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

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
  - Past TxDOT Research
  - National Research (FHWA, TRB)
  - Synthesize
  - 0-5629 Research
  - Traffic Signal Operations Handbook
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

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
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

<table>
<thead>
<tr>
<th>Phase</th>
<th>Approach Type</th>
<th>Minimum Green, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through</td>
<td>Major-road</td>
<td>8 to 15</td>
</tr>
<tr>
<td>Through</td>
<td>Minor-road</td>
<td>5 to 10</td>
</tr>
<tr>
<td>Left-turn</td>
<td>All</td>
<td>5 to 8</td>
</tr>
</tbody>
</table>

Minimum Green Setting

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

<table>
<thead>
<tr>
<th>Distance between Stop Line and Detector, ft</th>
<th>Minimum Green, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 25</td>
<td>5</td>
</tr>
<tr>
<td>26 to 50</td>
<td>7</td>
</tr>
<tr>
<td>51 to 75</td>
<td>9</td>
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<tr>
<td>76 to 100</td>
<td>11</td>
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<tr>
<td>101 to 125</td>
<td>13</td>
</tr>
<tr>
<td>126 to 150</td>
<td>15</td>
</tr>
</tbody>
</table>
**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*

- **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

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 20 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

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**

- **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

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**Introduction to TSCO**

**TSCO Instructions**

- **Inputs**: blue cells, drop-down, check boxes
- **Intermediate calculations**: white cells
- **Results**: purple cells

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**Texas Signal Coordination Optimizer**

This software is used to assist with the development of effective traffic signal settings. It is intended for use by engineers responsible for traffic signal design.

This software is designed for use with the Handbook identified below. The analyst is encouraged to read the documents so that he or she will have an understanding of how best to use the software and interpret its output.

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
    - 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

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Month</th>
<th>Direction</th>
<th>Lane</th>
<th>Peak-Period Volume</th>
<th>Minimum Green</th>
<th>Approach with peak demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street</td>
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Example 1: Maximum Green

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Month</th>
<th>Direction</th>
<th>Lane</th>
<th>Peak-Period Volume</th>
<th>Minimum Green</th>
<th>Approach with peak demand</th>
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</thead>
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</table>

Example 1: Maximum Green

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

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:

<table>
<thead>
<tr>
<th>Movement Phase</th>
<th>Peak-Period Volume, veh/h</th>
<th>Min. Green, s</th>
<th>Maximum Green, s Based on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major thru</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minor thru</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major left</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Speed, mph</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow, s</td>
<td>3.0</td>
<td>3.2</td>
<td>3.6</td>
<td>3.9</td>
<td>4.3</td>
<td>4.7</td>
<td>5.0</td>
<td>5.4</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Speed, mph</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow, s</td>
<td>3.0</td>
<td>3.2</td>
<td>3.6</td>
<td>3.9</td>
<td>4.3</td>
<td>4.7</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Through Speed, mph</th>
<th>Left-Turn Speed, mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to 34</td>
<td>25</td>
</tr>
<tr>
<td>35 to 44</td>
<td>30</td>
</tr>
<tr>
<td>45 to 54</td>
<td>35</td>
</tr>
<tr>
<td>55 to 64</td>
<td>40</td>
</tr>
<tr>
<td>65 to 74</td>
<td>45</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Approach Speed, mph</th>
<th>Intersection Width, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>30</td>
<td>1.6</td>
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<tr>
<td>40</td>
<td>1.2</td>
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<tr>
<td>50</td>
<td>1.0</td>
</tr>
<tr>
<td>60</td>
<td>1.2</td>
</tr>
</tbody>
</table>
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

• Guidelines
  – Duration based on three goals
    • Ensure queue clearance
    • Satisfy driver expectancy (no unneeded extension)
    • Reduce max-out frequency
  – Equation
    • \[ PT = MAH - \frac{Lv + Ld}{1.47 V} \]
    • \( MAH \) = 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
      – \( PT = 85\text{th} \% \text{ speed in mph} / 20 \)

<table>
<thead>
<tr>
<th>Detection Zone Length, ft</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.5</td>
<td>2.0</td>
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<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>40</td>
<td>1.0</td>
<td>1.0</td>
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<td>1.5</td>
<td>2.0</td>
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<tr>
<td>60</td>
<td>0.0</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
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<tr>
<td>80</td>
<td>0.0</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
<td>1.0</td>
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</tbody>
</table>
Passage Time

