three
			High	
		Unbalanced	Low	Separate
			High	Three or separate

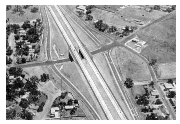
Selection of Phase Sequence

- **Guidelines**
  - *Selection of phase sequence*
    - Wide interchanges (> 800 ft)

Interchange Spacing	Arterial Through Traffic Volume	Frontage Road Traffic Pattern	Internal Left-Turn Traffic Volume	Typical Phase Sequence
More than 800 ft (wide)	Unbalanced	Balanced	Low	Three
			High	Separate
		Unbalanced	Low	Separate
			High	
	Balanced	Balanced	Low	Three
			High	
		Unbalanced	Low	Separate
			High	

Actuated Phase Settings

- Guidelines
  - *Minimum green*
  - *Maximum green*



Minimum Green

- **Guidelines**
  - ***Except as noted, minimum green is based on guidelines provided in Chapter 2***
    - **Driver expectancy**
    - **Pedestrian crossing time**

Minimum Green

- **Guidelines**
  - ***Three-phase sequence***
    - **Phase 2 and 6 minimum green**
      - **Need to ensure that a vehicle starting on the arterial approach is not stopped in the interior**

Spacing, ft	Travel Time (*T*), s	Minimum Green for Phase 1, s				Minimum Green for Phase 5, s			
		5	6	7	8	5	6	7	8
		Minimum Green for Phase 2, s				Minimum Green for Phase 6, s			
400	15	5	5	5	5	5	5	5	5
500	17	7	6	5	5	7	6	5	5
600	19	9	8	7	6	9	8	7	6
700	21	11	10	9	8	11	10	9	8
800	24	14	13	12	11	14	13	12	11
900	26	16	15	14	13	16	15	14	13
1000	28	18	17	16	15	18	17	16	15

Minimum Green

- Guidelines
  - *Four-phase sequence*
    - Phases 2, 4, 6, 8, 12, and 16 minimum green should equal the larger of…
      - Min. green based on driver expectancy
      - Min. green based on pedestrian crossing time
      - Travel time within the interchange

Interchange Spacing, ft	Travel Time (*T*), s	Minimum Green for Phases 2 and 6, s	Minimum Green for Phases 4 and 8, s	Minimum Green for Phases 12 and 16, s
100	7	9	5	2
200	10	15	7	3
300	12	20	9	5
400	15	24	12	8

Maximum Green

- Guidelines
  - *Except as noted, maximum green is based on guidelines provided in Chapter 2*
    - Volume
    - Movement (turn or through)
    - Speed
    - Minimum green setting

Maximum Green

- Guidelines
  - *Three-phase sequence*
    - Phase 1 and 5 max. based on travel time
    - Phase 4 and 8 based on internal storage
    - Phase 10 max. = phase 10 min. (same for 14)

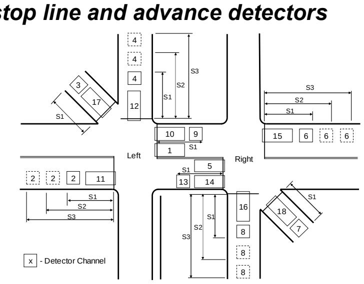
Interchange Spacing (*S*), ft	Travel Time (*T*), s	Maximum Green for Phases 1 and 5, s	Maximum Green for Phases 4 and 8, s
400	15	15	34
500	17	17	42
600	19	19	50
700	21	21	58
800	24	24	66
900	26	26	74
1000	28	28	82

Maximum Green

- **Guidelines**
  - *Four-phase sequence*
    - Phase 12 max. green = phase 12 min. green
    - Phase 16 max. green = phase 16 min. green

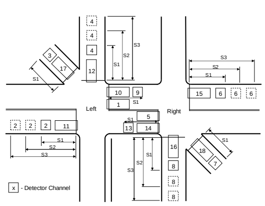
Loop Detection for Low Speeds

- **Guidelines**
  - *85th percentile speed of 40 mph or less*
  - *Use both stop line and advance detectors*
  - *Detector channel numbers*



