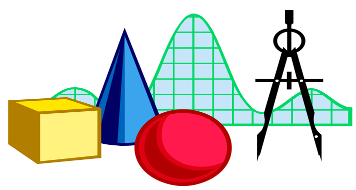
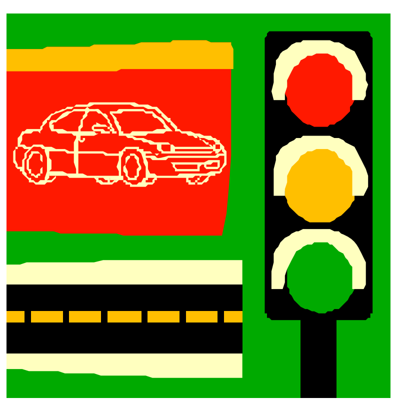
Traffic Signal Operations Handbook:

Workshop Training



Instructor Guide

Product 5-5629-01-P2



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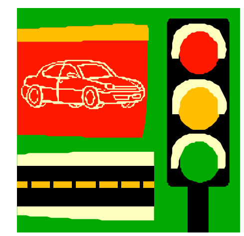

TRAFFIC SIGNAL OPERATIONS HANDBOOK: WORKSHOP TRAINING INSTRUCTOR GUIDE

by

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Project Title: Traffic Signal Operations Handbook Workshop

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DISCLAIMER

NOTICE

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The researchers acknowledge the support and guidance provided by the Project Monitoring Committee:

- Mr. Henry Wickes, Implementation Director (TxDOT, Traffic Operations Division).
- Mr. Wade Odell, Research Engineer (TxDOT, Research and Technology Implementation Office).

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INSTRUCTOR'S NOTES

INTRODUCTION

A *Traffic Signal Operations Handbook* was developed in TxDOT Project 0-5629 to document the best practices for operating traffic signals in Texas. The *Handbook* contains discussion of concepts related to signal timing, procedures for developing timing plans, and guidelines on when and how to use specific procedures and settings. An Excel®-based spreadsheet program called Texas Signal Coordination Optimizer (TSCO) was also developed to assist with the numerous calculations required to implement the procedures.

Workshop Description

Because the *Handbook* covers a diverse set of topics related to signal operations, the workshop is divided into lessons covering the following six topic areas:

- Signal controller timing,
- Signal coordination timing,
- Signal phasing and operation,
- Advanced signal timing settings,
- Detection design and operation, and
- Diamond interchange operations.

The workshop consists of approximately eight hours of instruction, which includes a presentation and interactive participant exercises. At the beginning of the workshop, the participants are told that the first topic area will be covered in the first lesson, and then three additional topics will be covered. The participants are asked to rank the latter five topic areas, and their rankings are used to decide which topic areas would be presented.

The visual aids used in each workshop consist primarily of PowerPoint® slides. The workbook also includes ten self-paced example problems for the participants to work on in an independent manner. The goal of these examples is to help the participants gauge their level of understanding of the course content.

How to Use this Document

This *Instructor Guide* provides a course instructor with the information needed for course preparation and presentation. Specifically, guidance is provided regarding course handouts and visual aids, equipment requirements, and emphasis of the key messages of the various workshop slides.

The front portion of this *Guide*, titled "Instructor's Notes", should be read by the instructor during preparation for the workshop. This material explains the objectives and intended audience of the workshop, describes the necessary materials for the instructor and the participants, and provides a checklist of tasks to be completed before, during, and after the workshop.

The second portion of this *Guide*, titled “Workshop Lesson Slides”, should be reviewed by the instructor before the workshop and kept within view while presenting the workshop. This portion provides detailed information on specific slides in the presentation, including key messages to emphasize during the presentation and background information that can help answer questions from participants.

The third section provides additional helpful information in the forms of solutions to the interactive exercises, an acronym and abbreviation list, and a list of references and source documents. This portion should be reviewed as needed, both before and during the workshop.

WORKSHOP OBJECTIVES

The first objective of the workshop is to inform participants about effective signal timing and design practices and the availability of tools to assist with signal timing and design. The *Handbook* was developed to assist with the timing of isolated or coordinated traffic signals, focusing on controller settings, coordination settings, advanced signal timing settings, and detection design. The complex calculations required to implement the *Handbook* guidance are facilitated by using the TSCO program.

The second objective of the workshop is to demonstrate how to use the *Handbook* and the TSCO program. This demonstration is accomplished with the use of hands-on example problems. At the beginning of each example, the participants are given input data describing a signalized intersection, including traffic volumes, approach configurations, signal phasing, and other relevant information. The participants are then shown how to enter these data into the TSCO program and obtain information about the computed signal timing parameters.

After attending the workshop, participants should be able to apply these evaluation tools to typical intersections to achieve effective signal timing.

INTENDED AUDIENCE

The workshop is intended for engineers and technicians involved with operating or designing traffic signals. The participants are assumed to have a working knowledge of traffic signal equipment. The analysis tools (*Handbook* and TSCO program) discussed in the workshop were developed to help practitioners identify effective signal timing parameters.

PARTICIPANTS’ MATERIALS

Each participant is provided with one copy of the following materials:

- Course Notes,
- *Handbook*, and
- CD containing the following files:
    - TSCO program,
    - Electronic copy of the Course Notes,
    - Electronic copy of the *Handbook*,

- Electronic copy of the final project report, *Development of a Traffic Signal Operations Handbook*,
- An Excel spreadsheet and two media video files used for the two example problems focusing on detection evaluation, and
- PDF file containing screen-size, color reproductions of the PowerPoint slides.

The Course Notes booklet contains handout-sized copies of the PowerPoint slides (with three slides per page and space to take notes), worksheets used in the example problems, and workshop evaluation forms that are filled out by the participants.

INSTRUCTOR'S MATERIALS

To conduct the workshop, the instructor must have the following materials:

- Instructor Guide,
- Course Notes,
- *Handbook*, and
- CD containing the following files:
    - PowerPoint file containing the presentation slides,
    - TSCO program,
    - Electronic copy of the Course Notes,
    - Electronic copy of the *Handbook*,
    - Electronic copy of the final project report, *Development of a Traffic Signal Operations Handbook*,
    - An Excel spreadsheet and two media video files used for the two example problems focusing on detection evaluation, and
    - PDF file containing screen-size, color reproductions of the PowerPoint slides.

Of these four items, the CD and the Instructor Guide are the most essential. The CD is contained in a pocket inside the back cover of the Instructor Guide. The Course Notes provide space for taking notes during the presentation, and also contain a copy of the worksheets that the participants use to complete the interactive exercises. The *Handbook* and the TSCO program should be kept available in case they are needed to answer questions from the participants.

EQUIPMENT REQUIREMENTS

In the workshop classroom, a computer must be provided for the instructor. This computer must be connected to a projector for the purpose of displaying the PowerPoint presentation slides, and it must have a CD drive so the presentation slides can be accessed. The provision of TSCO screen shots in the slides allows the presentation to be made without using TSCO. However, the computer should have Excel in case a question involves its use during the workshop.

The workshop classroom must also have computers available for each participant. These computers must have CD drives and Excel so that the participants can use the TSCO program that is provided to them on a CD.

If it is desired to broadcast the workshop to additional locations via virtual teleconferencing (VTC), then the necessary equipment for VTC interfacing must also be provided.

WORKSHOP AGENDA

The workshop lessons are listed in Table 1, along with the amount of time needed to present each lesson. Because the selection and presentation order for Lessons 2 through 6 depend on the polling of the participants, times and sequences for the lessons cannot be provided. A total of four lessons are presented at each workshop—Lesson 1 and the three highest-ranking lessons from Lessons 2 through 6. The instructor should plan to present up to 450 minutes of lesson material and allow breaks for lunch time (60 minutes) as well as mid-morning and mid-afternoon (two 15-minute breaks).

Table 1. Workshop Agenda.

Time Needed, minutes	Lesson	Material Covered
20	Introduction	Background, *Handbook* organization, and introduction to TSCO.
95	Lesson 1: Signal Controller Timing	Phase settings (minimum and maximum green, change interval, recall, passage time), detector settings (delay, extend, queue), and pedestrian settings (WALK and pedestrian change interval).
140	Lesson 2: Signal Coordination Timing	Coordination potential, system settings (cycle length, offset, phase sequence), and phase splits.
65	Lesson 3: Signal Phasing and Operation	Left-turn mode and phasing, right-turn phasing, and pedestrian phasing.
85	Lesson 4: Advanced Signal Timing Settings	Settings for volume-density control, phase sequence, and rail preemption.
85	Lesson 5: Detection Design and Operation	Layout for loop detection (low and high speed) and video detection (low speed).
80	Lesson 6: Diamond Interchange Operations	Phasing and detection for diamond interchanges.
60	Lunch Break	
15	Mid-Morning Break	
15	Mid-Afternoon Break	

The lesson material was selected to inform the participants of the best practices for signal timing, introduce them to the guidance contained in the *Handbook*, and teach them how to use the portions of the *Handbook* that they believe to be most applicable to their typical tasks. The entire *Handbook* cannot be covered in a one-day workshop, but if the participants indicate (through polling) which portions of the *Handbook* are most relevant to the issues they face in their own jurisdictions, the workshop can be tailored to present the most important information for the audience at each particular workshop presentation.

The example problems and interactive exercises in each lesson are selected such that participants are introduced to every worksheet in the TSCO program. The two worksheets that are not used are for rural signalized intersections and urban unsignalized intersections. These worksheets need not be introduced to the participants because they are similar to the worksheets for urban signalized intersections and rural unsignalized intersections. The coverage of *Handbook* chapters, TSCO worksheets, and example problems in the lessons is summarized in Table 2.

Table 2. Material Used in Workshop Lessons.

Lesson Number	***Handbook* Chapters Covered**	**TSCO Worksheets Used**	**Exercise Numbers**
Introduction	None	Welcome, Volumes	
1	2	Volumes	1, 2
2	3	Analysis, Volumes, Splits	3, 4, 5, 6
3	Appendix A	Left-Turn Mode	7, 8
4	Appendix B	Preemption	9, 10
5	Appendix C	None	11, 12
6	Appendix D	None	None

INSTRUCTOR'S CHECKLISTS

The following checklists summarize the key tasks that the instructor must complete before, during, and after the workshop.

Before the Workshop

- ☐ Confirm the date, time, and location of the workshop with the TxDOT coordinator.
- ☐ Obtain a count of expected participants no less than one week before the workshop.
- ☐ Order one set of participant materials for each participant, plus a few spare sets if desired.
- ☐ Order one set of instructor materials.
- ☐ If people will be participating in the workshop via VTC, make arrangements to ship the required number of course materials to each VTC meeting location.
- ☐ Make all necessary arrangements to travel to the workshop venue. This may include a rental or corporate vehicle, plane tickets, and a hotel room.
- ☐ If driving to the workshop venue, place the instructor materials and the needed number of sets of participant materials in a box to be brought to the venue. If flying to the workshop venue, pack the instructor materials with personal luggage and ship the participant materials to the venue.
- ☐ Obtain a copy of the roster of expected participants at the workshop venue.
- ☐ Review the portions of this *Guide* that address the workshop lessons.
- ☐ Save a copy of the PowerPoint file of the workshop slides on a USB memory drive to be brought to the workshop venue.
- ☐ Arrive at the workshop venue 45 minutes to an hour before the start of the workshop, to ensure that the classroom can be arranged, participants and the instructor can log into computers, and VTC equipment is functional (if applicable).

- ☐ If the login data (name and password, as applicable) are not provided on the participants' computers, write this information on a board where all participants can see.
- ☐ If the participants' computers are connected to a shared network drive, determine how to make the TSCO program available via the shared network drive, in case some participants are unable to access CDs with their computers.
- ☐ Obtain the contact information for the information technology assistant at the workshop venue, in case equipment problems occur during the workshop.
- ☐ Distribute the participant materials to the participants in the classroom.

During the Workshop

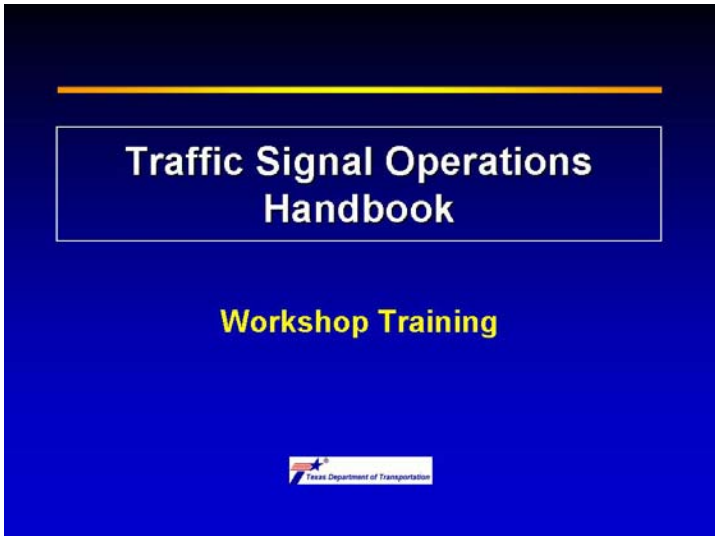
- ☐ Start on time and stay on track. Keep a copy of the workshop agenda in view and check it periodically to evaluate the presentation pace.
- ☐ If participants are attending via VTC, check that all VTC locations are online and capable of hearing and seeing the necessary information from the workshop venue. Perform this check at the beginning of each day and after the end of the lunch break on the first day.
- ☐ If participants are attending via VTC, mute the local microphone during break periods. During the course of the workshop, it may be necessary to remind people at the VTC locations to mute their microphones after asking questions.
- ☐ When participants begin to work on interactive exercises, remind them to turn to the back portion of their Course Notes booklets. These pages contain the input data and space for them to record their answers.
- ☐ Walk among the local participants as they work on interactive exercises and offer help when needed. When most of the participants are finished, return to the instructor's computer and continue presenting the workshop material.

After the Workshop

- ☐ Ask the participants to fill out their course evaluation forms.
- ☐ Collect the completed course evaluation forms from the local participants, and instruct the VTC participants to submit their course evaluation forms to their local training coordinators.
- ☐ Distribute course completion certificates if these are provided.
- ☐ Collect unused copies of the participant materials.
- ☐ Obtain all course evaluation forms before presenting the next workshop offering. Review the participants' comments and make necessary adjustments.

WORKSHOP LESSON SLIDES

Slide 1



Key Message:
None.

Interactivity:
Follow up: If some participants are attending via VTC, verify that all remote locations are connected to the main classroom.

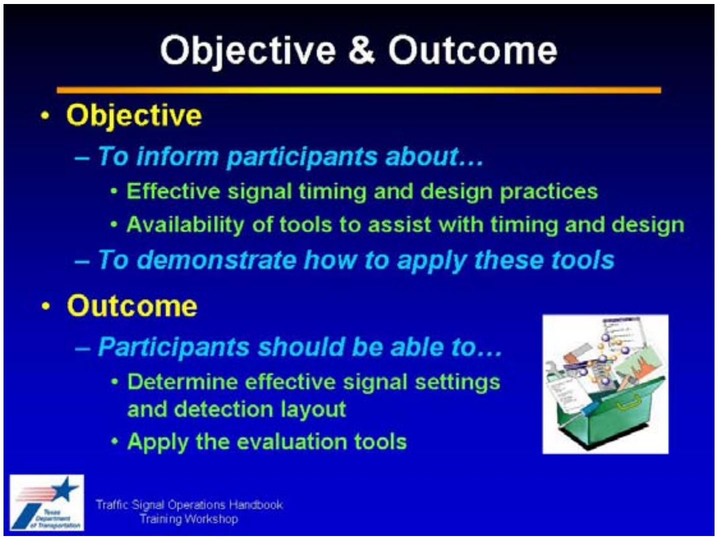
Slide 2

Key Message:
None.

Interactivity:
Ask: Do all participants have the following three items?

- Course Notes,
- *Traffic Signal Operations Handbook*, and
- CD inside the back cover of the Course Notes.

Slide 3



Key Message:
Historically, guidance on effective signal timing and design has been difficult to implement because it has been contained in disparate documents and the required calculations are complicated and data-intensive. Tools have been developed in project 0-5629 to assist practitioners with signal timing and design. The workshop participants will be trained in the use of these tools. The purpose of the tools is to assist with development of effective, but not necessarily optimal, signal timing and design.

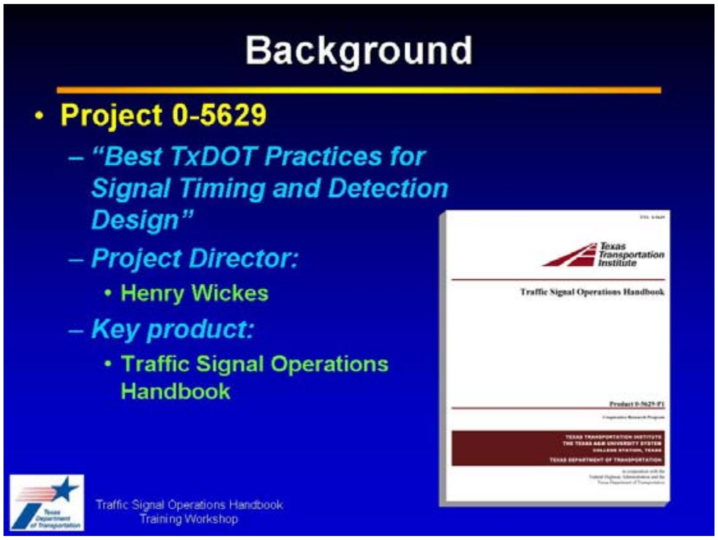
Background:
The workshop focuses on the following two tools from project 0-5629: The *Traffic Signal Operations Handbook* and the Texas Signal Coordination Optimizer (TSCO) Excel-based spreadsheet program.

Slide 4

Key Message:
The intended audience is engineers and technicians involved with signal timing and design. These people can benefit most from guidance and analysis tools to operate signals. The workshop focuses on effective practices, not necessarily optimal practices, which take more time and resources.

Notes:
The typical TxDOT audience for this workshop will likely consist of engineers and technicians who work at the district level to operate and design traffic signals.

Slide 5

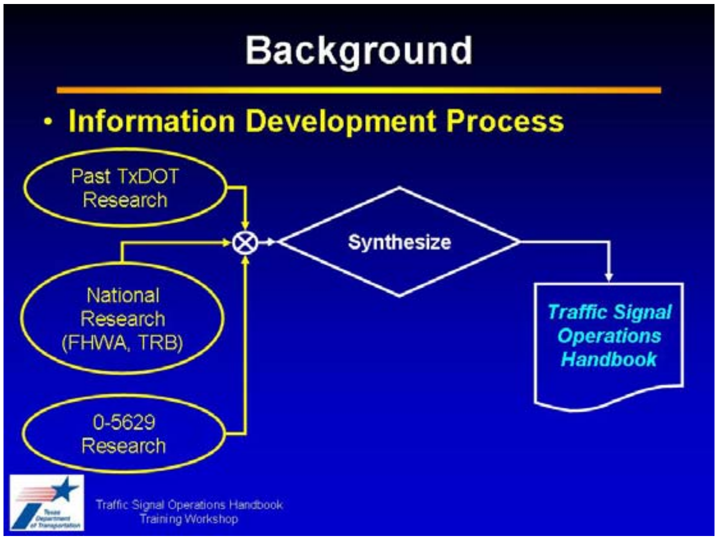


Key Message:
The *Traffic Signal Operations Handbook* is the key product that was developed in project 0-5629. Its purpose is to help traffic engineers to operate and design traffic signals effectively.

Background:
Project 0-5629 started in September 2006 and concluded in August 2008. The key product is the *Traffic Signal Operations Handbook.* A project report, *Development of a Traffic Signal Operations Handbook*, was also developed. This report contains a user's manual for the TSCO program.

Notes:
The documents produced in project 0-5629 are listed in the section titled "List of References and Source Documents" at the end of this document.

Slide 6

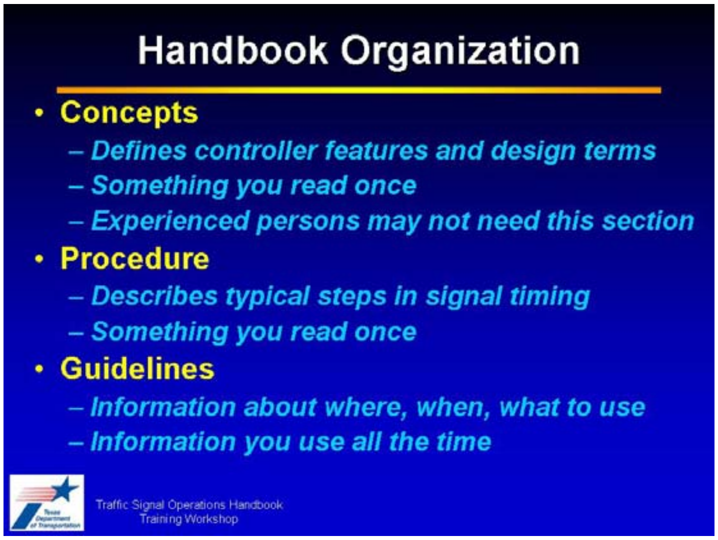


Key Message:
The *Traffic Signal Operations Handbook* represents a combination of new and previous research from Texas and other states.

Slide 7

Key Message:
The *Handbook* is organized for easy use. All guidelines in each chapter are placed together and formulated as look-up tables and figures whenever possible. The chapters also have overview, concepts, and procedure sections.