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

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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
  - 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

Vehicle off detector

Controller

Vehicle call is extended

Call no longer seen by the controller

Extend

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

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Walk Interval Duration (W), s</th>
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</thead>
<tbody>
<tr>
<td>High pedestrian volume areas (e.g., school, business district, etc.)</td>
<td>10 to 15</td>
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<tr>
<td>Typical pedestrian volume and longer cycle length</td>
<td>7 to 10</td>
</tr>
<tr>
<td>Typical pedestrian volume and shorter cycle length</td>
<td>7</td>
</tr>
<tr>
<td>Negligible pedestrian volume</td>
<td>4</td>
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</tbody>
</table>

Pedestrian Settings

• Guidelines
  – Pedestrian change interval (PCI)
    • Pedestrian walking speed
    • Pedestrian clearance time (PCT)
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: \( \text{PCT} = \frac{D_c}{V_p} \)
      - where,
        - \( D_c \) = curb to curb crossing distance (ft)
        - \( V_p \) = pedestrian walking speed (fps)

  - *Pedestrian change interval (PCI)*
    - Equation: \( \text{PCI} = \text{PCT} - (Y + R_c) \)

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

Option 1
- WALK
- Pedestrian Clearance Time
- Minimum Pedestrian Time
- Vehicular Green
- Yellow
- Red
- Flashing DW
- Steady DW
- Minimum Vehicle Time

Option 2
- WALK
- Vehicular Green
- Yellow
- Red
- Flashing DW
- Steady DW
- Minimum Pedestrian Time

Summary

- Chapter 2 Guidelines
  - Phase settings
    - Minimum green setting
    - Maximum green setting
    - Yellow change interval
    - Red clearance interval
    - Phase recall interval
    - 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

  ![Graph showing coupling index vs. segment volume and street segment length]

  \[ CI = V/L \]

  - Where:
    - \( CI \) = coupling index
    - \( V \) = 2-way volume, veh/h
    - \( L \) = segment length, ft

**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

<table>
<thead>
<tr>
<th>Average Segment Length, ft</th>
<th>Cycle Length by Street Class and Left-Turn Phasing, s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Major Arterial Street</td>
</tr>
<tr>
<td></td>
<td>No Left-Turn Phases</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>60</td>
</tr>
<tr>
<td>1000</td>
<td>90</td>
</tr>
<tr>
<td>1500</td>
<td>120</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
</tr>
<tr>
<td>2500</td>
<td>90</td>
</tr>
<tr>
<td>3000</td>
<td>90</td>
</tr>
<tr>
<td>3500</td>
<td>100</td>
</tr>
<tr>
<td>4000</td>
<td>110</td>
</tr>
<tr>
<td>4500</td>
<td>120</td>
</tr>
</tbody>
</table>

Offset

• Concepts
  – Put green time where it is needed in the cycle to maximize flow

• 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

Offset

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

Offset

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

---

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

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Int. 1</th>
<th>Int. 3</th>
<th>Int. 5</th>
<th>Int. 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset, s</td>
<td>0</td>
<td>55</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Ph. 1 Split, %</td>
<td>12</td>
<td>33</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Ph. 1 Y+RC, s</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ph. 1 Sequence</td>
<td>Lead</td>
<td>Lead</td>
<td>Lead</td>
<td>Lag</td>
</tr>
</tbody>
</table>

- Progression speed: 40 mph

- 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

Example 3: Offset

- Step 2: Identify Optimum Timing Plan
  - Click the “Search” button

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 Diagram]

- **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*

  System Master
  Time Zero
  Yield Point
  Begin Permissive Period
  End of Coordinated Phases

  Y+R
  Gmin
  Phase 2
  Y+R
  Phase 3
  Y+R
  Time (complete circle = 1 cycle)
  Y+R
  Phase 4
  Green
  Gmin
  Phase 1
  Green
  Gmin
  Force-Off Phases 3 & 7
  Force-Off Phases 4 & 8
  Force-Off Phases 1 & 5

Gmax for Phase 4
(Fixed mode)

Actual Phase Durations Shown

• Concepts
  – *Floating mode*

  Sytem Master
  Time Zero
  Yield Point
  Begin Permissive Period
  End of Coordinated Phases