Loop Detection for Low Speeds

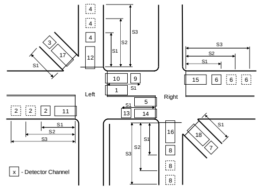
- **Guidelines**
  - *Three-phase sequence*
    - Phases 1, 2, 5, and 6
    - Phases 4 and 8
  - *Separate intersection sequence*



85th Percentile Speed, mph	Phases 1, 2, 5, and 6		Frontage Road Phases 4 and 8	
	Advance Detector Distance (*S1*), ft	Passage Time, s	Advance Detector Distance (*S1*), ft	Passage Time, s
30	100	2.0 to 3.0	100	2.0 to 3.0
35	135	2.0 to 3.0	135	2.0 to 3.0
40	170	2.0 to 3.0	170	2.0 to 3.0

Loop Detection for Low Speeds

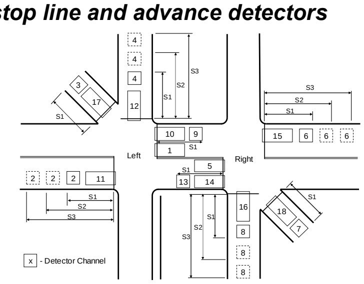
- **Guidelines**
  - ***Four-phase sequence***
    - **Phases 1, 2, 5, and 6**
    - **Phases 4 and 8**



85th Percentile Speed, mph	Phases 1, 2, 5, and 6		Frontage Road Phases 4 and 8				
	Advance Detector Distance (*S1*), ft	Passage Time, s	Interchange Spacing, ft				Passage Time, s
			100	200	300	400	
			Advance Detector Distance (*S1*), ft				
30	100	2.0 to 3.0	260	355	435	510	2.0 to 3.0
35	135	2.0 to 3.0	305	415	505	595	2.0 to 3.0
40	170	2.0 to 3.0	350	475	575	680	2.0 to 3.0

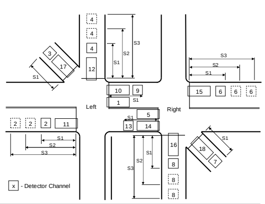
Loop Detection for High Speeds

- **Guidelines**
  - ***85th percentile speed of 45 mph or more***
  - ***Use both stop line and advance detectors***
  - ***Detector channel numbers***



Loop Detection for High Speeds

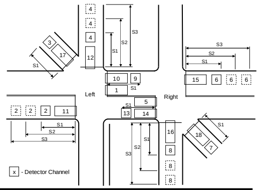
- **Guidelines**
  - ***Three-phase sequence***
    - **Phases 1, 2, 5, and 6**
    - **Phases 4 and 8**
  - ***Separate intersection sequence***



85th Percentile Speed, mph	Phases 1, 2, 5, and 6				Frontage Road Phases 4 and 8			
	Advance Detector Distance, ft			Passage Time, s	Advance Detector Distance (*S1*), ft			Passage Time, s
	S1	*S2*	*S3*		*S1*	*S2*	*S3*	
45	210	330	--	2.0	210	330	--	2.0
55	225	320	415	1.4 to 2.0	225	320	415	1.4 to 2.0
65	320	430	540	1.6 to 2.0	320	430	540	1.6 to 2.0

Loop Detection for High Speeds

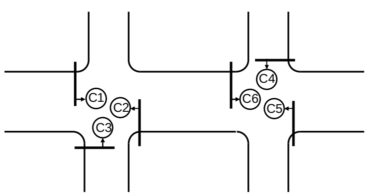
- **Guidelines**
  - ***Four-phase sequence***
    - **Phases 1, 2, 5, and 6**
    - **Phases 4 and 8**