Slide 8



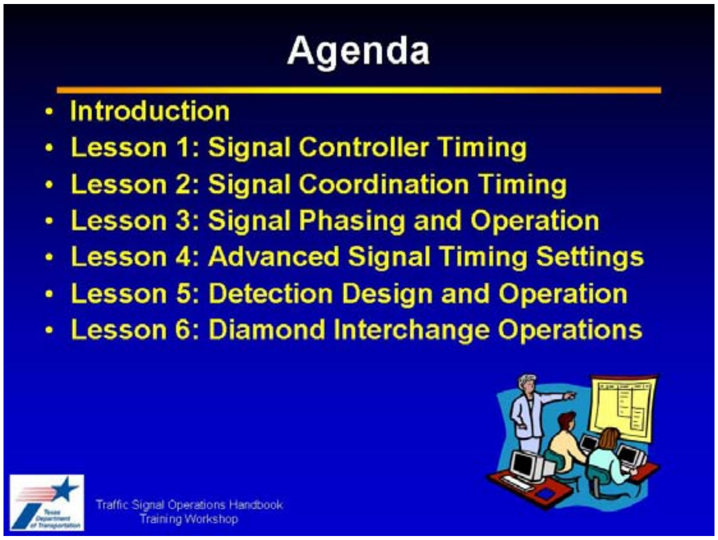
Key Message:
The *Handbook* chapters contain sections on concepts, procedure, and guidelines. The typical reader will use the Guidelines sections often and the Concepts and Procedure sections occasionally.

Interactivity:
Tell: The Concepts sections contain background information about controller features and design terms. These sections need to be read only once, and may be skipped by experienced readers.

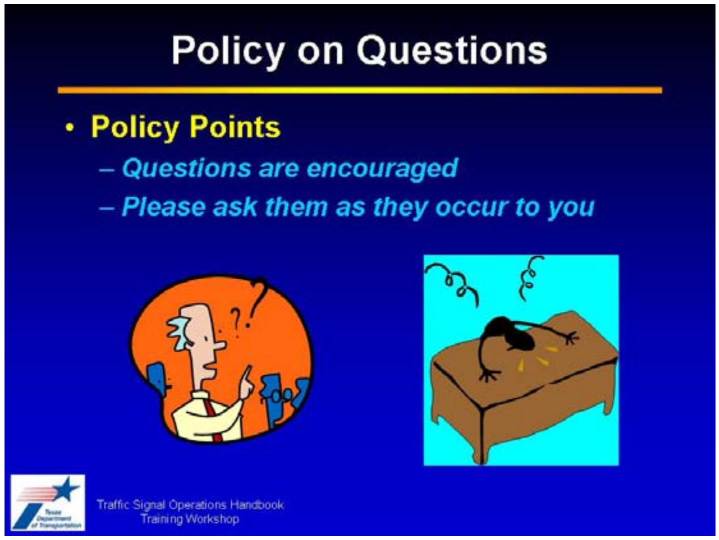
Tell: The Procedure sections describe typical steps in signal timing development. These sections need to be read only once.

Tell: The Guidelines sections contain specific information about how to operate signals. These sections will be used regularly.

Slide 9

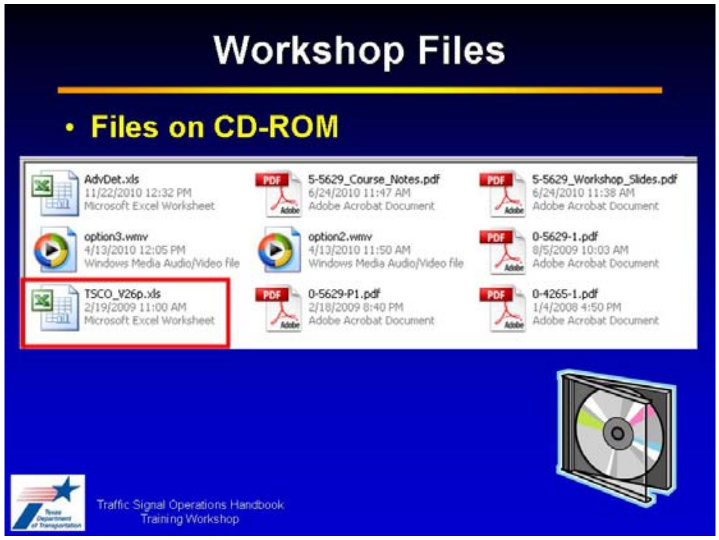

Agenda
• Introduction
• Lesson 1: Signal Controller Timing
• Lesson 2: Signal Coordination Timing
• Lesson 3: Signal Phasing and Operation
• Lesson 4: Advanced Signal Timing Settings
• Lesson 5: Detection Design and Operation
• Lesson 6: Diamond Interchange Operations
Traffic Signal Operations Handbook
Training Workshop

Slide 10



Key Message:
Questions are encouraged. The instructor will periodically ask if anyone has questions, but participants do not have to save their questions until invited to ask.

Slide 11

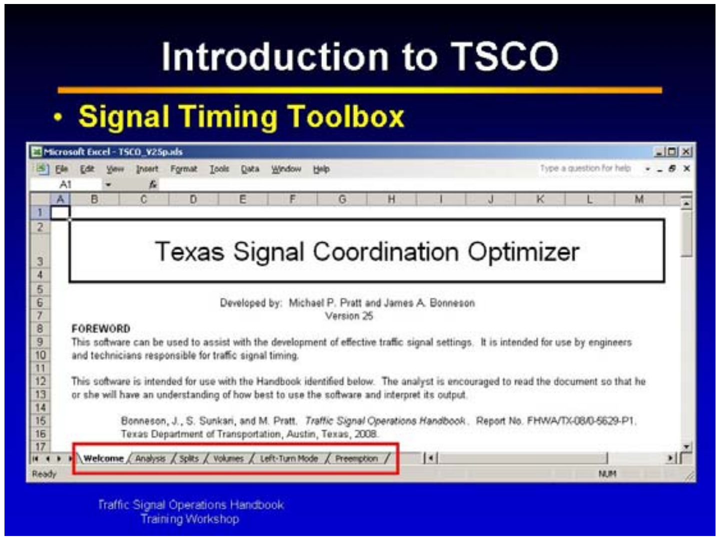


Key Message:
The CD inside the back cover of the Course Notes booklet contains files for the participants to use during the workshop and in their signal timing work.

Interactivity:
Tell: Insert your CD into your computer's CD drive and open the TSCO Excel spreadsheet file.

Tell: When you open TSCO, you may be prompted to enable or disable macros. For the TSCO features to function, macros must be enabled.

Slide 12



Key Message:
The Welcome worksheet is the first worksheet seen when TSCO is opened. The tabs on the bottom of the screen are used to access different worksheets.

Interactivity:
Tell: The red box indicates the location of the worksheet tabs.

Tell: The worksheets collectively comprise a toolbox that can assist with various signal timing tasks.

Tell: The Appendix of the final project report, *Development of a Traffic Signal Operations Handbook*, contains a user's manual for TSCO.

Slide 13

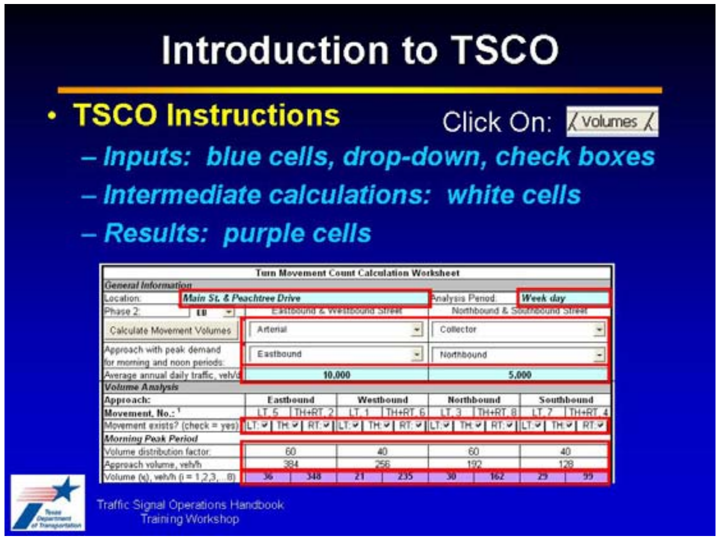
Key Message:
Each worksheet in TSCO is built to provide calculations for a specific signal timing task.

Background:
In addition to the Welcome worksheet, TSCO has the following worksheets:

- Analysis: Evaluates and optimizes timing plans for coordinated signals on arterials
- Splits: Calculates phase splits, using traffic volumes and lane counts as inputs
- Volumes: Estimates turn movement counts using AADT and roadway functional classification data
- Left-Turn Mode: Indicates when protected left-turn phases should be used
- Preemption: Evaluates settings for preemption at highway-rail at-grade crossings

Notes:
The Preemption worksheet represents a spreadsheet implementation of a fillable PDF worksheet developed by Engelbrecht et al. in research project 0-4265. The report for this project is listed in the section titled "List of References and Source Documents" at the end of this Instructor Guide.

Slide 14



Key Message:
This slide explains the color scheme that is used to help analysts navigate through the TSCO worksheets, and also introduces the participants to TSCO's Volumes worksheet.

Interactivity:
Tell: Go to the Volumes worksheet in TSCO to see the input cells shown on the slide. This worksheet uses AADTs to compute movement volumes.

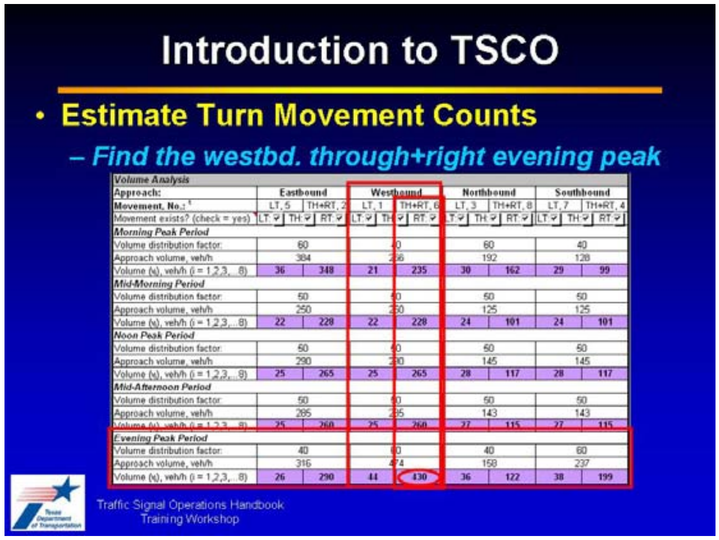
Click: Blue cells are used to input data describing the signalized intersection(s) being analyzed. The blue cells at the top of this worksheet contain descriptive data to identify the intersection and the analysis period.

Click: Some input data are entered using drop-down menus and check boxes. On this worksheet, drop-down menus are used to indicate the roadway functional classification and the morning peak-period traffic flow directions. Check boxes are used to indicate which movements exist at the intersection.

Click: White cells are protected. These cells often contain equations, explanatory titles, or other information that should not be changed.

Click: Purple cells contain calculated results. These cells are protected because they contain equations that should not be changed. The color-coding allows the analyst to identify the calculated results at a glance. On this worksheet, the purple cells contain movement volumes for five different time periods.

Slide 15



Key Message:
The TSCO Volumes worksheet provides traffic volumes for all specified movements, and for five time periods during the day.

Interactivity:
Tell: We would like to know the volume for the through and right-turn movement on the westbound approach during the evening peak period.

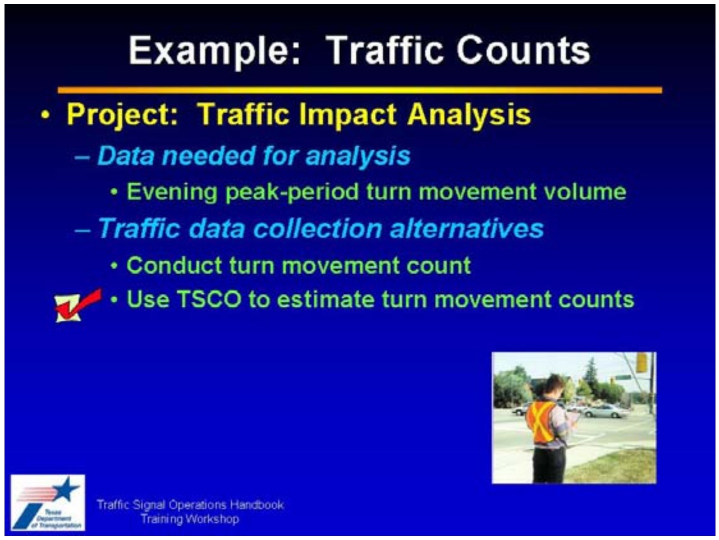
Click: First look at the two columns for the westbound approach.

Click: Focus on the second column, as it provides the volumes for the through and right-turn movement.

Click: The bottom set of rows provides volumes for the evening peak period.

Click: The desired volume is 430 veh/h.

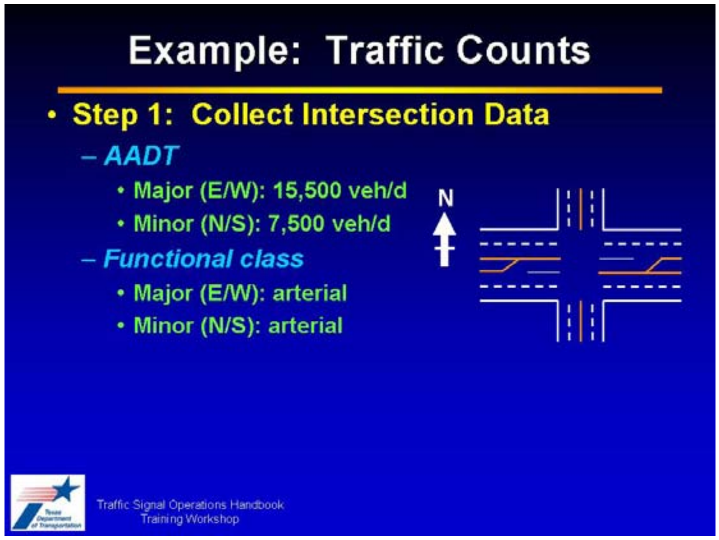
Slide 16



Key Message:
One application of the TSCO program is to estimate turn movement counts for use in a traffic impact analysis study.

Interactivity:
Tell: Turn movement counts can be collected in the field, or they can be estimated using the TSCO program. The following two slides will demonstrate how TSCO can be used to estimate turn movement counts from AADTs.

Slide 17

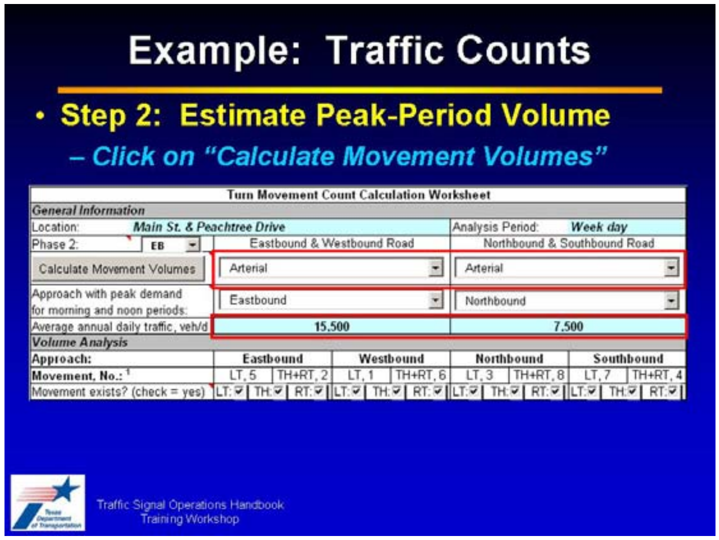


Key Message:
The first step in obtaining the desired turn movement counts is to collect the needed intersection data.

Interactivity:
Tell: The AADTs for the two intersecting streets are 15,500 veh/d and 7,500 veh/d.

Tell: Both of the streets are arterials.

Slide 18



Key Message:
The second step in obtaining the desired turn movement counts is to enter the data into TSCO and calculate the movement volumes.

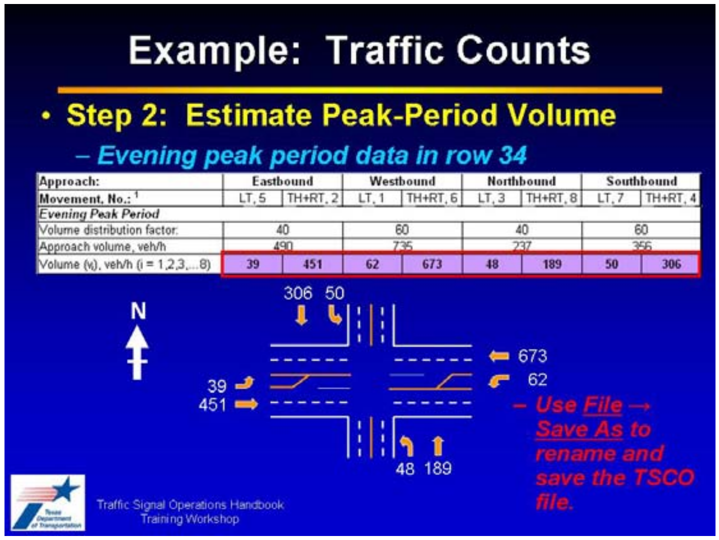
Background:
The TSCO Volumes worksheet uses a maximum likelihood algorithm to compute the traffic volumes. The computations are influenced by the calibration factors in rows 48-56 of the worksheet. These calibration factors represent reasonable values for most streets. The analyst may change these factors if desired, but should do so only if the adjustments are based on field data. Adjustments probably will be rarely needed. The yellow shading in the calibration factor cells indicates that the cells in the values may be changed, but only with caution.

Interactivity:
Tell: Use the drop-down menus to specify "arterial" for both streets' functional classes.

Tell: Enter the AADTs for the two streets into the blue cells.

Tell: Click the "Calculate Movement Volumes" button. This activates the macro that calculates the volumes. The calculation occurs quickly, but activity on the screen will be visible as the program works.

Slide 19

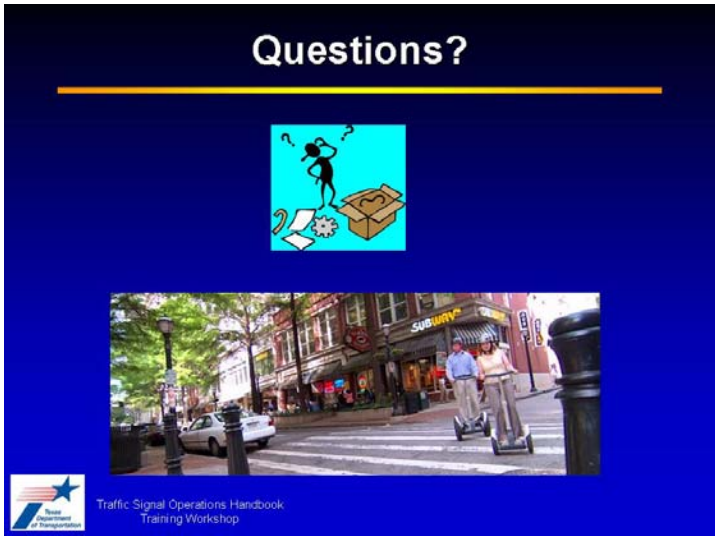


Key Message:
After the input data are entered and the calculations are run, the desired turn movement counts can be obtained in row 34 of the Volumes worksheet.

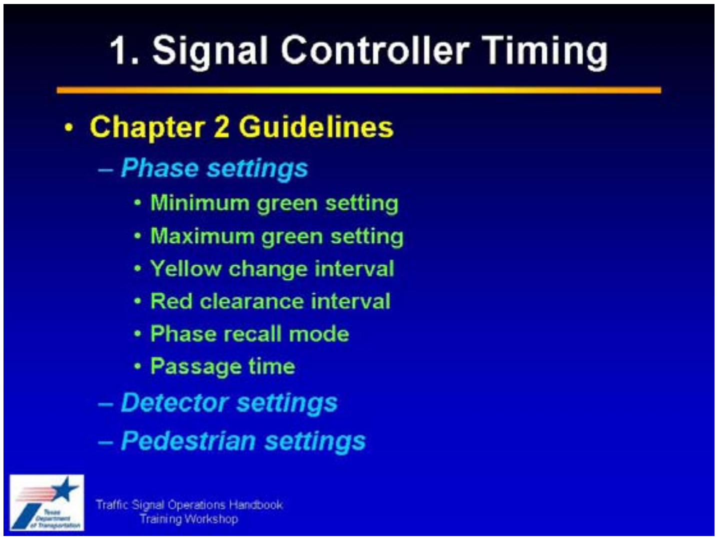
Interactivity:
Click: The evening peak period turn movement counts are found in row 34. This row is shaded purple because its values are computed results.

Click: Save the TSCO spreadsheet on your computer's local drive. The numbers in this example will be re-used in a later example.