  Y+R
  Gmin
  Phase 2 & 6
  Split
  Phase 3 & 7
  Split
  Y+R
  Time (complete circle = 1 cycle)
  Y+R
  Phase 4 & 8
  Split
  Phase 1 & 5
  Split
  Gmin
  Gmin
  Green
  Green
  Green
  Green
  Force-Off Phases 3 & 7
  Force-Off Phases 4 & 8
  Force-Off Phases 1 & 5

Gmax for Phases 4 & 8
(Floating mode)

Phase Split Durations Shown

• 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

<table>
<thead>
<tr>
<th>Minor Movement Volume</th>
<th>1st Choice Transition Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Short Cycle</td>
</tr>
<tr>
<td></td>
<td>Dwell</td>
</tr>
<tr>
<td>High</td>
<td>Dwell or</td>
</tr>
<tr>
<td></td>
<td>Short-way</td>
</tr>
</tbody>
</table>

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

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

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

<table>
<thead>
<tr>
<th>Movement</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak</td>
<td>60</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<tr>
<td>PM Peak</td>
<td>60</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Evening Peak</td>
<td>60</td>
<td>673</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Evening Peak,并与</td>
<td>60</td>
<td>673</td>
<td>62</td>
<td>62</td>
</tr>
</tbody>
</table>

Example 5: Phase Splits

• Step 2: Estimate Peak-Period Volume
  – Evening peak period was specified
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:
  - Copy

  "Splits" row 11:
  - Paste Special → Values

- **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

  - 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 3: Compute Phase Splits
  - Results from “Splits” worksheet
    - 63 percent of cycle available for phases 2 & 6

| Phase | L1 | L2 | L3 | L4 | L5 | L6 | L7 | Cycle
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Split 1</td>
<td>11</td>
<td>50</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>70</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th></th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phases</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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

![Graph of cycle number vs. cycle time with labeled phases and split adjustments]
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
  - 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

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

### Example 7: Left-Turn Mode

| Volume and Lane Counting Data | Left-turn | Right-turn | Approach BL | Opposing Approach Left-turn | Opposing Approach Right-turn | Total
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>L</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash history</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time period for crashes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach speed E/W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approach speed N/S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sight Distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adequate for left-turn drivers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

11 answers

High volumes of conflicting traffic
Example 7: Left-Turn Mode

• Step 2: Choose Left-Turn Modes

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

- **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**

- **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

- **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

- Minimum Pedestrian Time
- Leading Walk
- Lagging Walk
- Minimum Green
- Yellow
- Red
- Vehicular Green
- Yellow
- Red
- Flashing DW
- Steady DW
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

<table>
<thead>
<tr>
<th>Feature</th>
<th>Primary Influence of Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operations</td>
</tr>
<tr>
<td>Dynamic maximum</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable initial</td>
<td>Yes</td>
</tr>
<tr>
<td>Gap reduction</td>
<td>Yes</td>
</tr>
<tr>
<td>Phase-sequence settings</td>
<td>Yes</td>
</tr>
<tr>
<td>Rail preemption</td>
<td></td>
</tr>
</tbody>
</table>

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

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**

- **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
  - ![Diagram of initial settings](image)
**Added Initial**

- **Guidelines**

<table>
<thead>
<tr>
<th>Number of Detectors¹</th>
<th>Added Initial, s</th>
<th>Minimum</th>
<th>Desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right-turn on red significant</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>No right-turn on red</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>1</td>
<td>0.8</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>6 or more</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

---

**Maximum Initial**

- **Guidelines**

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

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

---

**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

<table>
<thead>
<tr>
<th>Detection Zone Length, ft</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage Time (PT), s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>40</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>60</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>80</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Time Before Reduction

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

![Diagram of Time Before Reduction](image)

Time To Reduce

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

<table>
<thead>
<tr>
<th>Minimum Green Setting, s</th>
<th>Time Before Reduction, s</th>
<th>Maximum Green Setting, s</th>
<th>TTR, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>n.a.</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>n.a.</td>
<td>5</td>
</tr>
</tbody>
</table>