85th Percentile Speed, mph	Phases 1, 2, 5, and 6				Frontage Road Phases 4 and 8			
	Advance Detector Distance, ft			Passage Time, s	Interchange Spacing, ft			Passage Time, s
	S1	*S2*	*S3*		100	200	300	
					Advance Detector Distance (*S1*), ft			
45	210	330	--	2.0	390	535	650	2.0 to 3.0
55	225	320	415	1.4 to 2.0	480	650	700	2.0 to 3.0
65	320	430	540	1.6 to 2.0	565	700	700	2.0 to 3.0

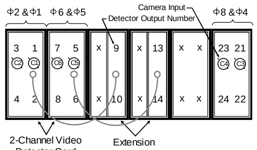
Video Detection Design

- **Guidelines**
  - ***Typically use six cameras***
    - **Three per intersection**
    - **High-speed approaches may use multiple cameras**



Video Detection Design

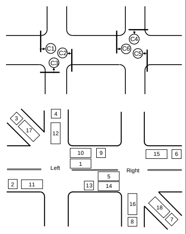
- **Guidelines**
  - ***Typically use two channel detector cards***
    - **Single-channel and four-channel cards are also occasionally used**
  - ***Use detector configuration meeting TxDOT specification***



Video Detection Design

- **Guidelines**
  - ***Typical video detector switching***

Camera Number	Detector Output Number	Phase Number	Assigned Detector Channel
C1	1	$\Phi1$	1
	2		not used
C2	3	$\Phi2$	11
	4		2
C5	5	$\Phi5$	5
	6		not used
C6	7	$\Phi6$	15
	8		6
C1 extension module	9	Overlap A ($\Phi1 + \Phi2$)	10
	10		9
C5 extension module	13	Overlap B ($\Phi5 + \Phi6$)	14
	14		13
C3	21	$\Phi4$	12
	22		4
C4	23	$\Phi8$	16
	24		8



Conditional Service

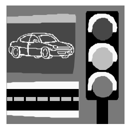
- **Guidelines**
  - ***Conditional service can be used when...***
    - **Three-phase operation is used**
    - **The difference between the average green interval of the two frontage roads exceeds 10 to 12 s**
    - **Minimum green for phases 10 and 14 is short**
      - **Typically 5 to 8 s**
  - ***Decision to use conditional service***
    - **Based on consideration of frontage road volume**
    - **Volume must be very unbalanced or additional delay may be incurred by arterial movements**

Summary

- **Appendix D Guidelines**
  - ***Selection of phase sequence***
  - ***Actuated phase settings***
  - ***Loop detection layout for low speeds***
  - ***Loop detection layout for high speeds***
  - ***Configuration of video detection outputs***
  - ***Conditional service***
- **Questions?**

Wrap-Up

- **Questions or Comments?**
- **A Request**
  - ***Please fill out the course review form***
  - ***Training course coordinators***
    - **Return course evaluations and sign-in sheets to Henry Wickes in TRF**
- **Thank You!**



EXAMPLE 1: MAXIMUM GREEN

Location: 4-leg signalized intersection

INPUT DATA

General Information

Phase 2 direction: Eastbound

Roadway	Major	Minor
Direction	East/West	North/South
Functional classification	Arterial	Collector
Morning and noon peak demand direction	Eastbound	Northbound
Average annual daily traffic (AADT), veh/d	10,000	5,000

Approach Configuration Data

Movements existing: Left-turn, through, and right-turn (all approaches)

Through lanes on major-road approaches: 2 (eastbound and westbound)

Signal Timing Data

Major-road minimum green setting: 10 s (eastbound and westbound)

CALCULATIONS

What is the peak-period volume (veh/h)? .... [ ]

What is the peak-period volume (veh/h/ln)? .... [ ]

The maximum green setting is the larger of:

1) 30 s

2) Minimum green setting + 10 s = [ ] s + 10 s = [ ] s

3) $^{1}/_{10}$ of the peak-period volume = $^{1}/_{10}$ x [ ] = [ ] s

OUTPUT SUMMARY

What is the maximum green setting (s)? .... [ ]