Slide 20

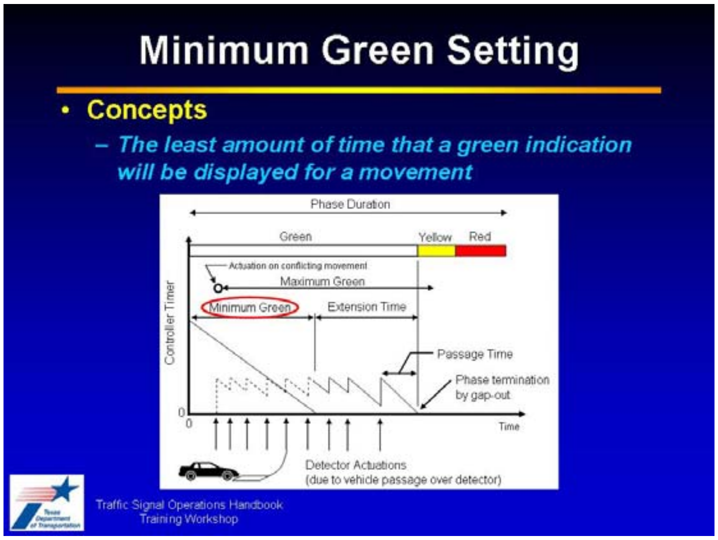

Questions?
Traffic Signal Operations Handbook
Training Workshop

Slide 21



Key Message:
This lesson covers Chapter 2 of the *Handbook*. Chapter 2 focuses on signal controller timing, including settings for phases, detectors, and pedestrians.

Slide 22

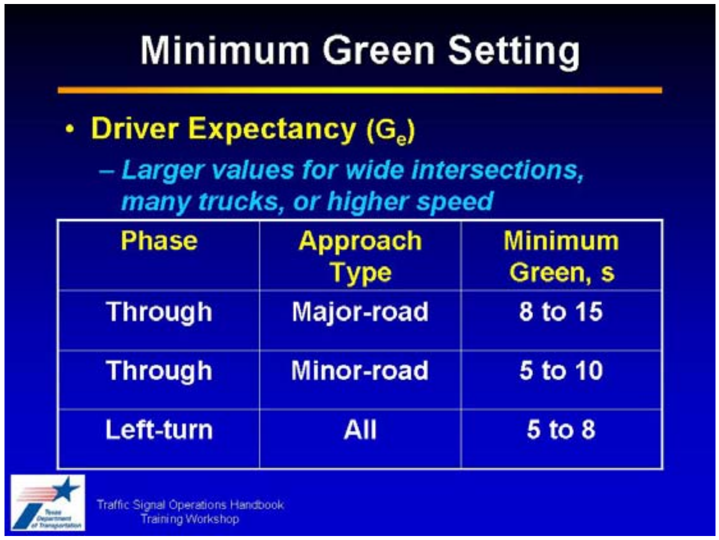


Key Message:
The minimum green interval is the least amount of time that a green indication may be displayed for a movement. It is not affected by detector actuations on conflicting movements.

Slide 23

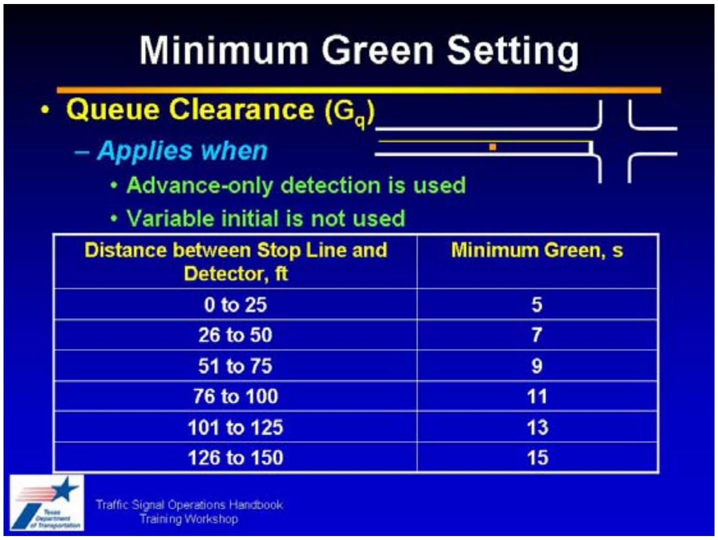
Key Message:
Minimum green should be set based on considerations of driver expectancy, queue clearance, and pedestrian crossing time. These considerations result in different minimum green requirements, and the largest requirement should be used.

Slide 24



Key Message:
The table on this slide provides ranges of minimum green intervals for different combinations of phases and approaches. Larger values within these ranges should be chosen if the movement is at a wide intersection or at an intersection with many trucks or higher-speed traffic.

Slide 25

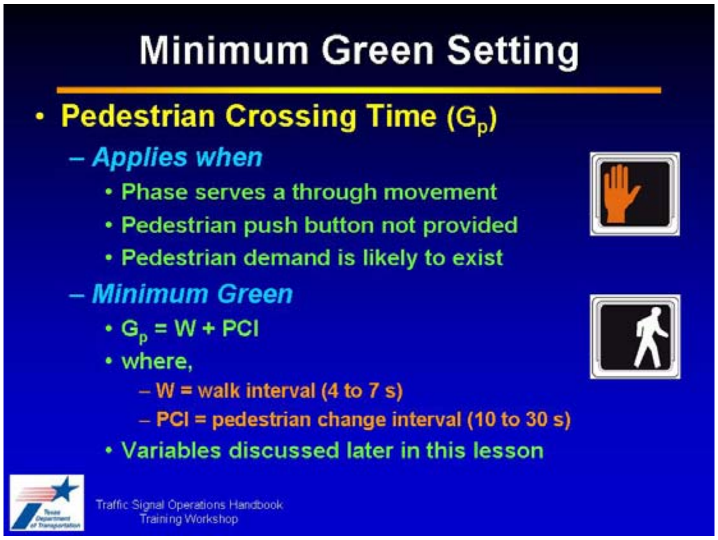


Distance between Stop Line and Detector, ft	Minimum Green, s
0 to 25	5
26 to 50	7
51 to 75	9
76 to 100	11
101 to 125	13
126 to 150	15

Key Message:
If advance detection is used without stop line detection, and the variable initial feature in the controller is not used, then the minimum green interval should provide enough time to discharge the vehicles queued between the stop line and the advance detection.

Background:
Without stop line detection, the controller receives no indication that queued vehicles have not discharged. The variable initial feature may be used to count the number of queued vehicles and provide the required amount of minimum green to allow them to discharge. If the variable initial feature is not used, the minimum green must be set assuming that the entire approach between the stop line and the advance detection is storing vehicles.

Slide 26

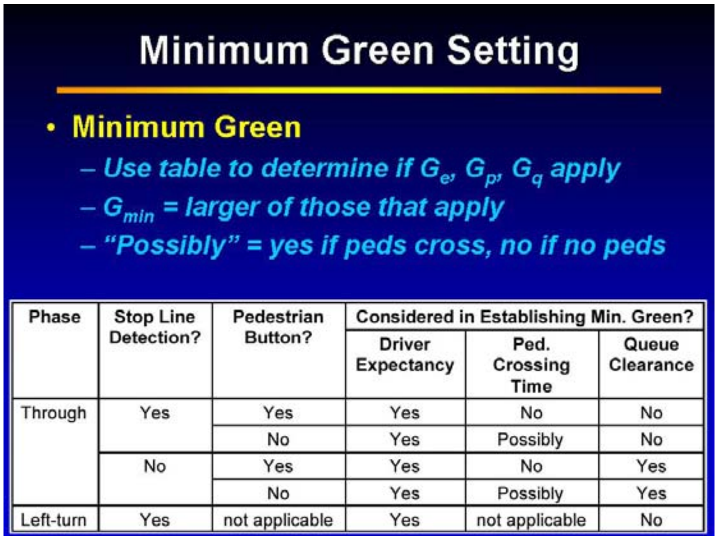


Key Message:
Minimum green intervals on through movements may be affected by pedestrian considerations. If pedestrian demand is likely to exist and pedestrian detection is not provided, the minimum green interval must equal or exceed the length of the WALK interval plus the pedestrian change interval.

Background:
Providing pedestrian detection allows a shorter minimum green to be used on cycles when pedestrians are not present.

Notes:
Guidelines on determining the length of the WALK and pedestrian change intervals will be covered later in this lesson.

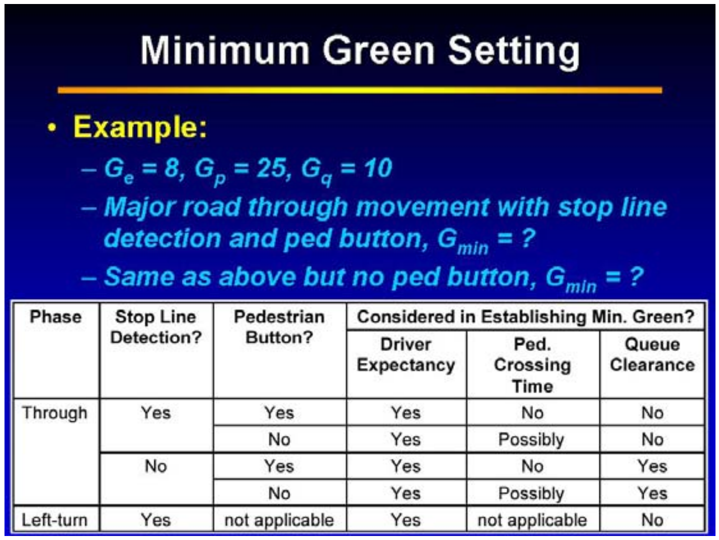
Slide 27



Key Message:
Three considerations in the setting of minimum green include driver expectancy, pedestrian crossing time, and queue clearance. The table on this slide clarifies when these three considerations are relevant.

Background:
Driver expectancy is always relevant. Pedestrian crossing time is relevant to through phases where pedestrians are sometimes present. Queue clearance is relevant to through phases where stop line detection is not provided.

Slide 28



Phase	Stop Line Detection?	Pedestrian Button?	Considered in Establishing Min. Green?		
			Driver Expectancy	Ped. Crossing Time	Queue Clearance
Through	Yes	Yes	Yes	No	No
		No	Yes	Possibly	No
	No	Yes	Yes	No	Yes
		No	Yes	Possibly	Yes
Left-turn	Yes	not applicable	Yes	not applicable	No

Key Message:
Three considerations in the setting of minimum green include driver expectancy, pedestrian crossing time, and queue clearance.

Interactivity:
Tell: Consider the given minimum green intervals based on driver expectancy, pedestrian crossing time, and queue clearance. Remember that the largest of the relevant times controls the setting of the minimum green.

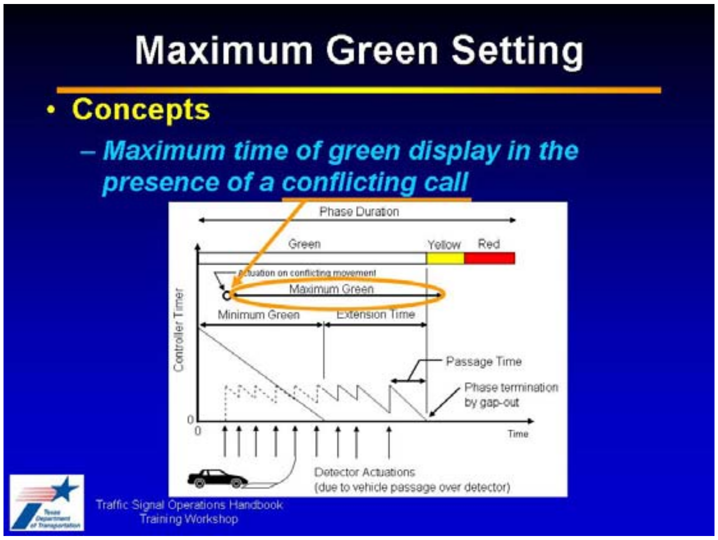
Ask: If the phase of interest is a through movement with stop line detection and a pedestrian button, what is the minimum green interval?

Tell: The only relevant consideration is driver expectancy. Hence, the minimum green interval is 8 s.

Ask: What if there is no pedestrian button on the phase of interest, but conditions are otherwise the same?

Tell: Driver expectancy is still relevant, and pedestrian crossing time is relevant if pedestrians are expected at the intersection. If pedestrians are expected, the minimum green must be set to 25 s. If not, the minimum green may be set to 8 s.

Slide 29

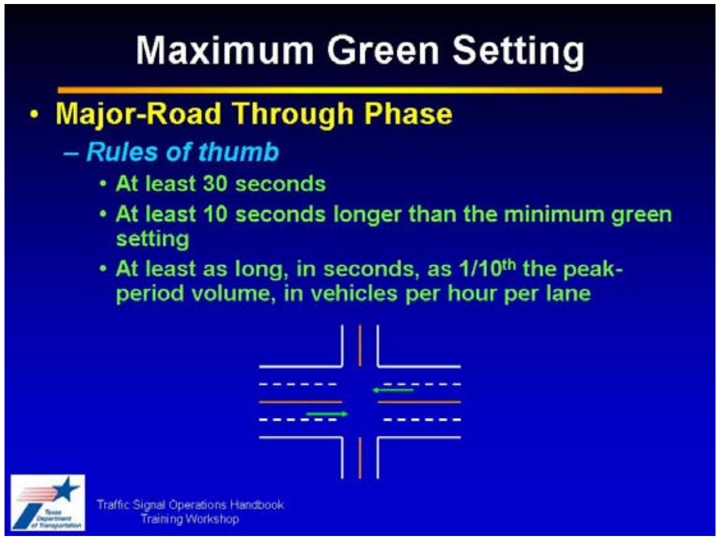


Key Message:
The maximum green interval is the greatest amount of time that a green indication may be displayed for a movement. The timing of maximum green begins when a detector actuation (or call) is received on a conflicting movement.

Slide 30

Key Message:
The *Handbook* provides guidelines for determining the maximum green interval. There are different guidelines for major-road through phases, minor-road through phases, and left-turn phases.

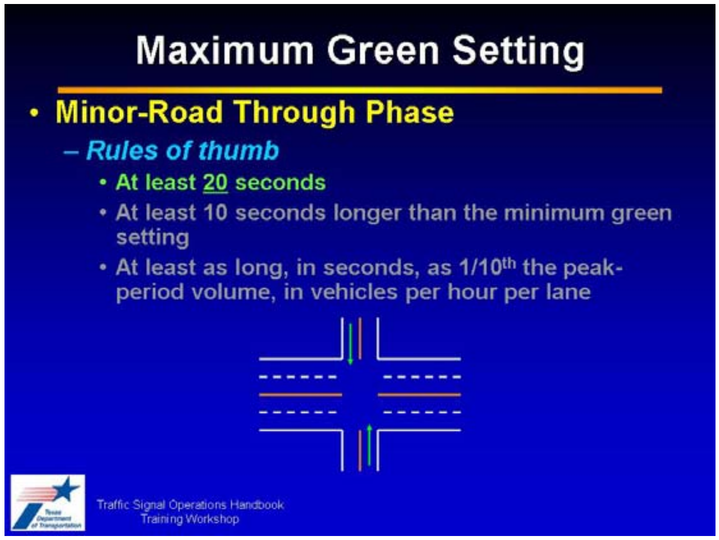
Slide 31



Key Message:
For major-road through phases, the maximum green interval should be (1) at least 30 s and (2) at least 10 s longer than the minimum green interval. It should also be (3) at least as long, in seconds, as the peak-period lane volume divided by 10.

Background:
The second consideration ensures that a sufficiently wide range of possible green times exists to allow the needed flexibility for actuated operation. The third consideration is a rule of thumb that provides some sensitivity to traffic volume.

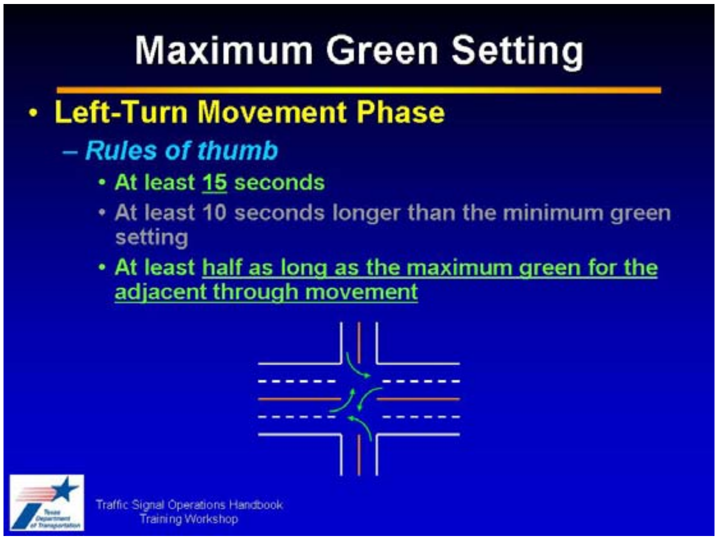
Slide 32



Key Message:
For minor-road through phases, the maximum green interval should be (1) at least *20 s* and (2) at least 10 s longer than the minimum green interval. It should also be (3) at least as long, in seconds, as the peak-period lane volume divided by 10.

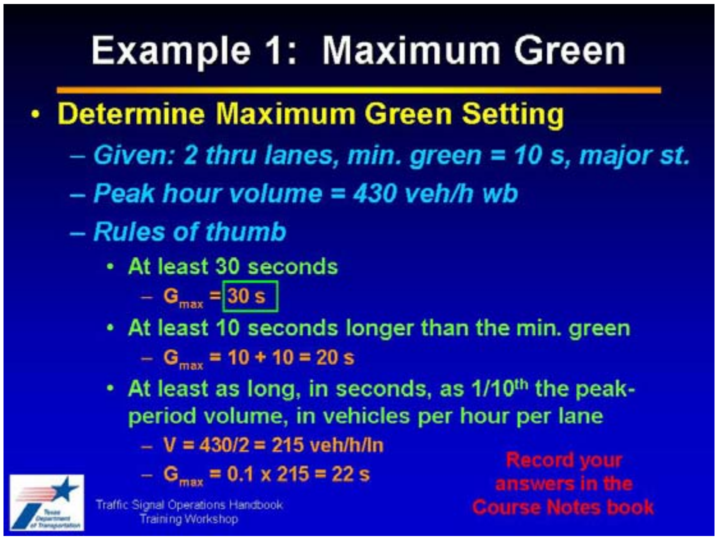
Notes:
The guidelines for a minor-road through phase are very similar to those for a major-road through phase. Only the first consideration differs.

Slide 33



Key Message:
For left-turn movement phases, the maximum green interval should be (1) at least 15 s and (2) at least 10 s longer than the minimum green interval. It should also be (3) at least half as long as the maximum green for the adjacent through movement.

Slide 34



Key Message:
The *Handbook* guidelines can be used to compute the maximum green interval for the through phase described by the given data.

Interactivity:
Tell: Go to page 101 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: For a major-road through phase, the maximum green interval should be at least 30 s.

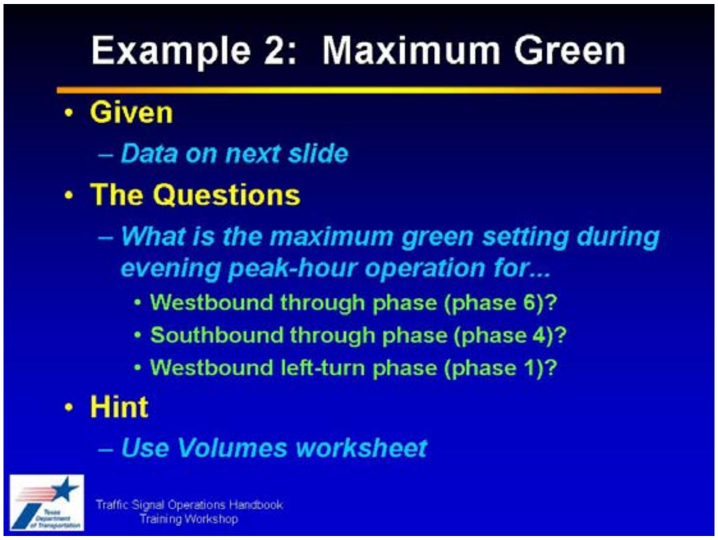
Tell: The maximum green interval should be at least 10 s longer than the minimum green interval. For this phase, that value is 20 s.

Tell: Given the peak-hour volume of 430 veh/h and two through lanes, the peak-period volume is 215 veh/h/ln. This volume suggests a maximum green interval of at least 22 s.

Ask: Based on the three considerations, what is the maximum green interval?

Click: The maximum green interval is 30 s, controlled by the first consideration.

Slide 35

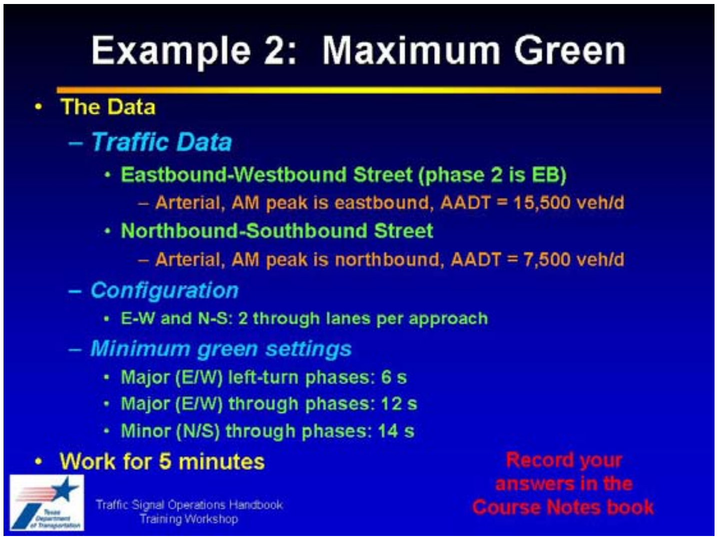


Key Message:
The *Handbook* guidelines can be used to compute the maximum green interval for the through phase described by the given data.