Minimum Gap

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

<table>
<thead>
<tr>
<th>Detection Zone Length, ft</th>
<th>85th Percentile Speed, mph</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Minimum Gap, s</td>
</tr>
<tr>
<td>8</td>
<td>1.5</td>
</tr>
<tr>
<td>20</td>
<td>1.0</td>
</tr>
<tr>
<td>40</td>
<td>0.5</td>
</tr>
<tr>
<td>60</td>
<td>0.0</td>
</tr>
<tr>
<td>80</td>
<td>0.0</td>
</tr>
</tbody>
</table>
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
    • (also known as Preemption Worksheet)
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

• 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
  - Preempt To Controller
  - Lights Start To Flash
  - Train Arrives At Crossing

Warning
- Advance Preemption Time (APT)
- Railroad Warning Time (WT = 20 Seconds)

Lights
- Preempt Trap
- 4 sec delay
- Gate Onset (Red)
- Gates Horizontal

Gates
- Gates Descending

Signal
- Track Green
- Red / Dwell

Queue
- Queue Clearance Time
- See Gates Furred

TSCO Demonstration

- Preemption Worksheet
  - Texas Signal Coordination Optimizer

Developed by: Michael P. Pitt and James J. Rinehart
Version 2.0

Right-of-Way Transfer

- Right-of-Way Transfer
  - Track Clear
  - Pipe in Place

- Right of Way Arrives
  - See Gates Furred

- Right of Way Leaves
  - Track Clear
TSCO Demonstration

**Queue Clearance Time**

<table>
<thead>
<tr>
<th>Section 2: Queue Clearance Time Calculation</th>
<th>Design Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVE</td>
<td>600 m</td>
</tr>
<tr>
<td>v</td>
<td>90</td>
</tr>
<tr>
<td>T</td>
<td>20</td>
</tr>
<tr>
<td>a</td>
<td>3</td>
</tr>
<tr>
<td>d</td>
<td>50</td>
</tr>
<tr>
<td>A</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>120</td>
</tr>
<tr>
<td>D</td>
<td>140</td>
</tr>
<tr>
<td>G</td>
<td>200</td>
</tr>
<tr>
<td>W</td>
<td>110</td>
</tr>
<tr>
<td>L</td>
<td>150</td>
</tr>
</tbody>
</table>

- Queue clearance time (seconds)
- Desirable track green duration (optional)

TSCO Demonstration

**Maximum Preemption Time**

- Section 3: Maximum Preemption Time Calculation
  - B: Built-up time (seconds) 10
  - C: Crosswalk (seconds) 15
  - D: Don't cross outside time line (seconds) 6.8 (For preemption)
- Minimum preemption time (seconds)

- Section 4: Soft Call Warning Time (optional)
  - Required minimum time, 90 seconds, per road lane 20.0 (as required by TMC)
  - Operation time, 0.5 second, get nominated 6.8 (As required by TMC)
  - Minimum required time, 90 seconds/20.0 + 6.8 = 26.8
  - Advance warning time, ART, equals time required for lane change 22.8
  - Additional warning time required for lane change 8.0
  - Total time required for lane change (seconds) 30.8

TSCO Demonstration

**Track Clearance Green Time**

- Section 5: Track Clearance Green Time Calculation (optional)
  - Advance green time, ART (seconds) 200
  - Maximum distance to stop (in seconds) 1.0
  - Maximum distance to stop (in seconds) 1.0
  - Minimum distance to stop (in seconds) 1.0
  - Time required to meet stop distance (in seconds) 4.5
  - Time required to meet stop distance (in seconds) 4.5
  - Minimum time, meeting stop time (seconds) 4.5
  - Minimum time, meeting stop time (seconds) 4.5
  - Time required for design vehicle to start moving (seconds) 4.5
  - Maximum distance to stop (in seconds) 1.0
  - Minimum time, meeting stop time (seconds) 4.5
  - Time required for design vehicle to start moving (seconds) 4.5

- Maximum distance to stop (in seconds) 1.0
- Minimum time, meeting stop time (seconds) 4.5
- Time required for design vehicle to start moving (seconds) 4.5
- Maximum distance to stop (in seconds) 1.0
- Minimum time, meeting stop time (seconds) 4.5
- Time required for design vehicle to start moving (seconds) 4.5
- Maximum distance to stop (in seconds) 1.0
- Minimum time, meeting stop time (seconds) 4.5
- Time required for design vehicle to start moving (seconds) 4.5

TSCO Demonstration

- Track Clearance Green Time (optional)
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

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time required to design vehicle to accelerate Trg (s)</td>
<td>3.5</td>
</tr>
<tr>
<td>Time required to design vehicle to decelerate Des (s)</td>
<td>3.1</td>
</tr>
<tr>
<td>Time required to design vehicle to stop from 50 mph (s)</td>
<td>4.9</td>
</tr>
<tr>
<td>Time required to design vehicle to stop from 60 mph (s)</td>
<td>7.5</td>
</tr>
<tr>
<td>Time required to design vehicle to stop from 70 mph (s)</td>
<td>11.1</td>
</tr>
</tbody>
</table>

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?