EXAMPLE 2: MAXIMUM GREEN

Location: 4-leg signalized intersection

INPUT DATA

General Information

Phase 2 direction: Eastbound

Roadway	Major	Minor
Direction	East/West	North/South
Functional classification	Arterial	Arterial
Morning and noon peak demand direction	Eastbound	Northbound
Average annual daily traffic (AADT), veh/d	15,500	7,500

Approach Configuration Data

Movements existing: Left-turn, through, and right-turn (all approaches)

Through lanes on major-road approaches: 2 (eastbound and westbound)

Signal Timing Data

Phase	Minimum green setting, s
Major left-turn	6
Major through	12
Minor through	14

CALCULATIONS

Movement phase	Peak-period volume, veh/h	Peak-period volume, veh/h/ln	Minimum green setting, s	Maximum green setting, s, based on. . .		
				Shortest	Min green	Volume
Major through			12	30		
Minor through			14	20		
Major left-turn			6	15		

OUTPUT SUMMARY

What is the maximum green setting (s)? Major through............................ [ ]

What is the maximum green setting (s)? Minor through............................ [ ]

What is the maximum green setting (s)? Major left-turn........................... [ ]

EXAMPLE 3: OFFSETS

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length range: 60 to 80 s

Phase 2 direction: Eastbound

Signal Timing Data

Phase	Intersection	1	3	5	9
	Distance coordinate (x), ft	0	2260	3950	7740
	Offset, s	0	55	6	0
1	Phase split, % of cycle	12	33	18	15
	Yellow + red clear, s	4	4	4	4
	Phase sequence	Lead	Lead	Lead	Lag
2	Phase split, % of cycle	52	30	44	41
	Yellow + red clear, s	6	4	6	6
5	Phase split, % of cycle	20	30	12	14
	Yellow + red clear, s	3	4	3	3
	Phase sequence	Lead	Lag	Lag	Lead
6	Phase split, % of cycle	44	33	50	42
	Yellow + red clear, s	6	4	6	6

Segment Data

Progression speed: 40 mph (segments A, C, E, and I)

OUTPUT SUMMARY

What is the optimal cycle length (s)?	
What are the optimal offsets (s)? .... Intersection 1:	
Intersection 3:	
Intersection 5:	
Intersection 9:	
What is the progression bandwidth associated with this timing plan?	

EXAMPLE 4: OFFSETS

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 70 s

Phase 2 direction: Eastbound

Signal Timing Data

Phase	Intersection	1	3	5	7	9
	Distance coordinate (x), ft	0	2260	3950	*	7740
	Offset, s	0	55	6	30	0
1	Phase split, % of cycle	12	33	18	15	15
	Yellow + red clear, s	4	4	4	4	4
	Phase sequence	Lead	Lead	Lead	Lag	Lag
2	Phase split, % of cycle	52	30	44	44	41
	Yellow + red clear, s	6	4	6	6	6
5	Phase split, % of cycle	20	30	12	15	14
	Yellow + red clear, s	3	4	3	3	3
	Phase sequence	Lead	Lag	Lag	Lead	Lead
6	Phase split, % of cycle	44	33	50	44	42
	Yellow + red clear, s	6	4	6	6	6

* The distance coordinate (x) for intersection 7 is 4,800 ft for alternative 1 and 5,200 ft for alternative 2.

Segment Data

Progression speed: 40 mph (segments A, C, E, G, and I)

OUTPUT SUMMARY

What is the optimal offset (s)? .... Alternative 1: [ ]

Alternative 2: [ ]

What is the bandwidth (s)? .... Alternative 1: [ ]

Alternative 2: [ ]

Which alternative is better? .... [ ]

EXAMPLE 5: PHASE SPLITS

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 80 s
Phase 2 direction: Eastbound
East/west road phasing: Left-turn phase and through phase
North/south road phasing: Left-turns and through movements in same phase

Roadway	Major	Minor
Direction	East/West	North/South
Functional classification	Arterial	Arterial
Morning and noon peak demand direction	Eastbound	Northbound
Average annual daily traffic (AADT), veh/d	15,500	7,500

Volume and Lane Geometry Input Data

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Volume, veh/h	39	451	62	673	48	189	50	306
Lanes	1	2	1	2	0	2	0	2

Change Period and Minimum Green Data

Yellow + red clearance: 5 s (all phases)

Phase	Minimum green setting, s
Major left-turn	6
Major through	12
Minor through	14

OUTPUT SUMMARY

What phase splits should be used?