Interactivity:
Ask: What are the maximum green intervals for the specified phases?

Tell: The data are given on the next slide. The Volumes worksheet in the TSCO program will be used to compute phase volumes from AADTs.

Slide 36



Key Message:
The *Handbook* guidelines can be used to compute the maximum green interval for the through phase described by the given data.

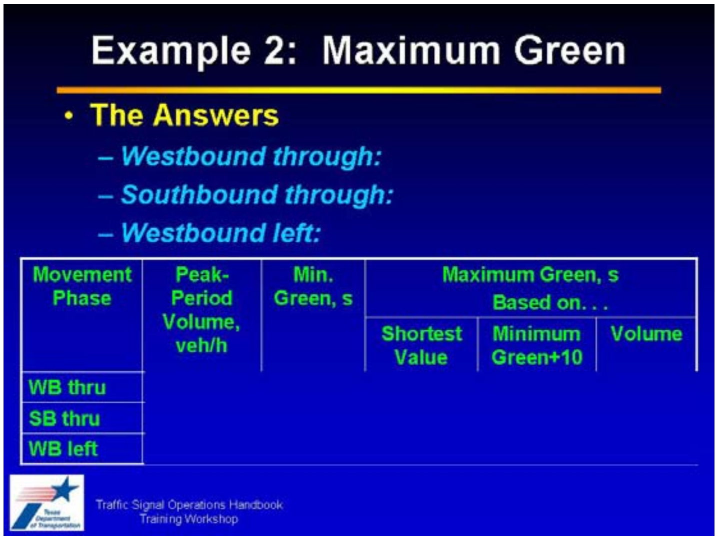
Background:
The previous example showed how to compute maximum green intervals using the *Handbook* guidelines. This example provides another opportunity to compute maximum green intervals. Additionally, this example shows how the needed phase volumes can be computed in TSCO using AADT data, which are more likely to be available to the practitioner.

Interactivity:
Tell: Go to page 102 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: Spend about five minutes entering the given data into TSCO. You will need to use the Volumes worksheet.

Follow up: Leave the instructor's podium and walk around the room as the participants work on the exercise. Offer help to individual participants when needed. When the participants appear to have arrived at the correct answer, return to the instructor's podium and continue the workshop presentation.

Slide 37



Key Message:
When the given data are entered into the Volumes worksheet, TSCO provides the phase volumes, which are then used to determine the maximum green intervals.

Interactivity:
Click: The peak-period volume for the westbound through phase is 670 veh/h. The maximum green interval for this phase is 34 s, based on the peak-period volume.

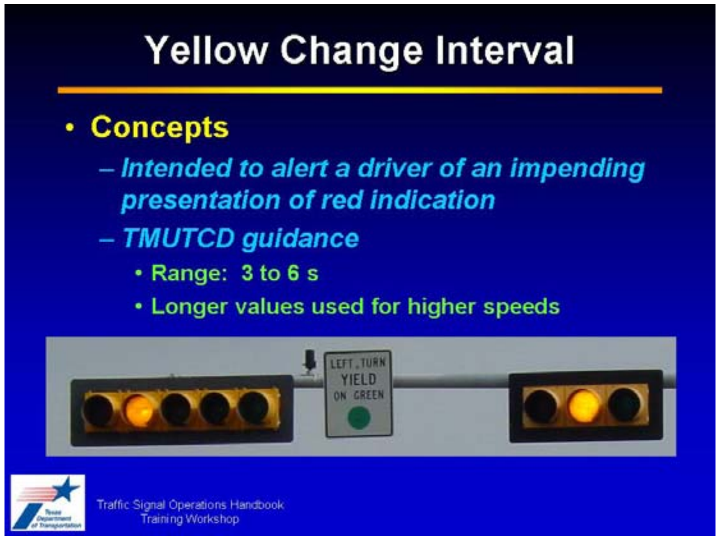
Click: The peak-period volume for the southbound through phase is 306 veh/h. The maximum green interval for this phase is 24 s, based on the minimum green interval.

Click: The maximum green interval for the westbound left-turn phase is 17 s, based on the peak-period volume.

Click: Rename and save the TSCO file. The calculations in this example will be re-used later in the workshop.

Notes:
If more interaction is desired and time allows, call on attendees to give their computed peak-period volumes and maximum green intervals for each phase.

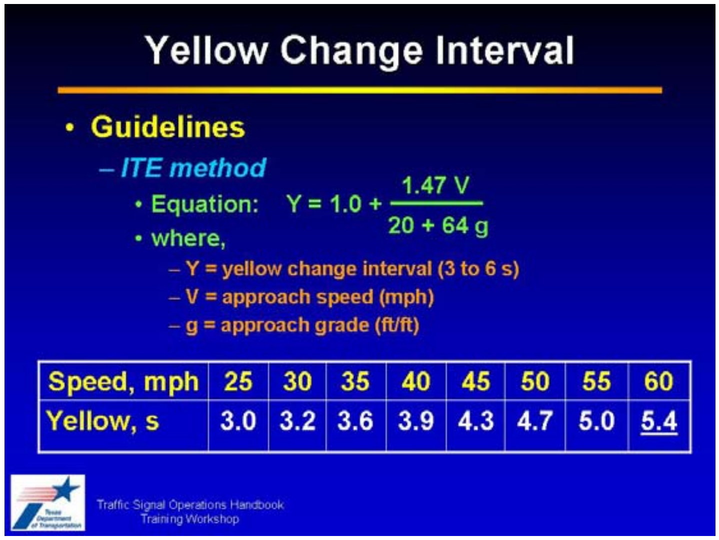
Slide 38



Key Message:
To provide drivers an adequate warning of an impending red indication, a yellow change interval in the range of 3-6 s should be used, with higher speeds requiring longer values.

Background:
Section 4D.10 of the TMUTCD states that a yellow change interval should have a duration in the range of 3-6 s, and longer intervals should be reserved for use on approaches with higher speeds.

Slide 39

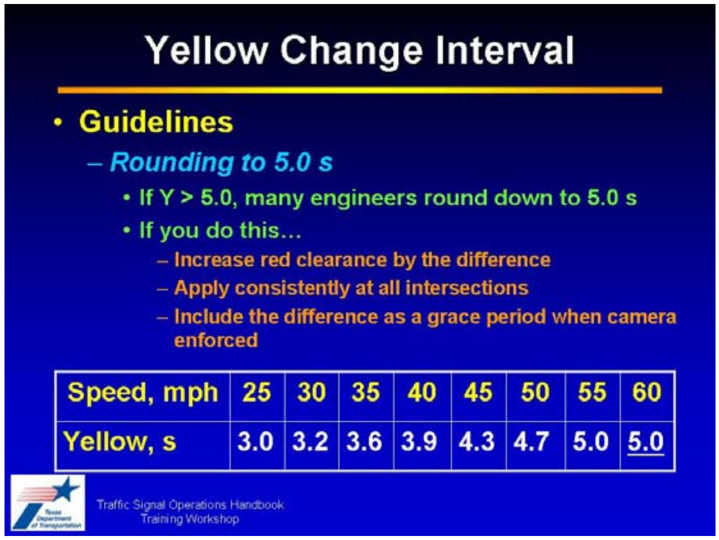


Key Message:
The ITE Equation yields yellow change interval durations that are sensitive to approach speed and approach grade. For approach speeds in the range of 25-60 mph, the equation calls for yellow change intervals in the range of 3-5.4 s.

Background:
The numbers in the table reflect yellow change intervals for the indicated approach speeds and zero approach grade. Longer intervals are needed for downhill grades, and shorter intervals are needed for uphill grades. The equation assumes a perception-reaction time of 1 s and a deceleration rate of 10 ft/s^2. More information about the ITE Equation can be found in "Determining Vehicle Change Intervals (proposed recommended practice), *ITE Journal*, Vol. 59, No. 7, 1989, pp. 21-27.

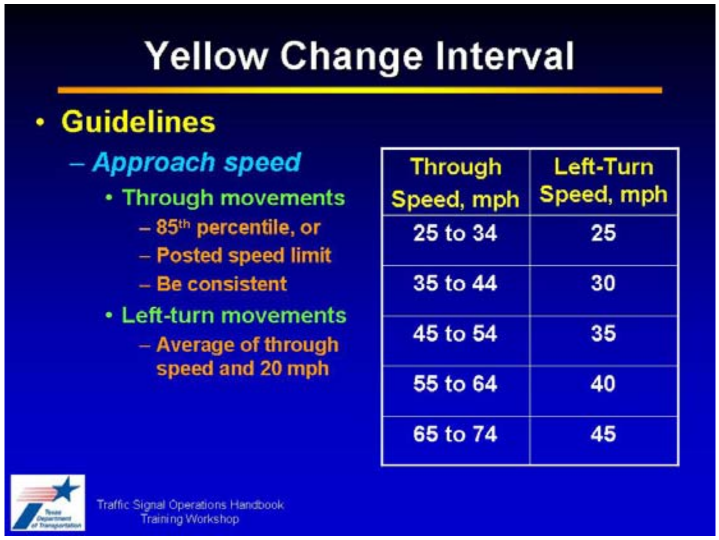
Interactivity:
Tell: For an approach speed of 60 mph and an approach grade of zero, the ITE Equation calls for a yellow change interval of 5.4 s.

Slide 40



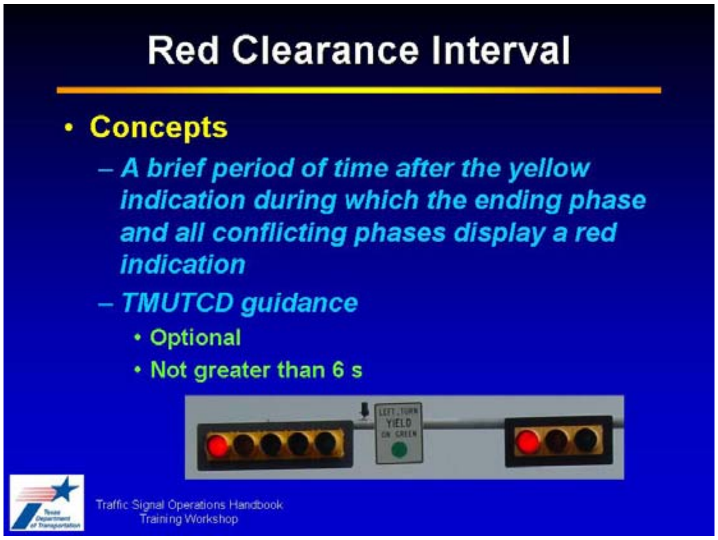
Key Message:
Yellow change intervals may be rounded down to 5 s if the difference is added to the red clearance interval and red-light camera grace periods, and applied consistently at all intersections.

Slide 41



Key Message:
Either the 85th percentile speed or the posted speed limit may be used as criteria for setting yellow change intervals, but the same criterion should be used consistently. For left-turn movements, the speed used should be the average of the speed for through vehicles and 20 mph.

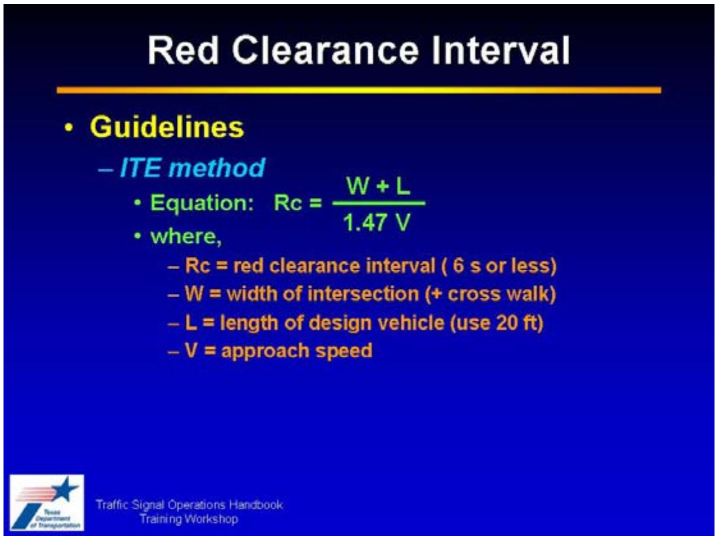
Slide 42



Key Message:
A red clearance interval is a brief time period following the yellow indication when the ending phase and all of its conflicting phases display a red indication.

Background:
Section 4D.10 of the TMUTCD states that a red clearance interval is optional and should have a duration not greater than 6 s if used.

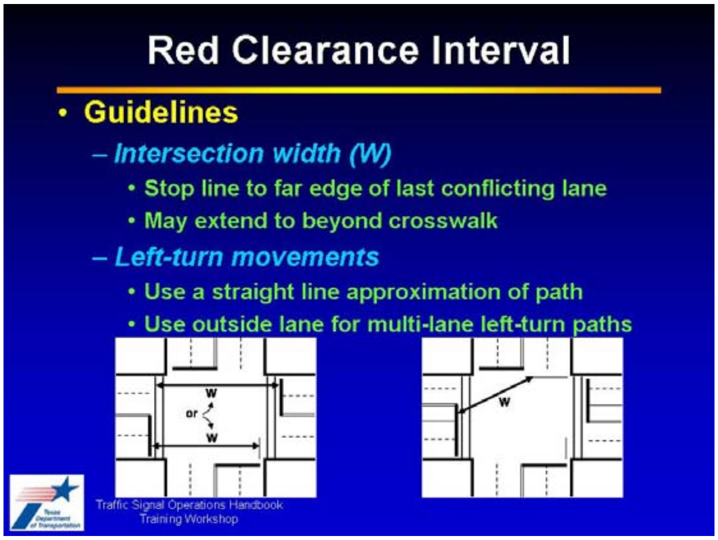
Slide 43



Key Message:
The ITE Equation yields red clearance intervals that are sensitive to intersection width and approach speed.

Background:
More information about the ITE Equation can be found in "Determining Vehicle Change Intervals (proposed recommended practice), *ITE Journal*, Vol. 59, No. 7, 1989, pp. 21-27.

Slide 44



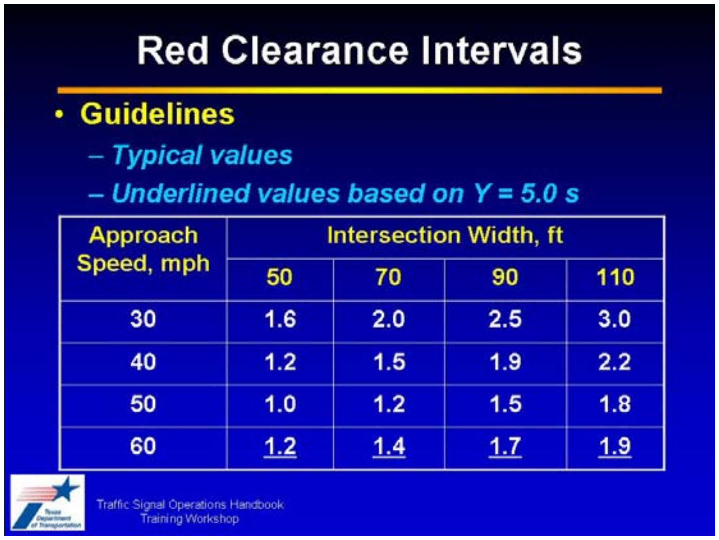
Key Message:
Intersection width is measured from the stop line to the far edge of the last conflicting lane, or it may be extended to just beyond the crosswalk. For left-turn movements, a straight-line approximation is sufficient, using the outside lane for multiple-lane left-turn paths.

Interactivity:
Tell: For through movements, intersection width is measured from the stop line to the far edge of the last conflicting lane.

Tell: If pedestrians are often present, a slightly larger width should be used by measuring to just beyond the crosswalk instead of to the far edge of the last conflicting lane.

Tell: For left-turn movements, the intersection width is approximated as a straight-line estimate of the left-turn path. If multiple paths are available, use the outermost path.

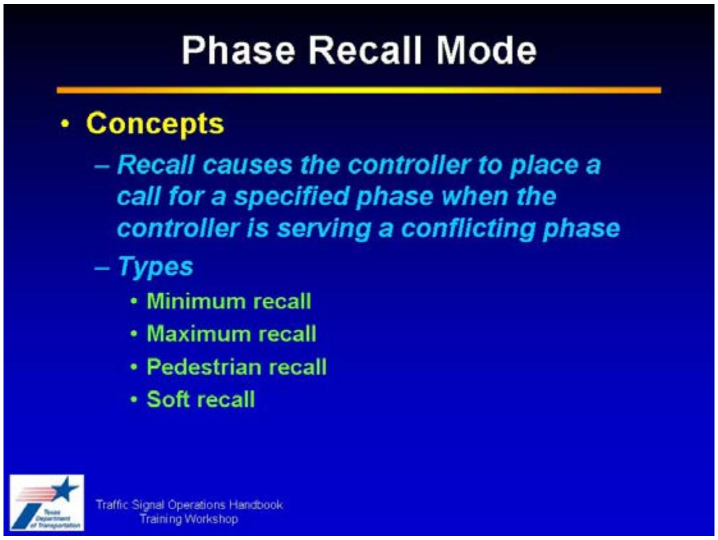
Slide 45



Key Message:
Red clearance intervals increase with larger intersection widths and lower approach speeds. For higher approach speeds, red clearance intervals may increase if the yellow change interval is capped at 5 s.

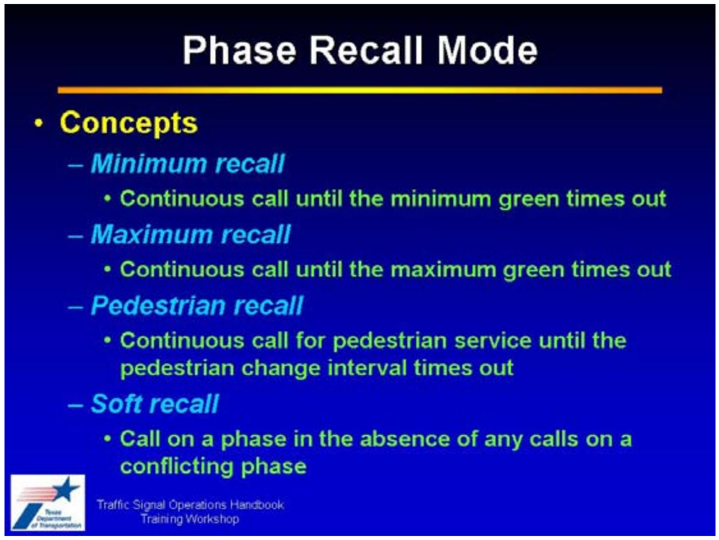
Interactivity:
Tell: The underlined values in the table reflect the red clearance interval lengths computed from the ITE Equation, plus an extra amount of time resulting from the capping of the yellow change interval at 5 s. Specifically, the amount added to each underlined red clearance interval length is 0.4 s.

Slide 46



Key Message:
A recall is a setting that causes the controller to place a call for a specified phase when a conflicting phase is being served. This call occurs regardless of whether vehicles are detected for the specified phase.

Slide 47



Key Message:
There are four types of recalls—minimum, maximum, pedestrian, and soft.

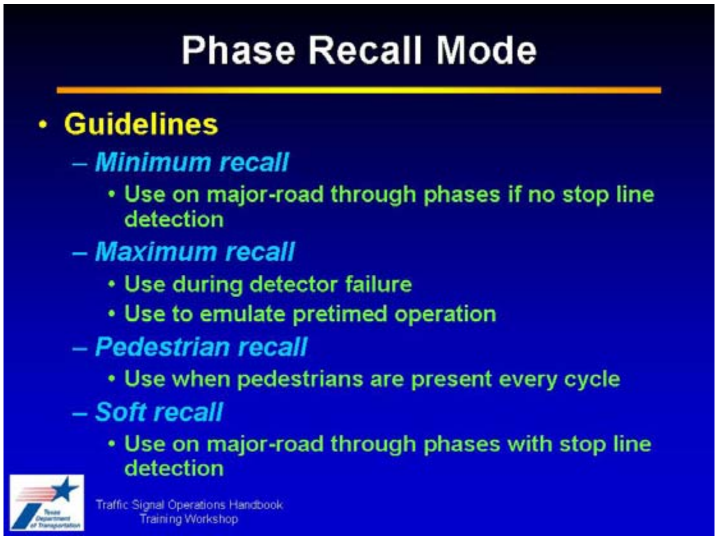
Interactivity:
Tell: A minimum recall places a continuous call on the specified phase until the phase's minimum green interval lapses.

Tell: A maximum recall places a continuous call on the specified phase until the phase's maximum green interval lapses.

Tell: A pedestrian recall places a continuous call for pedestrian service on the specified phase until the phase's pedestrian change interval lapses.

Tell: A soft recall places a call on the specified phase whenever there are no calls on any conflicting phases.

Slide 48



Key Message:
There are different situations in which the various phase recall modes should be used.