PCI = \frac{Dc}{Vp} - (Y + R)

Walking speed = 4 fps
Example 9 - Preemption

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

- Design vehicle = bus
- Grade = level

**Minimum Track Clearance Distance (MTCD)** = 25 ft

**Clear Storage Distance (CSD)** = 60 ft

---

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

- **APT** = 15.0 s

---

**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

\( D_ż = \text{Distance to the beginning of the indecision zone} \)
\( D_ɛ = \text{Distance to the end of the indecision zone} \)

Probable Stop
Probable Go

Indecision Zone

Distance to the beginning of the indecision zone
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

Detector

Loop Layout for Low Speeds

• Guidelines
  – 85th 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

Through Movement

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

<table>
<thead>
<tr>
<th>Category</th>
<th>80th Percentile Speed, mph</th>
<th>Design Element</th>
<th>Design Values by Detection Option</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Option 1</td>
</tr>
<tr>
<td>Detection layout</td>
<td>70</td>
<td>Distance from the stop line to the upstream edge of the advance detector, ft</td>
<td>600, 475, 350</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td></td>
<td>475, 375, 275</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td></td>
<td>350, 220</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td></td>
<td>330, 210</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td></td>
<td>330, 210</td>
</tr>
<tr>
<td>40 to 70</td>
<td>40</td>
<td>Stop line detection zone length, ft</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Advance detection lead-ins wired to channel separate from stop line detection</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Loop Layout for High Speeds

- Guidelines
  - **Controller settings**

<table>
<thead>
<tr>
<th>Category</th>
<th>Design Element</th>
<th>Design Values by Detection Option</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller settings</td>
<td>70</td>
<td>Passage time, s</td>
<td>1.4 to 2.0</td>
<td>1.4 to 2.0</td>
<td>1.0 to 1.2</td>
</tr>
<tr>
<td>45</td>
<td>1.6 to 2.0</td>
<td>1.6 to 2.0</td>
<td>1.0 to 1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1.4 to 2.0</td>
<td>1.4 to 2.0</td>
<td>1.0 to 1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>2.0</td>
<td>2.0</td>
<td>1.4 to 1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>2.0</td>
<td>1.4 to 1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 to 70</td>
<td>Detection mode</td>
<td>Presence</td>
<td>Presence</td>
<td>Presence</td>
<td></td>
</tr>
<tr>
<td>45 to 70</td>
<td>Controller malfunction</td>
<td>Nonlocking</td>
<td>Varies</td>
<td>Nonlocking</td>
<td></td>
</tr>
<tr>
<td>45 to 70</td>
<td>Stop line detection channel extend setting, s</td>
<td>2.0</td>
<td>not used</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>45 to 70</td>
<td>Stop line detection operation</td>
<td>Deactivate after go-out</td>
<td>not used</td>
<td>Continuously active</td>
<td></td>
</tr>
</tbody>
</table>

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

- **Legend**
  - Video camera

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

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

<table>
<thead>
<tr>
<th>Camera Location</th>
<th>Lateral Offset, ft</th>
<th>No Left Turn Lanes</th>
<th>One Left Turn Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left side of approach</td>
<td>-60</td>
<td>P 20</td>
<td>P 25</td>
</tr>
<tr>
<td>-40</td>
<td>P 20</td>
<td>P 25</td>
<td></td>
</tr>
<tr>
<td>-20</td>
<td>P 20</td>
<td>P 25</td>
<td></td>
</tr>
<tr>
<td>-0</td>
<td>P 20</td>
<td>P 25</td>
<td></td>
</tr>
<tr>
<td>-15</td>
<td>P 20</td>
<td>P 25</td>
<td></td>
</tr>
<tr>
<td>M = mast arm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P = strain pole</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = 5 ft riser</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L = luminaire arm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **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