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Phase split, s								
Phase split, percent of cycle								

EXAMPLE 6: PHASE SPLITS

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 70 s
Phase 2 direction: Eastbound
East/west road phasing: Left-turn phase and through phase
North/south road phasing: Left-turn phase and through phase

Roadway	Major	Minor
Direction	East/West	North/South
Functional classification	Arterial	Arterial
Morning and noon peak demand direction	Eastbound	Northbound
Average annual daily traffic (AADT), veh/d	15,500	7,500

Volume and Lane Geometry Input Data

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Volume, veh/h	39	451	62	673	48	189	50	306
Lanes	1	2	1	2	1	2	1	2

Change Period and Minimum Green Data

Yellow + red clearance: 5 s (all phases)

Phase	Minimum green setting, s
Major through	12
Minor through	14
Major left-turn	6
Minor left-turn	6

OUTPUT SUMMARY

What phase splits should be used?

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Phase split, s								
Phase split, percent of cycle								

EXAMPLE 7: LEFT-TURN MODE

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 100 s

Phase 2 direction: Eastbound

Volume and Lane Geometry Input Data

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Volume, veh/h	105	502	201	806	93	408	57	104
Lanes	1	2	1	2	0	2	0	2

Crash History Data

Approach	Eastbound	Westbound	Northbound	Southbound
Left-turn crashes	4	5	4	2

Time period for crashes: 2 years

Speed and Sight Distance Data

Major-road approach speed: 45 mph (eastbound and westbound)

Minor-road approach speed: 35 mph (northbound and southbound)

Sight distance: Adequate for all left-turn movements

OUTPUT SUMMARY

What is the suggested left-turn mode? (circle one)

Approach	Eastbound	Westbound	Northbound	Southbound
Left-turn mode	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive

EXAMPLE 8: LEFT-TURN MODE

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 100 s
Phase 2 direction: Eastbound

Volume and Lane Geometry Input Data

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Volume, veh/h	39	451	62	673	48	189	50	306
Lanes	1	2	1	2	1	2	1	2

Crash History Data

Approach	Eastbound	Westbound	Northbound	Southbound
Left-turn crashes	4	5	4	2

Time period for crashes: 2 years

Speed and Sight Distance Data

East/west approach speed: 45 mph
North/south approach speed: 35 mph
East/west sight distance: 335 ft
North/south sight distance: 400 ft

OUTPUT SUMMARY

What is the suggested left-turn mode? (circle one)

Approach	Eastbound	Westbound	Northbound	Southbound
Left-turn mode	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive	Protected-only Protected-permissive Permissive

TRAFFIC SIGNAL OPERATIONS WORKSHOP

Date: ____________________________
Location: ____________________________

Your Agency:____

Your Position:____

Course Content (circle one)

	Yes				No
1. Did the course meet your expectations? Comments: ____ ____	1	2	3	4	5
2. Was the material presented at the correct level of difficulty? Comments: ____ ____	1	2	3	4	5
3. Was the topic of the course covered adequately (nothing left out, no one topic overemphasized)? Comments: ____ ____	1	2	3	4	5
4. Was the software easy to use? Comments: ____ ____	1	2	3	4	5

General Observations

5. What did you like most about the course?

6. What did you like the least about the course?

7. What can we do to improve this workshop?

8. Other Comments:

Thank you for taking the time to complete this course evaluation form. Please make sure the course instructor receives it before you leave.