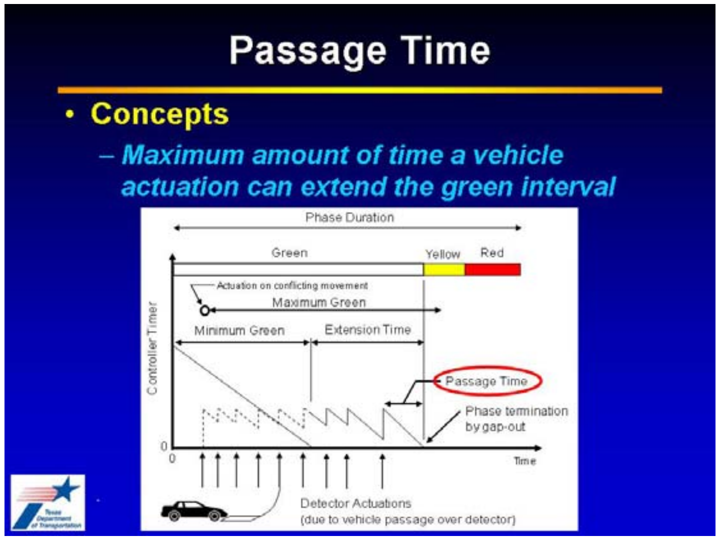
Interactivity:
Tell: Use minimum recall on major-road through phases if these movements do not have detection.

Tell: Use maximum recall during detector failure (e.g., inductive loop malfunction or foggy conditions for video detection) or to emulate pretimed operation.

Tell: Use pedestrian recall when pedestrians are present every cycle.

Tell: Use soft recall on major-road through phases that have stop line detection.

Slide 49

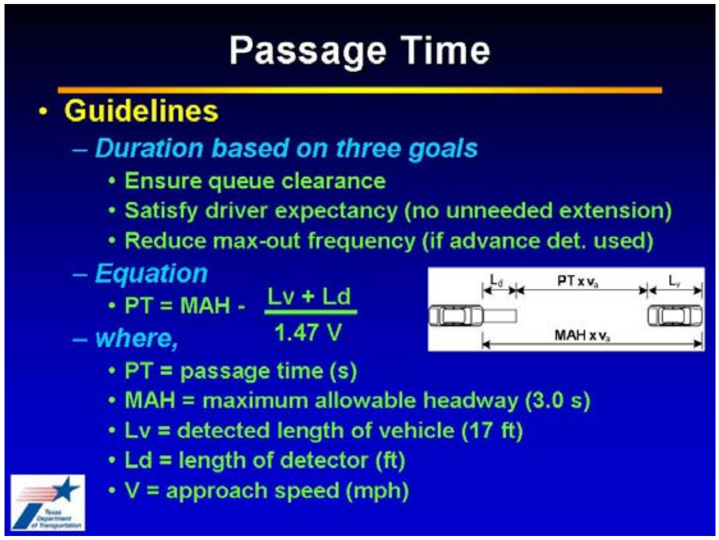


Key Message:
Passage time is the maximum amount of time that a vehicle actuation can extend the green interval.

Interactivity:
Tell: On the bottom of the illustration, the vertical arrows represent detector actuations. The horizontal distance between the arrows is the time elapsed between actuations.

Tell: At the right side of the illustration, after the last detector actuation, the passage time lapses without another actuation. This causes the green indication to end before the maximum green interval lapses.

Slide 50



Key Message:
The passage time should be set long enough to ensure queue clearance, but not so long that the green interval frequently extends to maximum or extends longer than drivers expect.

Background:
It is assumed that headways longer than the MAH (3 s) will not occur within the queue.

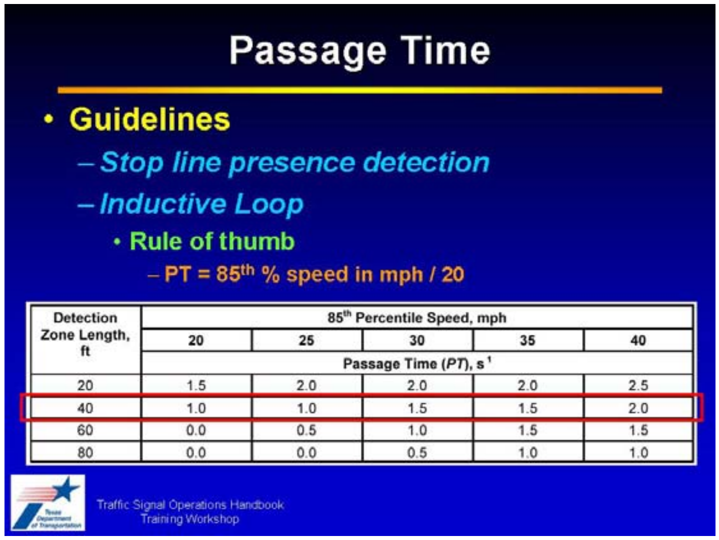
Interactivity:
Tell: The passage time should be set long enough to ensure that the green phase does not end before the queue clears.

Tell: If the passage time is set too long, the major-road through phase will be extended longer than needed, resulting in longer delay for minor movements.

Tell: For approaches with advance detection, the passage time should not be set so long that it results in frequent max-outs. When the green phase ends by max-out, no indecision zone protection is provided.

Tell: The computed passage time value is influenced by the assumed MAH, vehicle length, detection zone length, and approach speed.

Slide 51



Key Message:
Passage time increases with increasing vehicle speed and decreasing detection zone length.

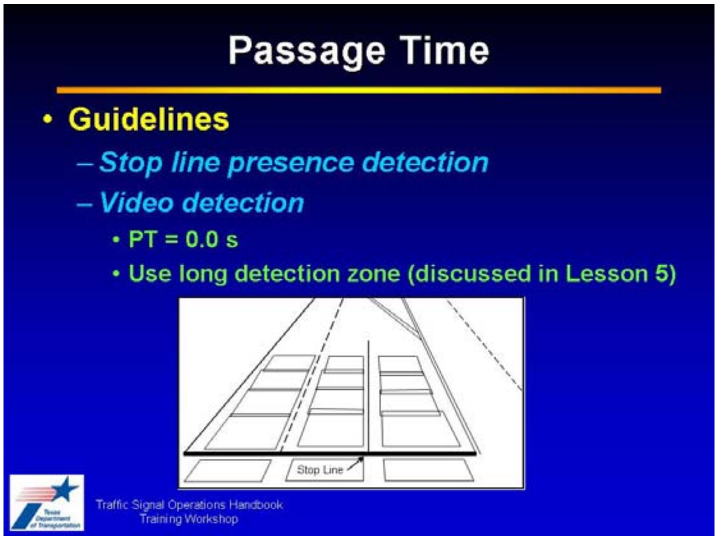
Background:
When passage time is used, the green will be extended by an amount equal to the passage time after the last queued vehicle leaves. This extension is inefficient because the time is not needed. The most efficient operation is achieved with a long detection zone and little or no passage time.

Interactivity:
Tell: The table's first column is labeled "*detection zone* length" because it applies to all detection types, not just inductive loops.

Tell: A 40-foot stop line detection zone is common, so this case is highlighted by the red box. For this detection zone length, the computed passage time is approximately the 85th percentile speed divided by 20.

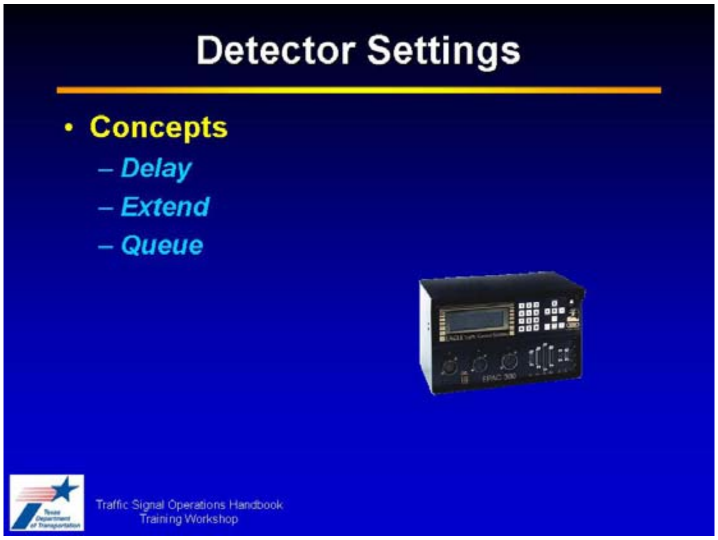
Tell: The greatest efficiency can be achieved with long detection zones and little or no passage time. This ideal situation is expensive to achieve with inductive loops, but feasible with video or other types of detection.

Slide 52



Key Message:
If video detection is used, a long detection zone can be used with minimal cost, and the passage time can be set to 0.0 s. This operation is the most efficient because the green will not be extended unnecessarily after the last vehicle leaves.

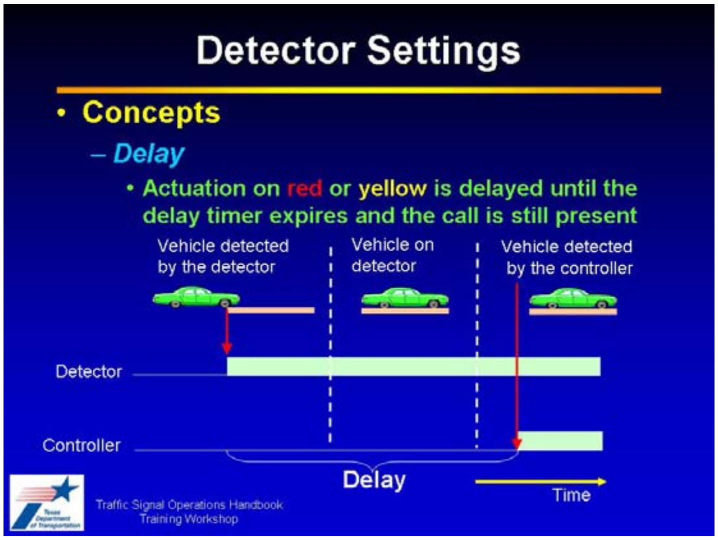
Slide 53



Key Message:
Delay, extend, and queue are detector settings. They are specific to each individual detection channel.

Background:
Detector settings can be programmed in the controller or the detection amplifiers. The settings should be programmed in the controller so they will not be lost if the amplifiers are replaced.

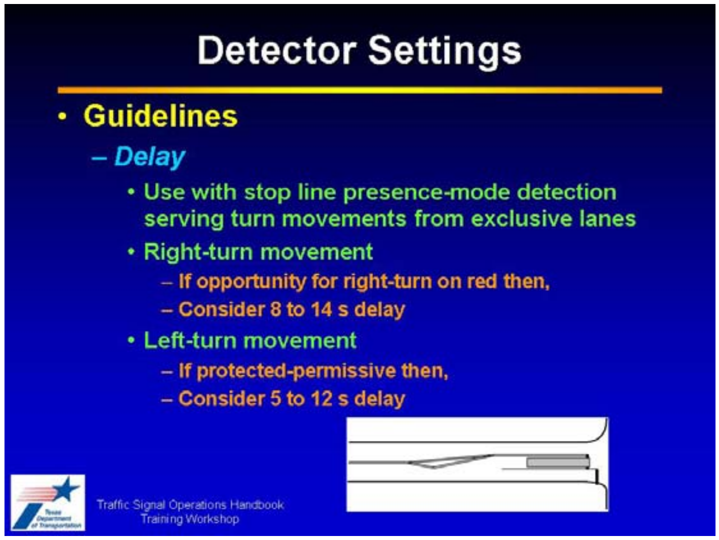
Slide 54



Key Message:
The delay setting causes a delay to occur between the time that a vehicle enters the detection zone and the time that the controller registers the vehicle actuation. This setting only applies during yellow or red indications.

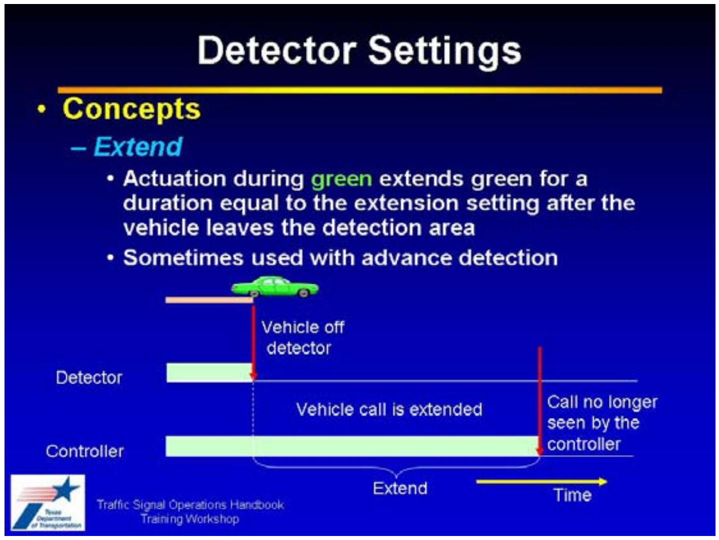
Background:
The delay setting is implemented with a delay timer that starts at the delay value and counts down to zero. The timer resets to the delay setting if the vehicle leaves the detection zone before the timer counts down to zero. Hence, if the vehicle leaves the detection zone before the delay timer reaches zero, the controller never sees the vehicle.

Slide 55



Key Message:
The delay setting can be used to avoid unnecessarily calling phases. This can occur with right-turn-on-red or permissive left-turn movements served by exclusive lanes. If the driver can find a safe gap to turn permissively during the delay time, the phase serving the driver's turn movement need not be served.

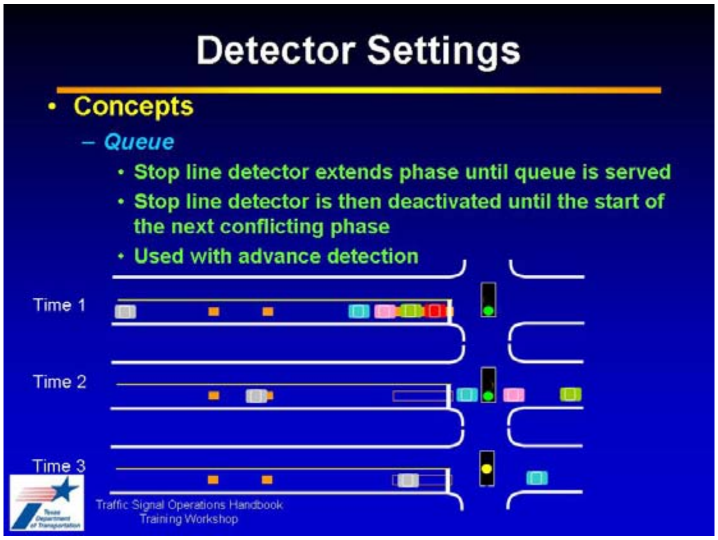
Slide 56



Key Message:
The extend setting causes a vehicle actuation to continue beyond the time that the vehicle leaves the detection zone. This setting applies only during green indications.

Background:
This setting can be used to prevent undesired gap-outs if advance detection is provided. The passage time (which applies to all detector channels) may not be sufficient to allow a vehicle to pass from one advance detector to the next before the end of green. In this case, the extend setting (which can be set to different values for individual channels) can provide the additional time needed for a vehicle to reach the next advance detector.

Slide 57



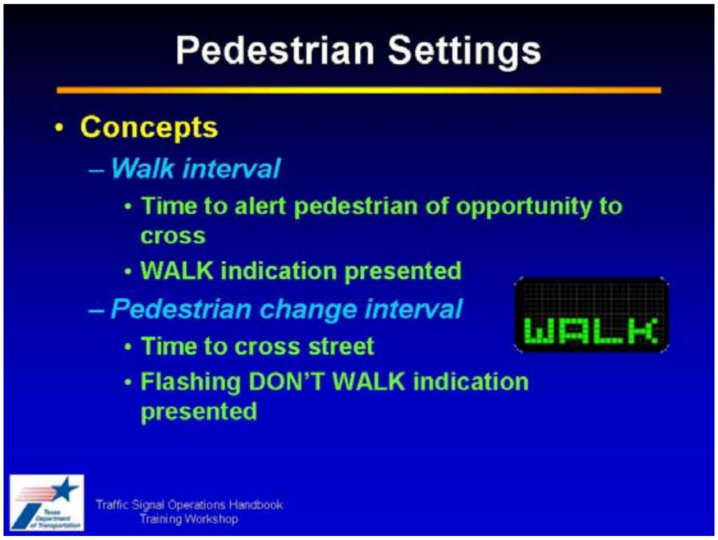
Key Message:
The queue feature is used when advance detection is provided. The setting allows the stop line detector to be deactivated after queue clearance, preventing it from unnecessarily extending the green interval.

Interactivity:
Tell: The purpose of the stop line detector is to extend the green interval until the queue is served, as shown at Time 1 in the illustration.

Tell: Once the queue has been served, the stop line detector is no longer needed and can be turned off if the queue setting is used. (Notice that the stop line detector is shown as solid in the Time 1 illustration and outline in the Time 2 and Time 3 illustrations.) During this time, only the advance detectors will extend the green interval, as shown at Time 2.

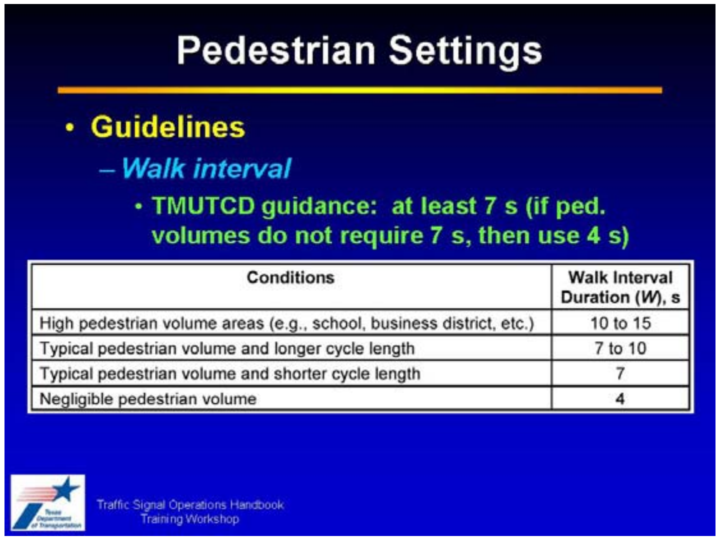
Tell: With the queue setting activated, a non-queued vehicle will not extend the green interval when it passes over the stop line detector, as shown at Time 3. If the stop line detector were not deactivated, it would extend the green interval unnecessarily, which can cause more frequent max-outs.

Slide 58



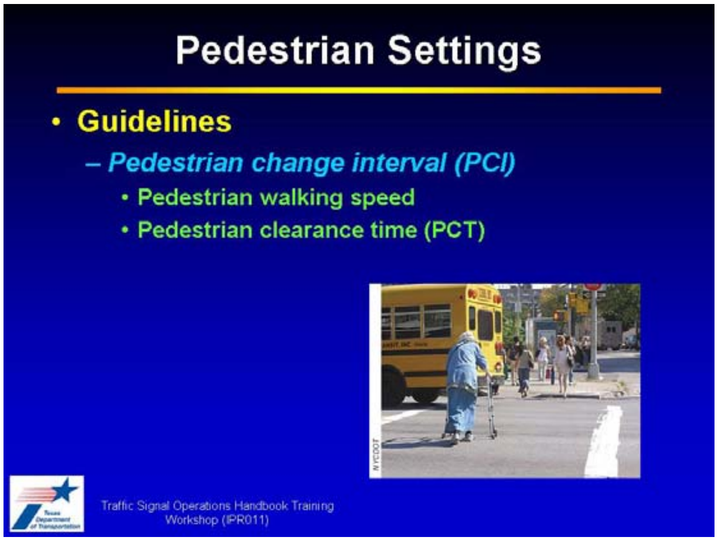
Key Message:
The WALK interval is provided to alert pedestrians of the opportunity to cross the road. The pedestrian change interval is set based on the time needed to cross the street, and corresponds with the display of a flashing DON'T WALK indication.

Slide 59



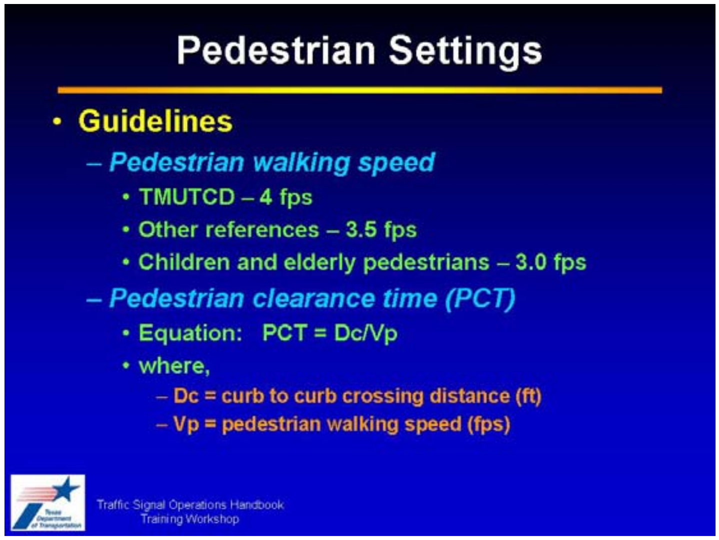
Key Message:
The WALK interval should be long enough to allow pedestrians to begin crossing the road. Intervals as low as 4 s can be used for negligible pedestrian volume, and at least 7 s should be provided for typical pedestrian volume. Longer intervals should be used for longer cycles or in high pedestrian volume areas.

Slide 60



Key Message:
The pedestrian change interval (PCI) is influenced by walking speed and crosswalk length. The pedestrian clearance time (PCT) is the time needed to cross the road, and is part of the pedestrian change interval.