Legend - video camera
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*
    - 85th 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

- **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

![Diagram of video detection layout](image)

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

<table>
<thead>
<tr>
<th>85th Percentile Speed, mph</th>
<th>Distance between Camera and Stop Line, ft</th>
<th>Camera Height, ft</th>
<th>Stop Line Detection Zone Length, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td>50</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
<td>130</td>
<td>135 135 135 135</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>120</td>
<td>125 125 125 125</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>110</td>
<td>120 120 120 120</td>
</tr>
</tbody>
</table>

- **Detection mode and settings**

![Diagram of video detection modes](image)
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
- Three interchange spacing categories

<table>
<thead>
<tr>
<th>Interchange Category</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow</td>
<td>&lt; 400 ft</td>
</tr>
<tr>
<td>Intermediate</td>
<td>400 to 800 ft</td>
</tr>
<tr>
<td>Wide</td>
<td>&gt; 800 ft</td>
</tr>
</tbody>
</table>

Traffic Patterns
- Frontage road traffic
  - Balanced
  - Unbalanced

Traffic Patterns
- 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

<table>
<thead>
<tr>
<th>10</th>
<th>4</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Interchange Spacing</th>
<th>Arterial Through Traffic Volume</th>
<th>Frontage Road Traffic Pattern</th>
<th>Internal Left-Turn Traffic Volume</th>
<th>Typical Phase Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 400 ft (narrow)</td>
<td>Unbalanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Four</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unbalanced</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Balanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Four or three</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Four</td>
<td></td>
</tr>
<tr>
<td>Unbalanced</td>
<td>Low</td>
<td>Four or three</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Four</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Selection of Phase Sequence

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

<table>
<thead>
<tr>
<th>Interchange Spacing</th>
<th>Arterial Through Traffic Volume</th>
<th>Frontage Road Traffic Pattern</th>
<th>Internal Left-Turn Traffic Volume</th>
<th>Typical Phase Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 400 and 600 ft (intermediate)</td>
<td>Unbalanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Three</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td>Three or separate</td>
</tr>
<tr>
<td></td>
<td>Unbalanced</td>
<td>Low</td>
<td>Separate</td>
<td></td>
</tr>
<tr>
<td>Balanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Three</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Three or separate</td>
<td></td>
</tr>
<tr>
<td>Unbalanced</td>
<td>Low</td>
<td>Separate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Three or separate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Selection of Phase Sequence

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

<table>
<thead>
<tr>
<th>Interchange Spacing</th>
<th>Arterial Through Traffic Volume</th>
<th>Frontage Road Traffic Pattern</th>
<th>Internal Left-Turn Traffic Volume</th>
<th>Typical Phase Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than 800 ft (wide)</td>
<td>Unbalanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Three</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td>Separate</td>
</tr>
<tr>
<td></td>
<td>Unbalanced</td>
<td>Low</td>
<td>Separate</td>
<td></td>
</tr>
<tr>
<td>Balanced</td>
<td>Balanced</td>
<td>Low</td>
<td>Three</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Separate</td>
<td></td>
</tr>
<tr>
<td>Unbalanced</td>
<td>Low</td>
<td>Separate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Separate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Spacing (ft)</th>
<th>Travel Time (s)</th>
<th>Minimum Green for Phase 1 (s)</th>
<th>Minimum Green for Phase 2 (s)</th>
<th>Minimum Green for Phase 3 (s)</th>
<th>Minimum Green for Phase 4 (s)</th>
<th>Minimum Green for Phase 5 (s)</th>
<th>Minimum Green for Phase 6 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>500</td>
<td>17</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>600</td>
<td>18</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>700</td>
<td>21</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
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<tr>
<td>800</td>
<td>24</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>1000</td>
<td>28</td>
<td>18</td>
<td>16</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Interchange spacing (ft)</th>
<th>Travel Time (T) (s)</th>
<th>Minimum Green for Phases 2 and 6 (s)</th>
<th>Minimum Green for Phases 4 and 8 (s)</th>
<th>Minimum Green for Phases 12 and 16 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7</td>
<td>9</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>200</td>
<td>10</td>
<td>15</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
<td>20</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>400</td>
<td>15</td>
<td>24</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Interchange Spacing (ft)</th>
<th>Travel Time (T) (s)</th>
<th>Maximum Green for Phases 1 and 5 (s)</th>
<th>Maximum Green for Phases 4 and 8 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>15</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td>500</td>
<td>17</td>
<td>17</td>
<td>42</td>
</tr>
<tr>
<td>600</td>
<td>19</td>
<td>19</td>
<td>50</td>
</tr>
<tr>
<td>700</td>
<td>21</td>
<td>21</td>
<td>58</td>
</tr>
<tr>
<td>800</td>
<td>24</td>
<td>24</td>
<td>66</td>
</tr>
<tr>
<td>900</td>
<td>26</td>
<td>26</td>
<td>74</td>
</tr>
<tr>
<td>1000</td>
<td>28</td>
<td>28</td>
<td>82</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>85th Percentile Speed, mph</th>
<th>Phases 1, 2, 5, and 6</th>
<th>Frontage Road Phases 4 and 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advance Detector Distance (S1), ft</td>
<td>Advance Detector Distance (S1), ft</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>35</td>
<td>135</td>
<td>135</td>
</tr>
<tr>
<td>40</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>
Loop Detection for Low Speeds