Slide 61

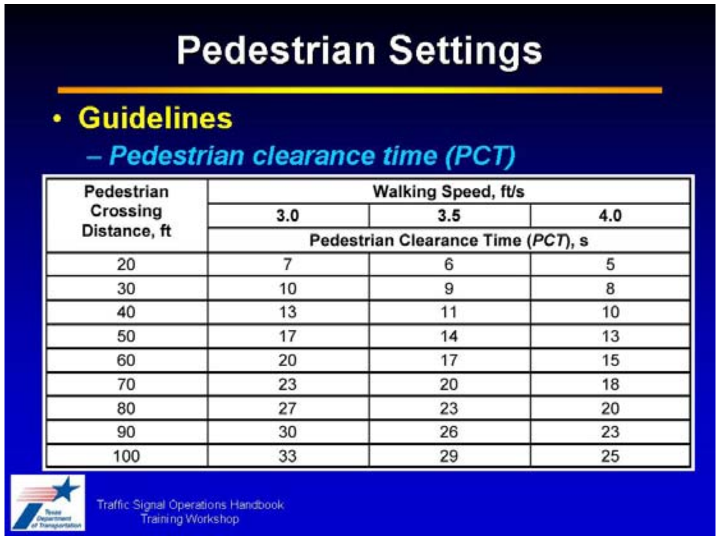


Key Message:
The pedestrian clearance time is equal to the crossing distance divided by the pedestrian walking speed.

Interactivity:
Tell: The curb-to-curb crossing distance used to compute the pedestrian clearance time.

Tell: The 2006 TMUTCD calls for a walking speed of 4 ft/s, but other references, including the 2010 MUTCD, call for 3.5 ft/s. Speeds as low as 3 ft/s should be used for sites with many children or elderly pedestrians. The use of lower speeds will result in longer pedestrian clearance times.

Slide 62

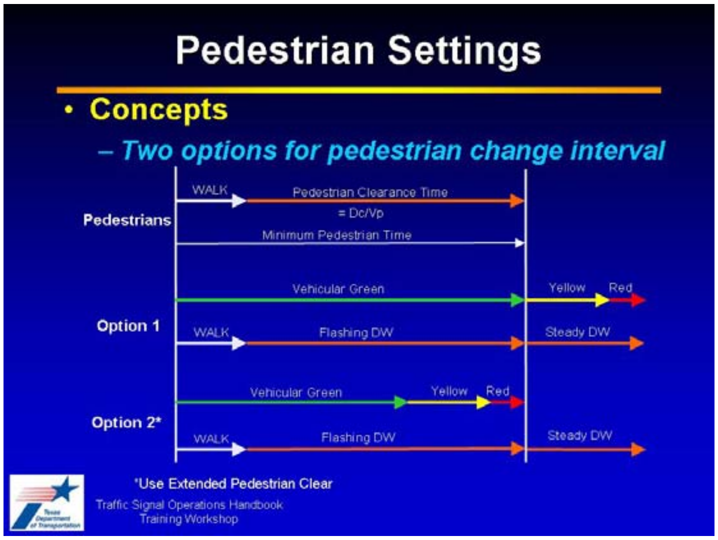


Pedestrian Crossing Distance, ft	Walking Speed, ft/s		
	3.0	3.5	4.0
	Pedestrian Clearance Time (*PCT*), s		
20	7	6	5
30	10	9	8
40	13	11	10
50	17	14	13
60	20	17	15
70	23	20	18
80	27	23	20
90	30	26	23
100	33	29	25

Key Message:
Pedestrian clearance time increases with decreasing walking speed or increasing crossing distance.

Background:
The pedestrian clearance times in the table may result in green interval durations that are longer than needed to serve vehicular demand, especially with longer crosswalks or low vehicular volumes.

Slide 63



Key Message:
There are two options for the pedestrian change interval. It may be equal to the pedestrian clearance time, or the yellow and red clearance times may be subtracted from the pedestrian clearance time.

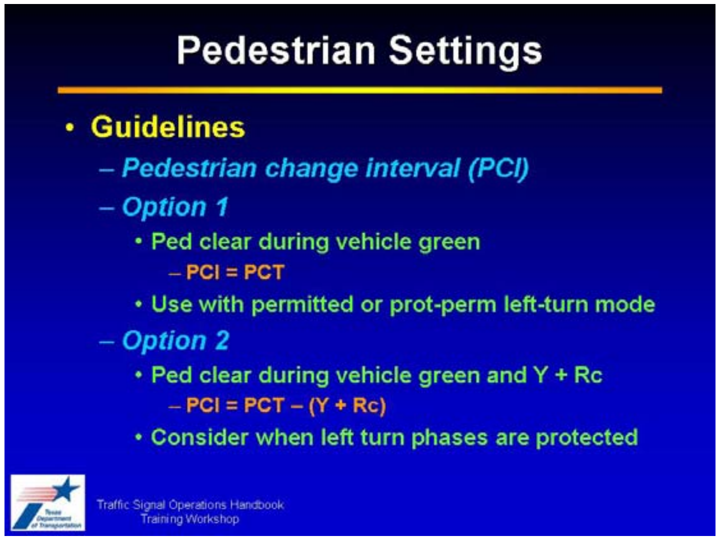
Interactivity:
Tell: The pedestrian clearance time is the time during which the flashing DON'T WALK indication is displayed.

Tell: Option 1 is to provide the pedestrian change interval only during vehicular green. In this case, the flashing DON'T WALK indication continues no longer than the start of yellow.

Tell: Option 2 is to allow the pedestrian change interval to continue into the vehicular yellow and red clearance. In this case, the flashing DON'T WALK continues into the yellow and red clearance.

Tell: In terms of pedestrian safety, option 1 is more conservative because its intent is to have pedestrians finish crossing before the start of yellow. Option 2 allows pedestrians to be in the crosswalk during the yellow and red clearance, at which times permissive left-turning drivers may be impatient to clear the intersection and may conflict with pedestrians. Hence, option 2 is more likely to be useful if the conflicting left-turn movements are protected.

Slide 64

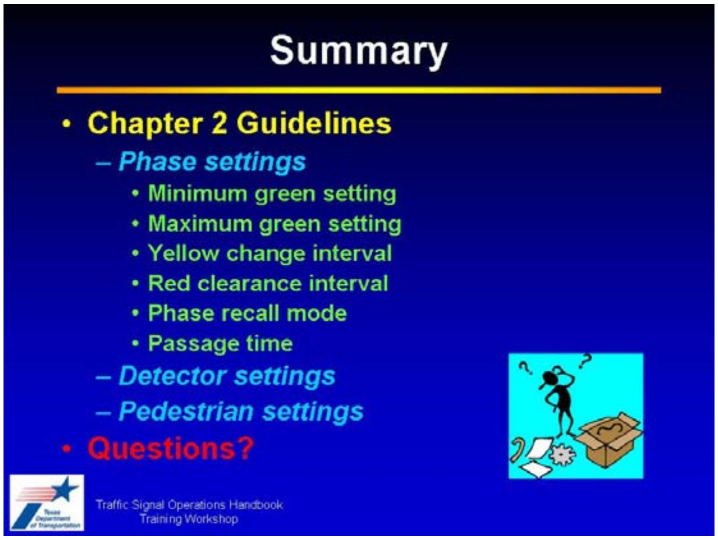


Key Message:
By allowing the pedestrian change interval to extend into yellow and red clearance, option 2 allows shorter vehicular green intervals to be used. This can help mitigate the increase in vehicular green interval length that occurs when slower walking speeds are used to compute the pedestrian clearance time.

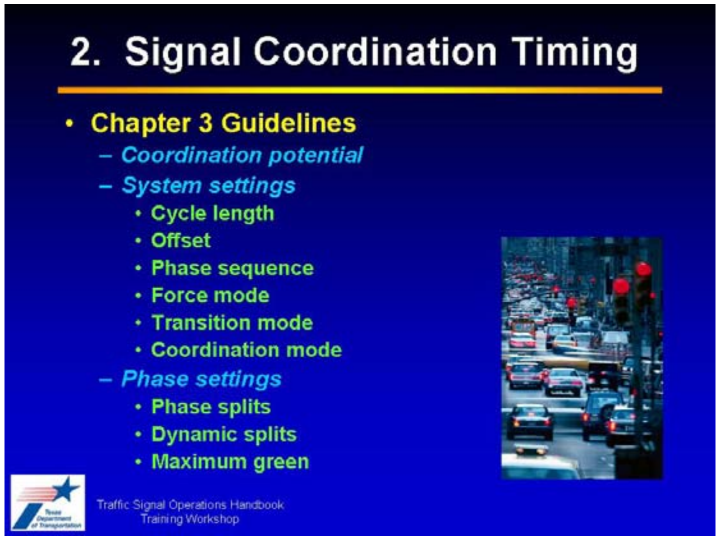
Interactivity:
Tell: Option 1 shows the flashing DON'T WALK indication ending at the start of yellow.

Tell: Option 2 shows the flashing DON'T WALK indication ending at the end of the red clearance.

Slide 65

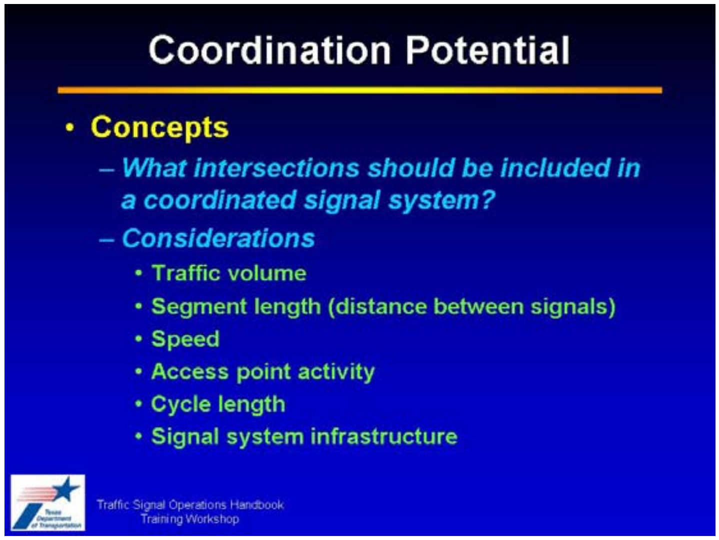

Summary
• Chapter 2 Guidelines
– Phase settings
• Minimum green setting
• Maximum green setting
• Yellow change interval
• Red clearance interval
• Phase recall mode
• Passage time
– Detector settings
– Pedestrian settings
• Questions?
Traffic Signal Operations Handbook
Training Workshop

Slide 66



Key Message:
This lesson covers Chapter 3 of the *Handbook*. Chapter 3 focuses on signal coordination timing, including determining coordination potential in a system of signalized intersections and obtaining proper settings for the system and the various intersections' phases.

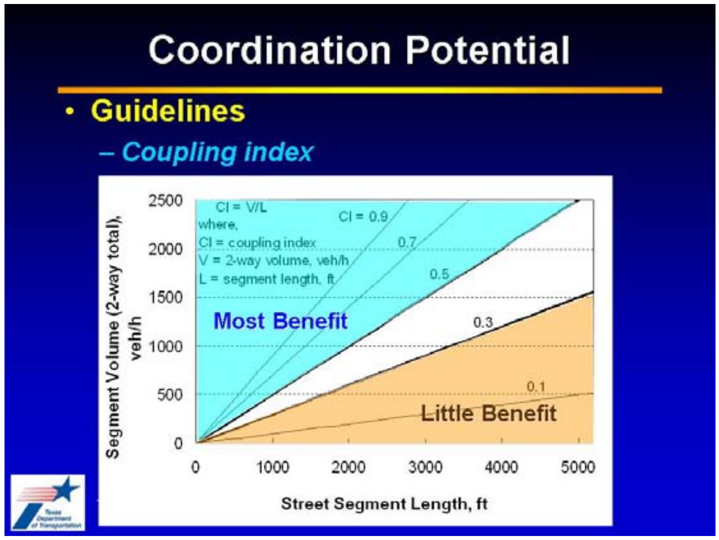
Slide 67



Key Message:
The first step in signal coordination is to determine the signal system's potential to benefit from coordination. A signal system may or may not be suitable for coordination, depending on traffic volumes, signal spacing, traffic speed, access point activity, cycle length, and signal system infrastructure.

Background:
The expected benefits of signal coordination include reductions in travel time, delay, stops, fuel consumption, and emissions.

Slide 68

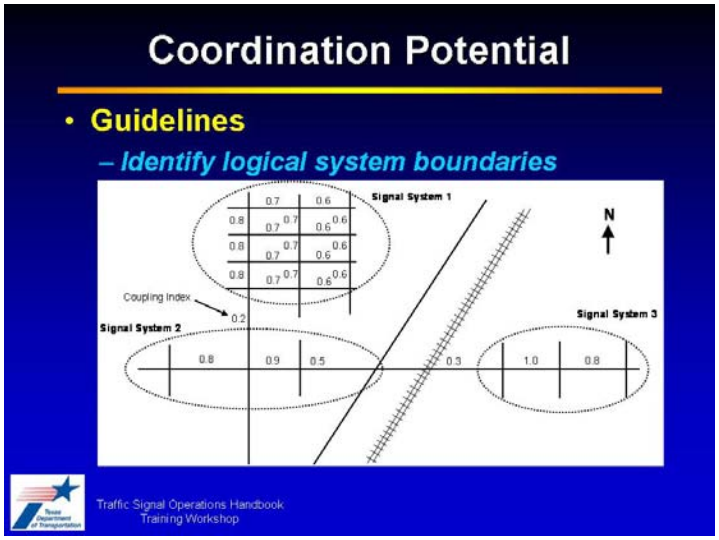


Key Message:
Coordination is most likely to yield a benefit if traffic volumes are high and signal spacing is short. The coupling index helps identify intersections that can benefit from coordination.

Interactivity:
Tell: Signal coordination is most likely to yield a benefit if the roadway segments between the signals are short and traffic volumes are high. The coupling index captures these two considerations.

Click: A coupling index of 0.3 or less suggests little benefit would be realized from coordination, while a coupling index of 0.5 or more suggests the most benefit would be realized.

Slide 69



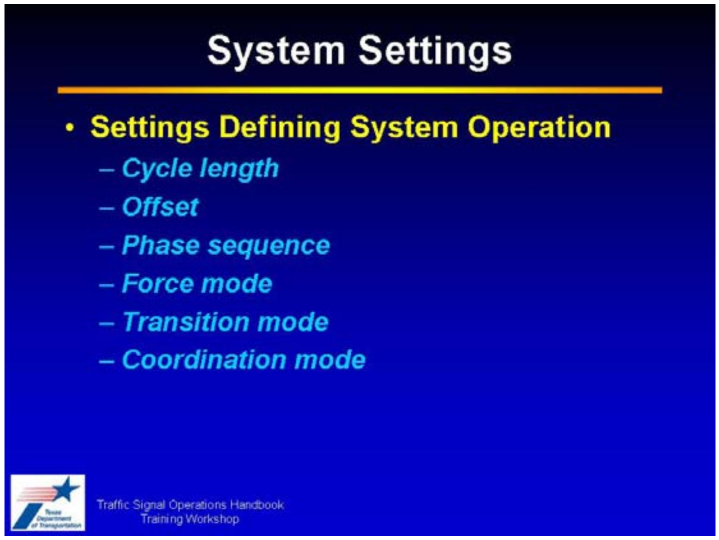
Key Message:
The coupling index can be used to identify logical boundaries between adjacent coordinated signal systems.

Interactivity:
Tell: A coupling index is computed for every road link that is bounded by two signals.

Tell: A grouping of signals with high coupling indices represents a system that is likely to benefit from coordination. In the illustration, there are three such systems, which can be coordinated independent from each other.

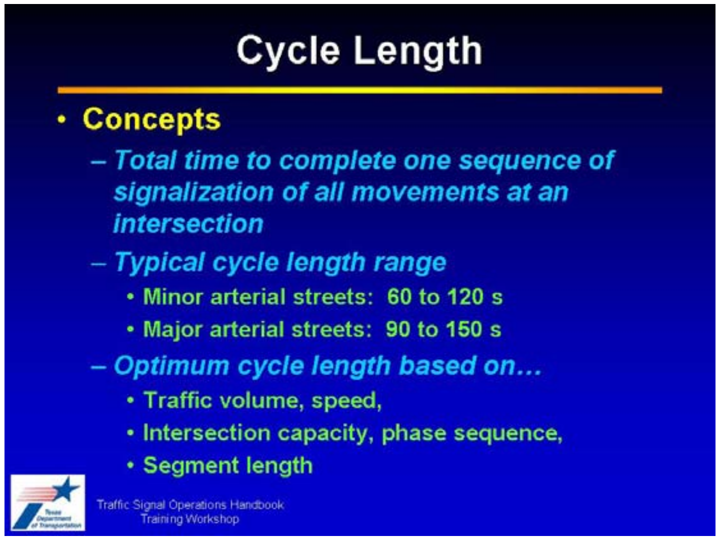
Tell: A road link with a low coupling index can represent a boundary between two coordinated signal systems. This boundary can occur because of physical constraints (like a railroad track) or differences in traffic volumes or segment length. In the illustration, two boundaries are shown.

Slide 70



Key Message:
The settings that define a coordinated signal system's operation include cycle length, offset, phase sequence, force mode, transition mode, and coordination mode.

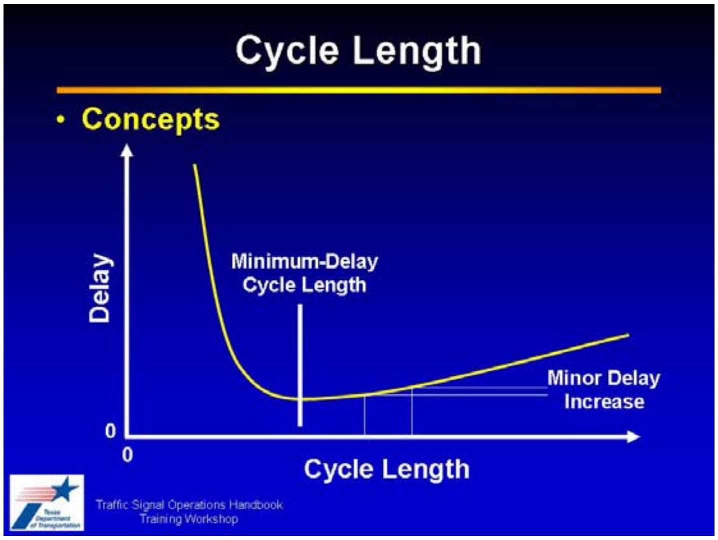
Slide 71



Key Message:
Cycle length is the time it takes to complete one sequence of service to all signalized movements at an intersection. Cycle length values in Texas typically range from 60 to 150 s, based on the roadway type. The optimum cycle length (corresponding to minimum delay) is based on traffic volumes and speeds, intersection capacity, phase sequence, and segment length.

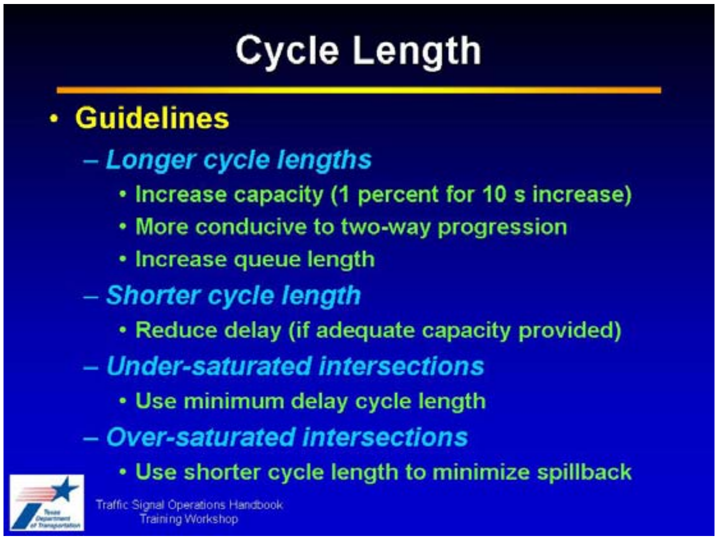
Background:
Different reference documents will have subtle variations on the definition of cycle length, but all agree on the generic definition provided in this slide.

Slide 72



Key Message:
The optimum cycle length is the cycle length yielding the minimum delay. Delay increases more significantly when cycle length decreases below the optimum than when cycle length increases above the optimum.

Slide 73



Key Message:
The determination of cycle length is based on considerations of capacity, delay, queuing, and occurrence of spillback (queuing that extends from one intersection to another).

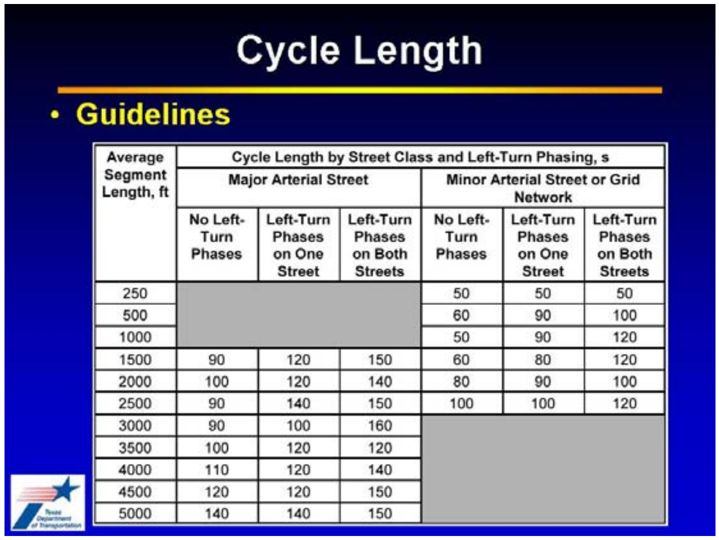
Interactivity:
Tell: A longer cycle increases capacity, but not significantly. The capacity increase is usually about one percent for a 10-s cycle length increase. Longer cycles also facilitate two-way progression, but result in increased queue lengths.

Tell: A shorter cycle reduces delay, provided adequate capacity is provided.

Tell: Use the minimum delay cycle length for under-saturated intersections.

Tell: Use shorter cycle lengths to minimize spillback at over-saturated intersections. Generally, when a coordinated signal system is over-saturated, the priority shifts from minimizing delay to minimizing spillback.

Slide 74

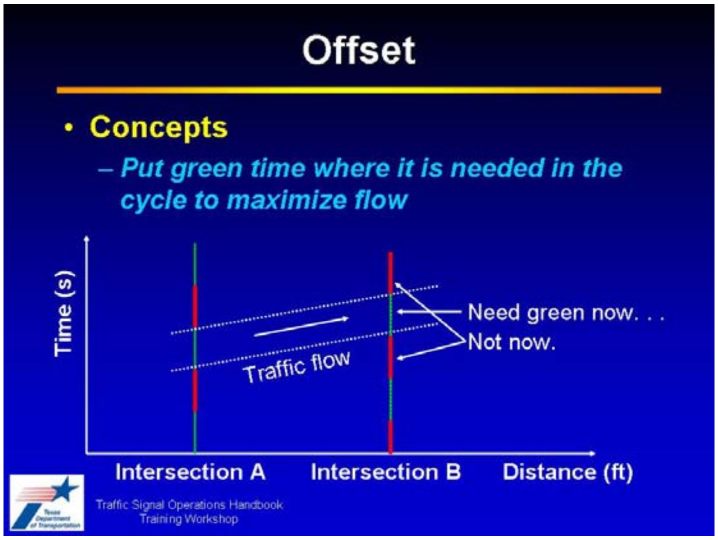


Average Segment Length, ft	Cycle Length by Street Class and Left-Turn Phasing, s					
	Major Arterial Street			Minor Arterial Street or Grid Network		
	No Left-Turn Phases	Left-Turn Phases on One Street	Left-Turn Phases on Both Streets	No Left-Turn Phases	Left-Turn Phases on One Street	Left-Turn Phases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

Key Message:
The table provides reasonable cycle length values for coordinated signal systems. It includes values for different types of systems (major arterial street versus minor arterial street or grid network) based on average segment length and presence of protected left-turn phases.

Background:
This table provides reasonable cycle length values, but not the optimum. Software programs like PASSER II can provide more precise estimates of optimum cycle length, but require the collection of traffic volume data.

Slide 75



Key Message:
Offsets are set with the goal of providing green time when it is needed to accommodate a platoon of vehicles moving from one intersection to the next.

Interactivity:
Tell: In the example shown, there are two intersections, A and B, separated by a distance along the x-axis.

Tell: The signal indications of red and green for the coordinated through movement are shown on the vertical bar for intersection A. For this demonstration, the signal is assumed to be two-phase.

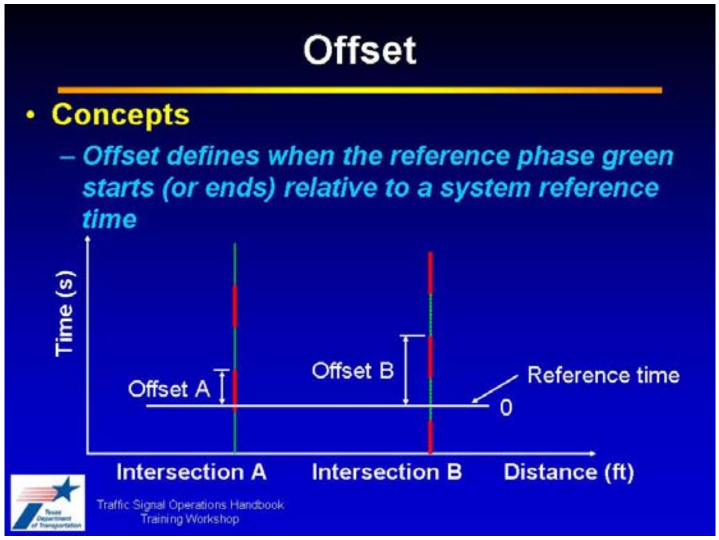
Click: The white band shows traffic flow moving from intersection A to intersection B. The flow originates from intersection A while the signal indication is green.

Click: The green at intersection B should be provided when the platoon arrives.

Click: Providing green to the through movement elsewhere in the cycle would not facilitate traffic flow.

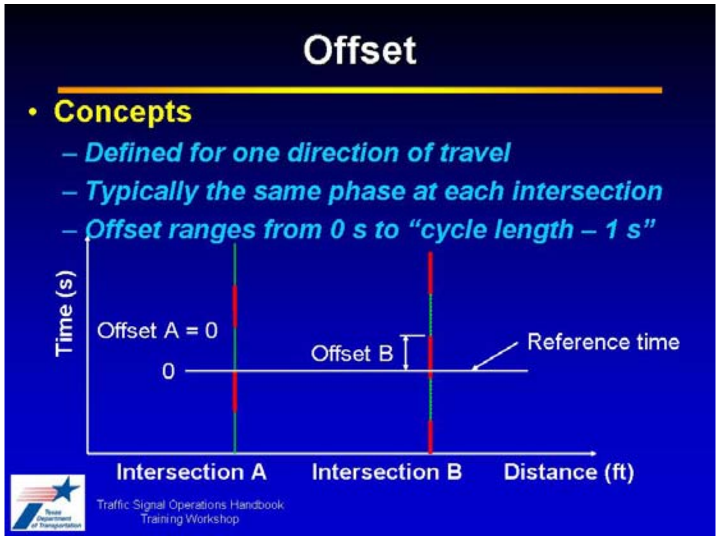
Tell: This example showed progression for a one-way movement. It is more complicated to determine optimum offsets when progression is needed for two-way traffic.

Slide 76



Key Message:
The offset at each intersection is defined as the time that a reference phase green starts or ends relative to a system reference time. In the illustration, the offsets at intersections A and B are defined based on the starts of green.

Slide 77

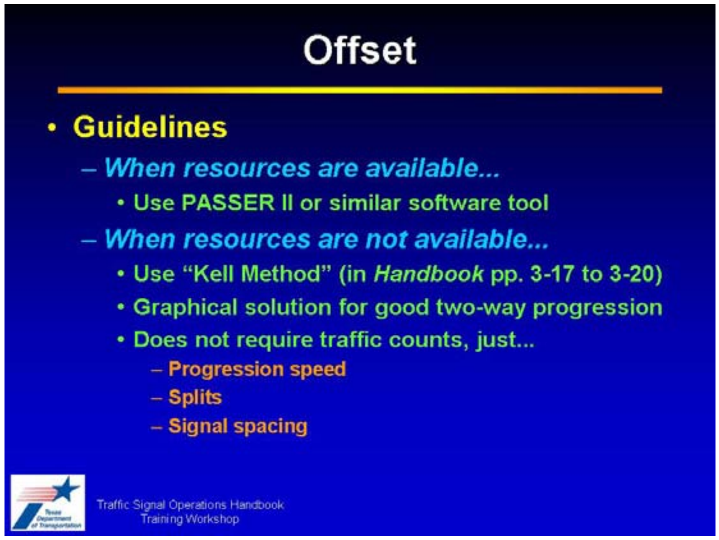


Key Message:
Offsets are defined for one direction of travel, and typically reference the same phase green at each intersection. Offset values range from 0 s to the cycle length minus 1 s.

Interactivity:
Tell: In the illustration, the system reference time is the start of green at intersection A. Hence, the offset at intersection A will always be zero.

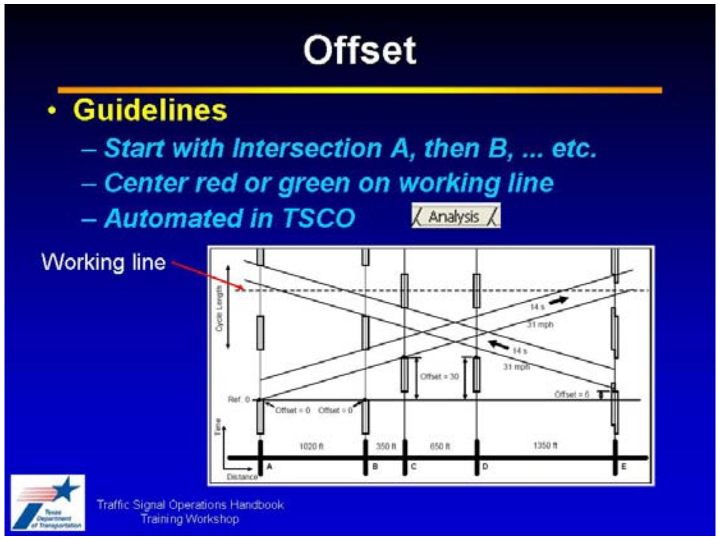
Tell: Another green will start exactly one cycle length after the illustrated start of green at intersection B. However, we define the offset based on the first start of green after the system reference time.

Slide 78



Key Message:
When resources are available to collect traffic volume data, software tools like PASSER II should be used to determine the optimum offsets. When resources are not available, a graphical method called the "Kell Method" can provide good offset values using progression speed, phase splits, and signal spacing.

Slide 79



Key Message:
The Kell Method involves centering the red or the green at each intersection on a horizontal working line. The process is automated in the TSCO Analysis worksheet.

Background:
The TSCO Analysis worksheet can be used to compute coordinated system settings for an arterial street. TSCO does not have the capability to provide settings for networks.

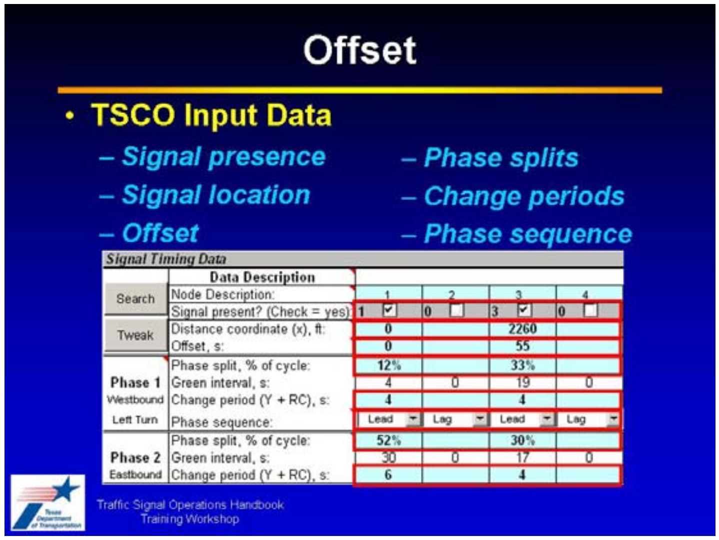
Interactivity:
Tell: The TSCO Analysis worksheet automates the calculation of optimum offsets. It requires signal spacing, phase splits, and phase sequences.

Tell: Another TSCO worksheet provides phase splits using volume data, and another worksheet provides volume data using AADTs. Hence, it is possible to use TSCO to obtain reasonable signal coordination using only AADTs, signal spacing, and signal phase data.

Tell: Start the TSCO program and select the Analysis worksheet.

Tell: There is a User Guide for TSCO in the Appendix of report 0-5629-1, which is on the CD.

Slide 80



Key Message:
The TSCO Analysis worksheet requires the listed input data. The worksheet cells are color-coded or populated with controls (drop-down menus and check boxes) to facilitate data entry.

Interactivity:
Tell: Data entry cells are shaded blue. Columns E though N each represent one node, which can be a signalized intersection or a speed change point.

Click: The check boxes (row 9) are used to indicate the presence of a signal. This feature can be used to evaluate the impact of adding a signal to a coordinated system.

Click: Node location (row 10) is described in terms of a distance coordinate, with the first node having a distance coordinate of zero.

Click: Offsets (row 11) can be provided if the user is analyzing an existing coordination timing plan. TSCO can also compute the optimum offsets if the user starts with dummy values entered into the cells.

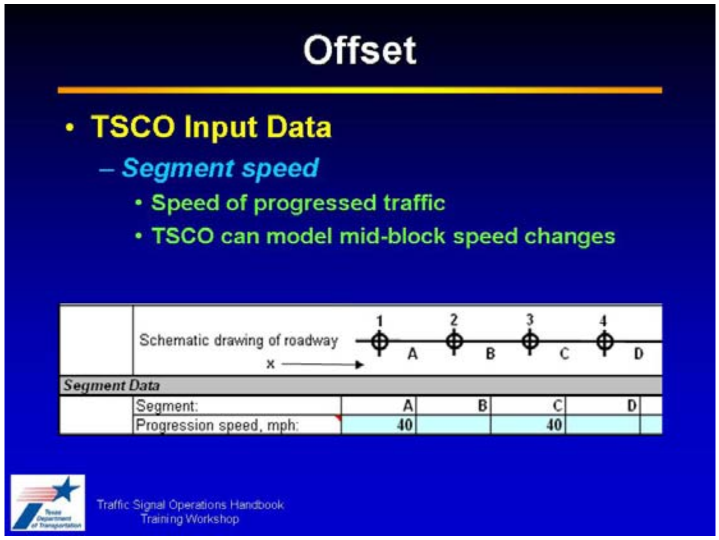
Click: Phase splits are entered in rows 13, 17, 20, and 24 for phases 1, 2, 5, and 6, respectively. They are entered in terms of percentage of cycle length to facilitate the cycle length optimization calculations.

Tell: The cardinal direction labels in the leftmost column can be changed by adjusting the drop-down menu in cell F4. This menu indicates the direction of phase 2.

Click: Change periods (yellow plus red clearance) are entered on rows 15, 19, 22, and 26.

Click: Drop-down menus in rows 16 and 23 are used to specify the left-turn phase sequences.

Slide 81

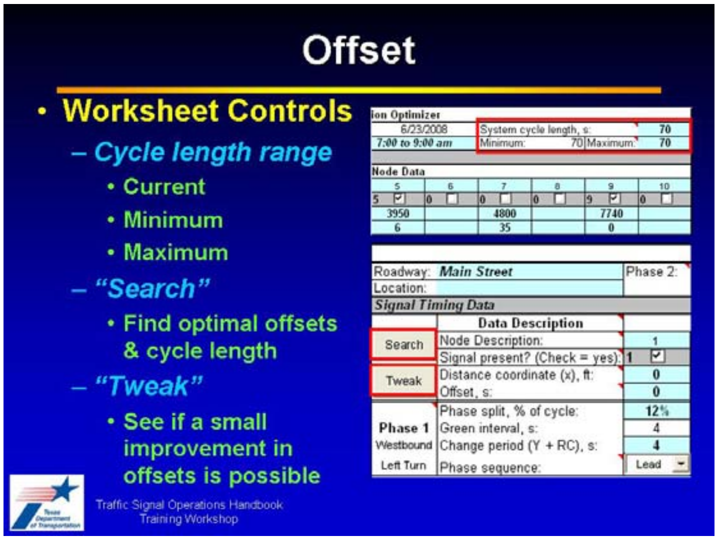


Key Message:
The progression speed for each roadway segment is entered in row 30. This speed is the actual speed of progressed traffic, which may differ from the posted speed limit.

Interactivity:
Tell: The drawing in row 27 shows the relationship between the lettered segments and the numbered nodes.

Tell: A column can be used to indicate the presence of a mid-block speed change point. In this case, a distance coordinate for the speed change point must be provided in row 10 and the speeds on either side of the speed change point must be specified in row 30.

Slide 82



Key Message:
The cycle length entry cells are located in the upper-right corner of the Analysis worksheet. They can be used to specify a single cycle length or a range of cycle lengths to be evaluated. The "search" and "tweak" buttons are used to initiate two different types of optimization analysis procedures.

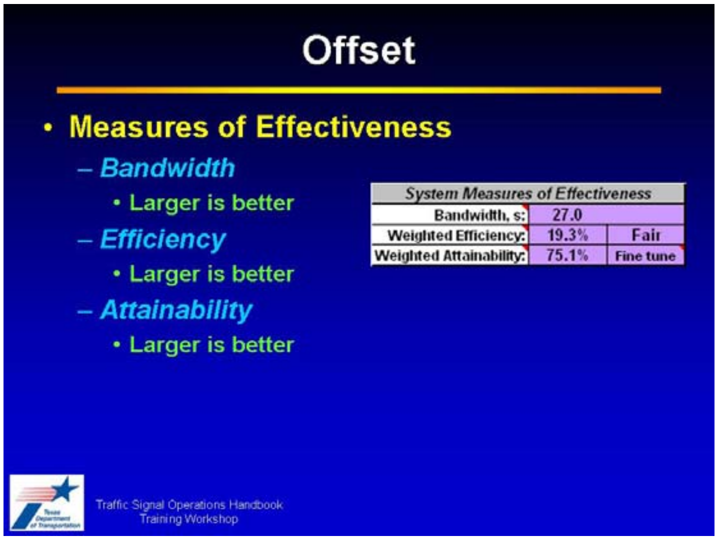
Interactivity:
Click: There are two blue cells in the upper-right corner of the Analysis worksheet. If the user wishes to evaluate only one cycle length value, only the top cell needs to be used. If the user wishes to evaluate a range of cycle length values, the minimum value must be entered in the top cell and the maximum value must be entered in the bottom cell.

Tell: Evaluating a larger range of cycle length values will increase the time needed to complete the optimization computations. Cycle length precision, or the amount by which the cycle length is incremented between each optimization run, is specified in cell N71.

Click: The Search button initiates a comprehensive optimization run that computes the optimum cycle length and offset values. The time needed to complete the run is influenced by the number of signals, the range of cycle lengths, the cycle length precision, and the offset precision (cell E71). When finished, TSCO puts the optimum cycle length and offset values in the worksheet.

Click: The Tweak button initiates a quick evaluation run that determines whether small changes to an existing timing plan can yield improved coordination.

Slide 83



Key Message:
TSCO operates on the principle of maximizing progression bandwidth. It provides the progression bandwidth for the specified cycle length and offsets, and also computes the progression efficiency and attainability. These measures of effectiveness were also used in PASSER II.

Interactivity:
Tell: The TSCO Analysis worksheet's Search and Tweak algorithms identify timing plan parameters that result in the greatest amount of progression bandwidth.

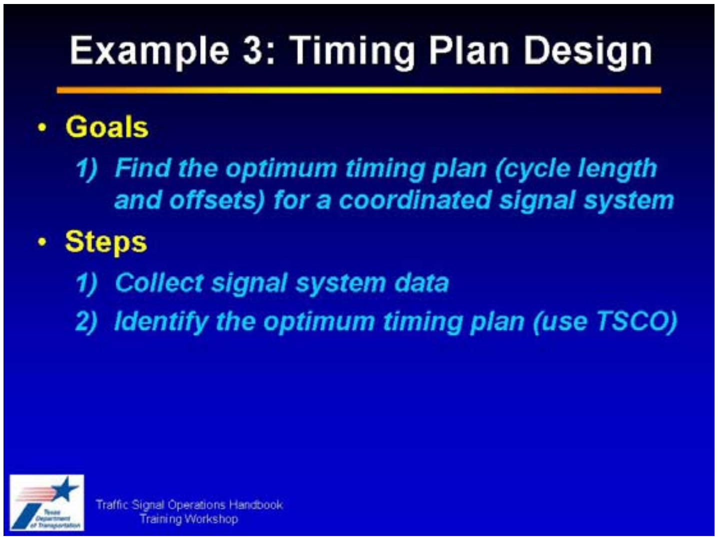
Tell: The reported bandwidth is the sum of bandwidths in both directions (i.e., phases 2 and 6).

Tell: Efficiency is the sum of the bandwidths in both directions divided by twice the cycle length. This measure indicates what portion of the cycle is used for coordinated signal progression.

Tell: Attainability is the sum of the bandwidths in both directions divided by the sum of the constraining (or "critical") green times in each direction. This measure indicates what portion of the green time on the coordinated road is used for coordinated signal progression.

Tell: Many of the TSCO cells, including four in this slide's graphic, have small red triangles in them. These triangles indicate the existence of comment boxes to assist the user in entering data or interpreting results. Place the mouse cursor on top of a cell's red triangle to read the comment for the cell.

Slide 84



Key Message:
The TSCO Analysis worksheet can be used to find an optimum coordination timing plan described by the given data.

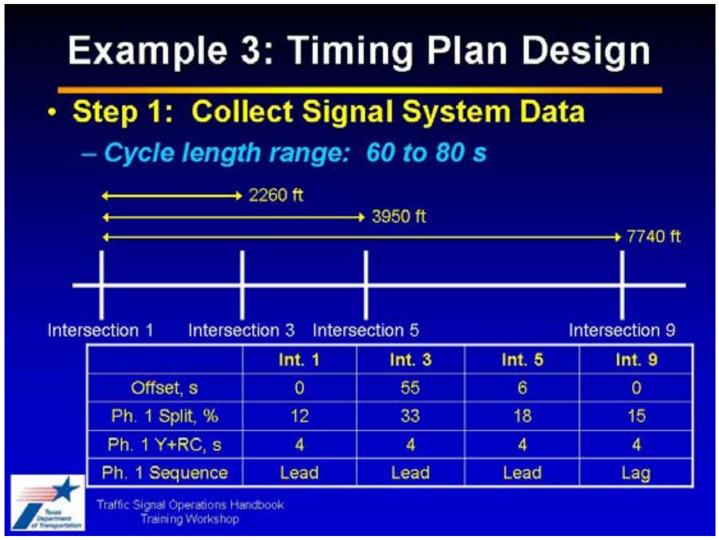
Interactivity:
Tell: Go to page 103 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: First, we will need to collect data to describe the signal system. Volume data are not needed to exercise the TSCO Analysis worksheet.