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

<table>
<thead>
<tr>
<th>85th Percentile Speed, mph</th>
<th>Phases 1, 2, 5, and 6</th>
<th>Frontage Road Phases 4 and 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advance Detector Distance (ft), ft</td>
<td>Passage Time, s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 200 300 400</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>2.0 to 3.0</td>
</tr>
<tr>
<td>35</td>
<td>135</td>
<td>2.0 to 3.0</td>
</tr>
<tr>
<td>40</td>
<td>175</td>
<td>2.0 to 3.0</td>
</tr>
</tbody>
</table>

Loop Detection for High Speeds

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

<table>
<thead>
<tr>
<th>85th Percentile Speed, mph</th>
<th>Phases 1, 2, 5, and 6</th>
<th>Frontage Road Phases 4 and 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advance Detector Distance (ft), ft</td>
<td>Passage Time, s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51 52 53</td>
</tr>
<tr>
<td></td>
<td>Advance Detector Distance (ft), ft</td>
<td>Passage Time, s</td>
</tr>
<tr>
<td>45</td>
<td>210</td>
<td>2.0</td>
</tr>
<tr>
<td>55</td>
<td>225</td>
<td>1.4 to 2.0</td>
</tr>
<tr>
<td>65</td>
<td>320</td>
<td>1.6 to 2.0</td>
</tr>
</tbody>
</table>
Loop Detection for High Speeds

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

<table>
<thead>
<tr>
<th>68th Percentile Speed, mph</th>
<th>Phases 1, 2, 5, and 6</th>
<th>Frontage Road Phases 4 and 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advance Detector Distance, ft</td>
<td>Passage Time, s</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>45</td>
<td>210</td>
<td>330</td>
</tr>
<tr>
<td>55</td>
<td>225</td>
<td>320</td>
</tr>
<tr>
<td>65</td>
<td>320</td>
<td>430</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Camera Number</th>
<th>Detector Output Number</th>
<th>Phase Number</th>
<th>Assigned Detector Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>C3</td>
<td>3</td>
<td>3</td>
<td>not used</td>
</tr>
<tr>
<td>C4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>C6</td>
<td>6</td>
<td>6</td>
<td>not used</td>
</tr>
<tr>
<td>C1 extension module</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C1 extension module</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>C2 extension module</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>C3</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>C4</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

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

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

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) $\frac{1}{10}$ of the peak-period volume = $\frac{1}{10} \times$ s = 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

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

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

<table>
<thead>
<tr>
<th>Phase</th>
<th>Minimum green setting, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major left-turn</td>
<td>6</td>
</tr>
<tr>
<td>Major through</td>
<td>12</td>
</tr>
<tr>
<td>Minor through</td>
<td>14</td>
</tr>
</tbody>
</table>

CALCULATIONS

<table>
<thead>
<tr>
<th>Movement phase</th>
<th>Peak-period volume, veh/h</th>
<th>Peak-period volume, veh/h/ln</th>
<th>Minimum green setting, s</th>
<th>Maximum green setting, s, based on...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortest</td>
<td>Min green</td>
</tr>
<tr>
<td>Major through</td>
<td></td>
<td></td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Minor through</td>
<td></td>
<td></td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Major left-turn</td>
<td>15</td>
<td></td>
<td>6</td>
<td>15</td>
</tr>
</tbody>
</table>

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

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

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

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

* 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

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

Volume and Lane Geometry Input Data

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>39</td>
<td>451</td>
<td>62</td>
<td>673</td>
</tr>
<tr>
<td>Thru</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume, veh/h</td>
<td>48</td>
<td>189</td>
<td>50</td>
<td>306</td>
</tr>
<tr>
<td>Lanes</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Change Period and Minimum Green Data
- Yellow + red clearance: 5 s (all phases)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Minimum green setting, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major left-turn</td>
<td>6</td>
</tr>
<tr>
<td>Major through</td>
<td>12</td>
</tr>
<tr>
<td>Minor through</td>
<td>14</td>
</tr>
</tbody>
</table>

OUTPUT SUMMARY

What phase splits should be used?

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Thru</td>
<td>Left</td>
<td>Thru</td>
</tr>
<tr>
<td>Phase split, s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase split, percent of cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

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

Volume and Lane Geometry Input Data

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Left</td>
<td>Thru</td>
<td>Left</td>
<td>Thru</td>
</tr>
<tr>
<td>Volume, veh/h</td>
<td>39</td>
<td>451</td>
<td>62</td>
<td>673</td>
</tr>
<tr>
<td>Lanes</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Change Period and Minimum Green Data
Yellow + red clearance: 5 s (all phases)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Minimum green setting, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major through</td>
<td>12</td>
</tr>
<tr>
<td>Minor through</td>
<td>14</td>
</tr>
<tr>
<td>Major left-turn</td>
<td>6</td>
</tr>
<tr>
<td>Minor left-turn</td>
<td>6</td>
</tr>
</tbody>
</table>

OUTPUT SUMMARY

What phase splits should be used?

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Left</td>
<td>Thru</td>
<td>Left</td>
<td>Thru</td>
</tr>
<tr>
<td>Phase split, s</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phase split, percent of cycle</th>
</tr>
</thead>
</table>
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

<table>
<thead>
<tr>
<th>Movement</th>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, veh/h</td>
<td>Left</td>
<td>105</td>
<td>502</td>
<td>201</td>
<td>806</td>
</tr>
<tr>
<td>Lanes</td>
<td>Left</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Crash History Data

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-turn crashes</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-turn mode</td>
<td>Protected-only</td>
<td>Protected-only</td>
<td>Protected-only</td>
<td>Protected-only</td>
</tr>
<tr>
<td></td>
<td>Protected-permissive</td>
<td>Protected-permissive</td>
<td>Protected-permissive</td>
<td>Protected-permissive</td>
</tr>
<tr>
<td></td>
<td>Permissive</td>
<td>Permissive</td>
<td>Permissive</td>
<td>Permissive</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement</td>
<td>Left Thru</td>
<td>Left Thru</td>
<td>Left Thru</td>
<td>Left Thru</td>
</tr>
<tr>
<td>Volume, veh/h</td>
<td>39 451</td>
<td>62 673</td>
<td>48 189</td>
<td>50 306</td>
</tr>
<tr>
<td>Lanes</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
<td>1 2</td>
</tr>
</tbody>
</table>

Crash History Data

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-turn crashes</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Approach</th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-turn mode</td>
<td>Protected-only</td>
<td>Protected-only</td>
<td>Protected-only</td>
<td>Protected-only</td>
</tr>
<tr>
<td>Permissive</td>
<td>Permissive</td>
<td>Permissive</td>
<td>Permissive</td>
<td>Permissive</td>
</tr>
</tbody>
</table>
TRAFFIC SIGNAL OPERATIONS WORKSHOP

Date: __________________________
Location: __________________________

Your Agency: ____________________________________________________________

Your Position: ____________________________________________________________

**Course Content** (circle one)

| 1. Did the course meet your expectations? | Yes | 1 | 2 | 3 | 4 | 5 |
| Comments: | |

| 2. Was the material presented at the correct level of difficulty? | Yes | 1 | 2 | 3 | 4 | 5 |
| Comments: | |

| 3. Was the topic of the course covered adequately (nothing left out, no one topic overemphasized)? | Yes | 1 | 2 | 3 | 4 | 5 |
| Comments: | |

| 4. Was the software easy to use? | Yes | 1 | 2 | 3 | 4 | 5 |
| Comments: | |
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.