Tell: Second, we will use TSCO to identify the optimum timing plan.

Notes:
At various points during this exercise, it may be beneficial to review the TSCO Analysis worksheet with the participants instead of presenting only from the slides.

Slide 85



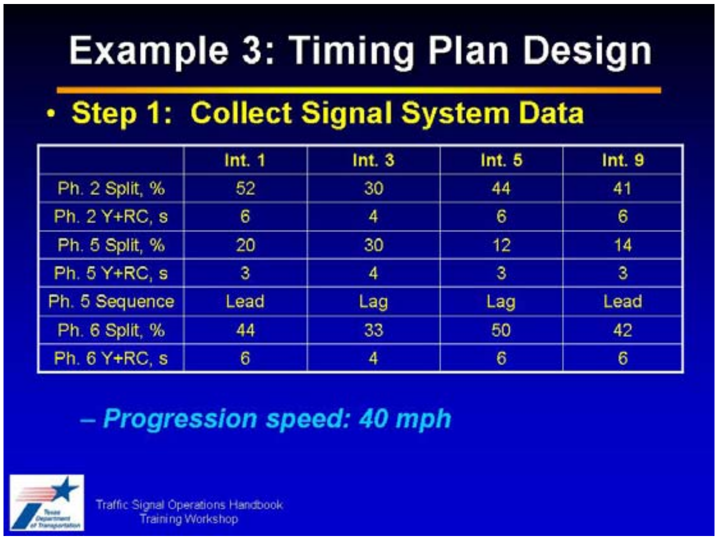
Key Message:
The given data include a range of cycle lengths to be evaluated, signal spacing, and phase data.

Interactivity:
Tell: The four signalized intersections in our system are numbered 1, 3, 5, and 9. The other numbers were skipped because we may want to add new signals between the existing signals.

Tell: In most cases, the default data entered into the Analysis worksheet match the data for this exercise.

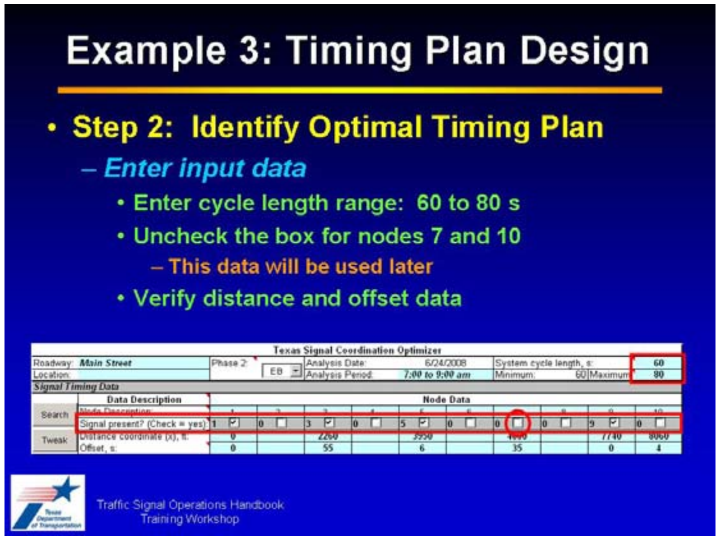
Tell: Data in unchecked columns do not affect the computation results.

Slide 86



Key Message:
The given data include phase data and progression speed.

Slide 87

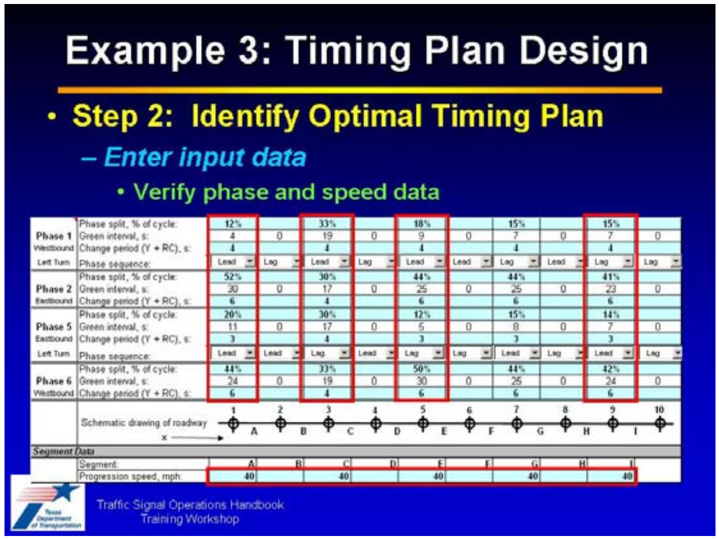


Key Message:
All of the given data must be entered into the Analysis worksheet, including the desired cycle length range. Unused signals should also be unchecked.

Interactivity:
Click: Enter the minimum and maximum cycle lengths. Note that there is an equation in the entry cell for maximum cycle length. Type over this equation.

Click: Verify that only the boxes for nodes 1, 3, 5, and 9 are checked.

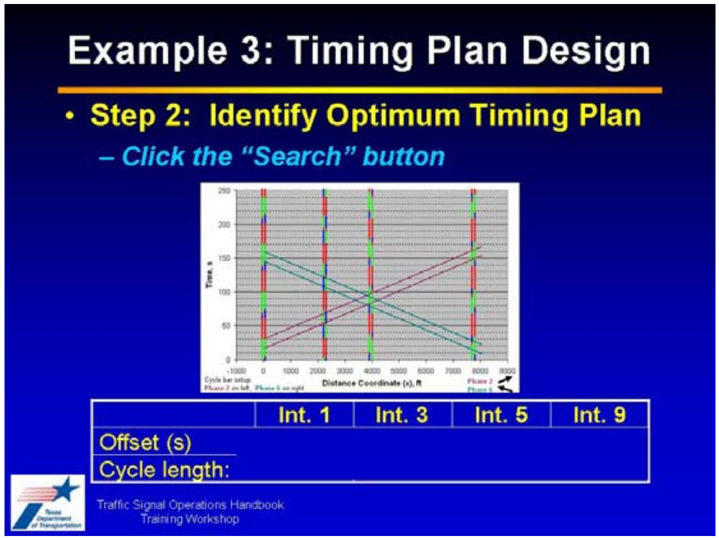
Slide 88



Key Message:
All of the given data must be entered into the Analysis worksheet, including the phase and speed data.

Interactivity:
Click: Verify the given data for nodes 1, 3, 5, and 9.

Slide 89



Key Message:
The optimum timing plan can be obtained by clicking the Search button after the given data are entered.

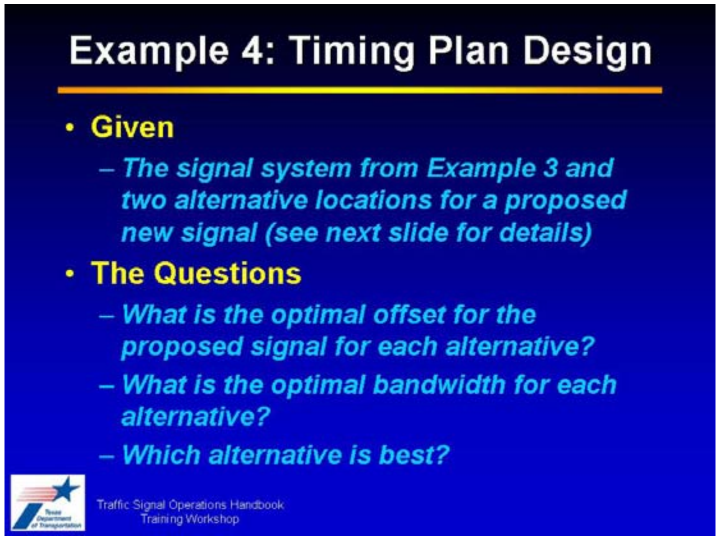
Interactivity:
Tell: Click the Search button. The time-space diagram will update itself periodically as the program iterates through different solutions. It will display the optimum timing plan when the program is finished with its iterations.

Tell: The worksheet also shows progress estimates in the Advisory Messages and Checks section and the box to the right of the time-space diagram.

Click: The participants should obtain the revealed answers if they entered all of the input data correctly.

Notes:
If some input data are changed (e.g., a different set of offsets is used in the beginning), it is possible to obtain a set of offsets that is different but mathematically equivalent to the ones shown on the slide. The cycle length and bandwidth results should not vary. It is also possible to obtain a time-space diagram that differs in appearance from the one shown on the slide, but it should be possible to reproduce the diagram on the slide by using the graph adjustment controls.

Slide 90



Key Message:
The TSCO Analysis worksheet can be used to determine the best location to add a signal to a coordinated signal system.

Interactivity:
Tell: Go to page 104 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: We are using the same coordinated signal system that we used in the previous example. We are going to add a signal at two different locations to determine which location would have the least impact on progression bandwidth.

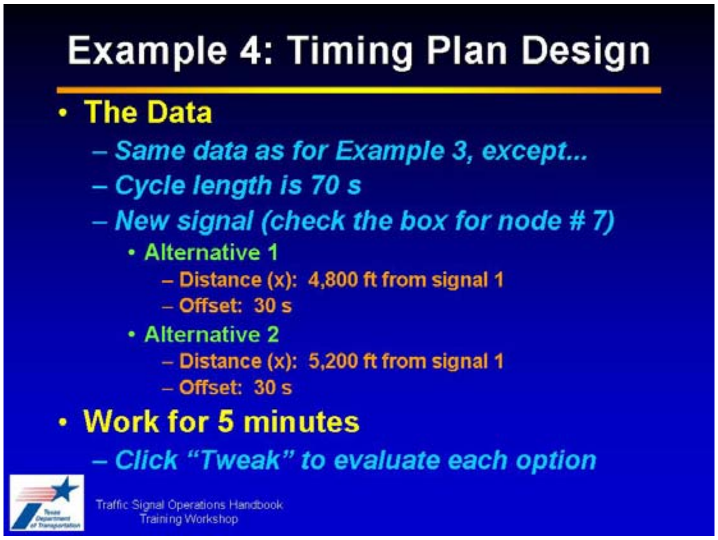
Ask: For each of the alternative signal locations, what is the optimal offset?

Ask: For each alternative, what is the optimal bandwidth?

Ask: Which alternative is best?

Notes:
At various points during this exercise, it may be beneficial to review the TSCO Analysis worksheet with the participants instead of presenting only from the slides.

Slide 91



Key Message:
The given data describing the cycle length and the two locations for the proposed new signal must be entered into TSCO. The Tweak algorithm is sufficient to determine the best location.

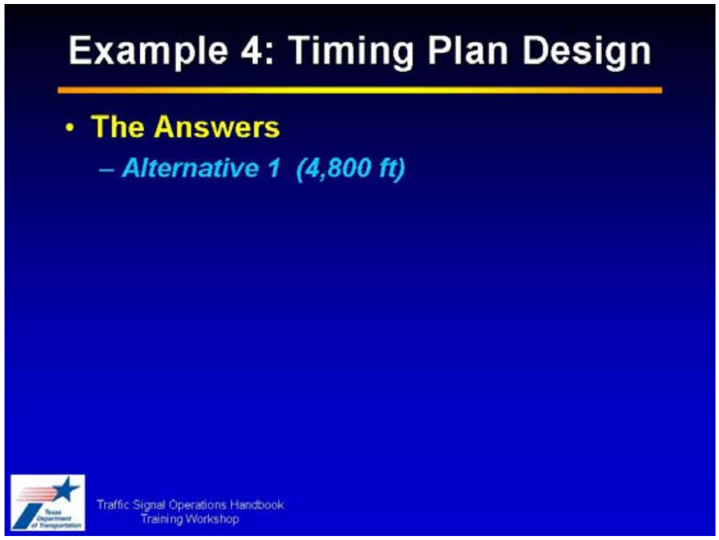
Interactivity:
Tell: Check the box for node 7. This column will be used to describe the new signal.

Tell: Spend about five minutes entering the given data into TSCO. You will use the Tweak algorithm to evaluate each alternative.

Follow up: Leave the instructor's podium and walk around the room as the participants work on the exercise. Offer help to individual participants when needed. When the participants appear to have arrived at the correct answer, return to the instructor's podium and continue the workshop presentation.

Notes:
Some of the participants may get offsets that differ from the answers provided in the next two slides. This can happen if they start with a set of offsets that differs from those obtained in the previous exercise. However, the participants should obtain the same bandwidths as those provided in the answers.

Slide 92



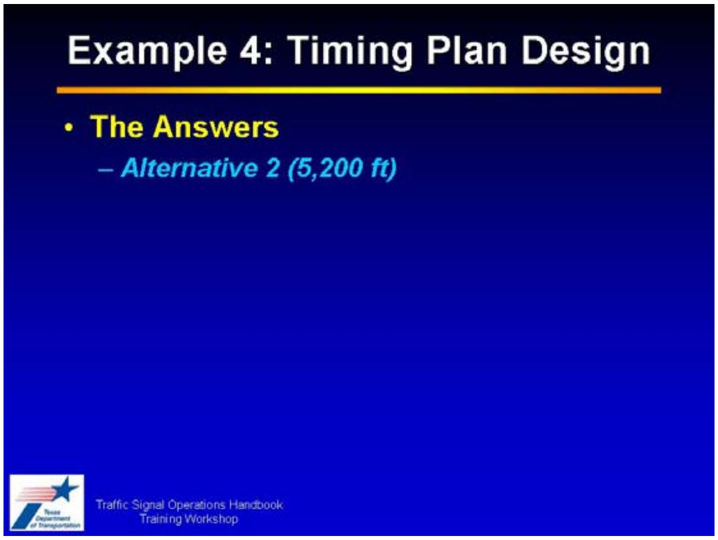
Key Message:
When the given data are entered and the Tweak algorithm is run, TSCO estimates that the first alternative location for the proposed new signal reduces progression bandwidth by roughly half.

Interactivity:
Click: Reveal the answers.

Tell: The optimal bandwidth with the new signal is 13.6 s.

Tell: The optimal bandwidth without the new signal was 27.0 s. Hence, the new signal cuts the bandwidth in half, even if optimally coordinated with the other signals.

Slide 93



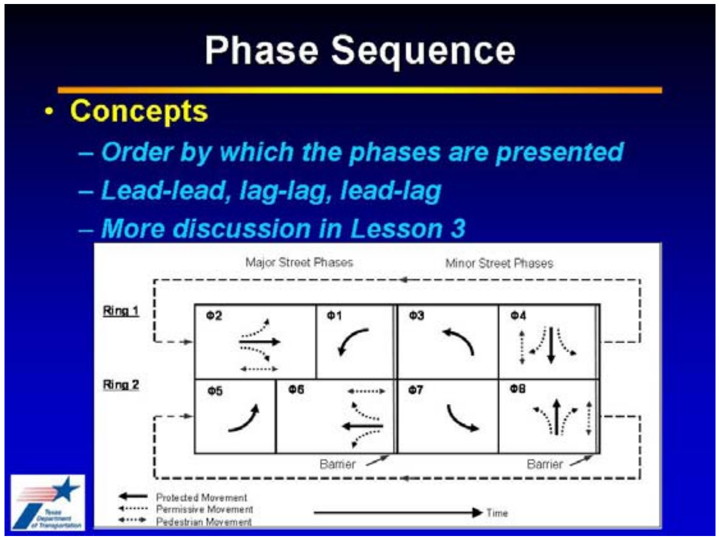
Key Message:
When the given data are entered and the Tweak algorithm is run, TSCO estimates that the second alternative location for the proposed new signal has no impact on progression bandwidth.

Interactivity:
Click: Reveal the answers.

Tell: The optimal bandwidth with the new signal is 27.0 s.

Tell: The optimal bandwidth without the new signal was 27.0 s. Hence, the new signal has been carefully located such that it does not disrupt progression bandwidth.

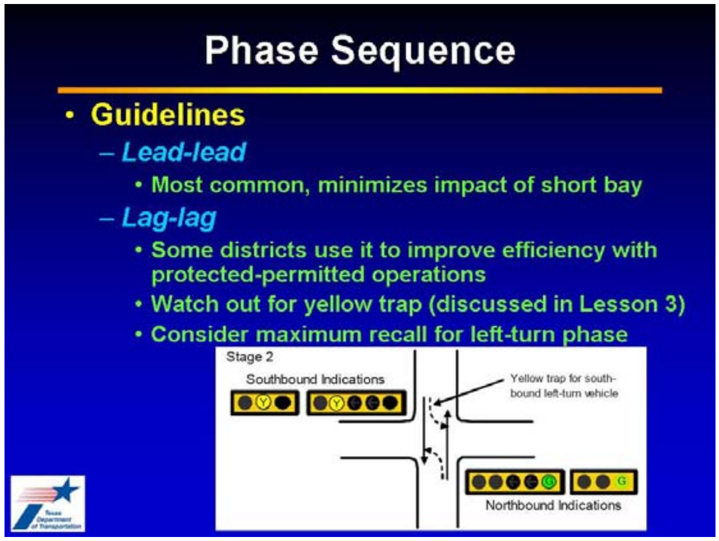
Slide 94



Key Message:
Phase sequence is the order by which phases are presented. A protected left-turn phase can either lead or lag the conflicting through phase on the same ring. The phase sequence need not be the same on the two rings.

Interactivity:
Tell: On the illustration, the major street has a lead-lag phase sequence and the minor street has a lead-lead (or "dual lefts leading") phase sequence.

Slide 95



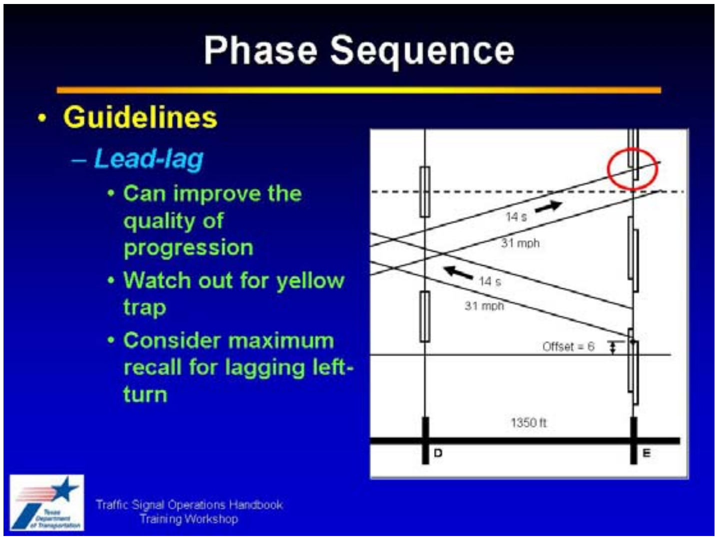
Key Message:
Lead-lead is the most common phase sequence, and it can minimize spillback caused by overfilling of a short left-turn bay. Lag-lag phasing can improve efficiency with protected-permitted operational mode, but can also cause a yellow trap, and may require maximum recall in coordinated signal systems.

Interactivity:
Tell: Lead-lead phasing is the most common. One of its benefits is to clear queued left-turning vehicles before the start of the adjacent through phase, so that the through lanes are less likely to be blocked by left-turning vehicles if the left-turn bay is too short.

Tell: Some districts use lag-lag phasing with protected-permitted left turn operations because if the left-turning vehicles can successfully turn permissively, the protected left-turn phase can be omitted.

Tell: If lagging left turns are used, a yellow trap may result. The yellow trap will be discussed in greater detail in Lesson 3.

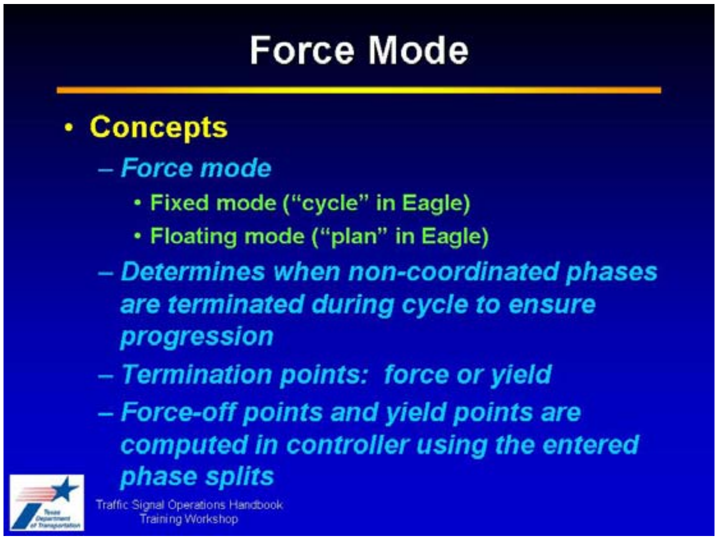
Slide 96



Key Message:
Lag-lag phasing may require maximum recall in coordinated signal systems.

Interactivity:
Tell: Consider using maximum recall if the left-turn phase is being lagged because of signal coordination. In this case, it is likely that part of the progressed platoon in the adjacent through lanes will arrive during the left-turn phase, so it is important that the left-turn phase occurs every cycle. Without the maximum recall, the left-turn phase may not force the adjacent through phase to extend as long as needed to preserve the latter portion of the progression band.

Slide 97

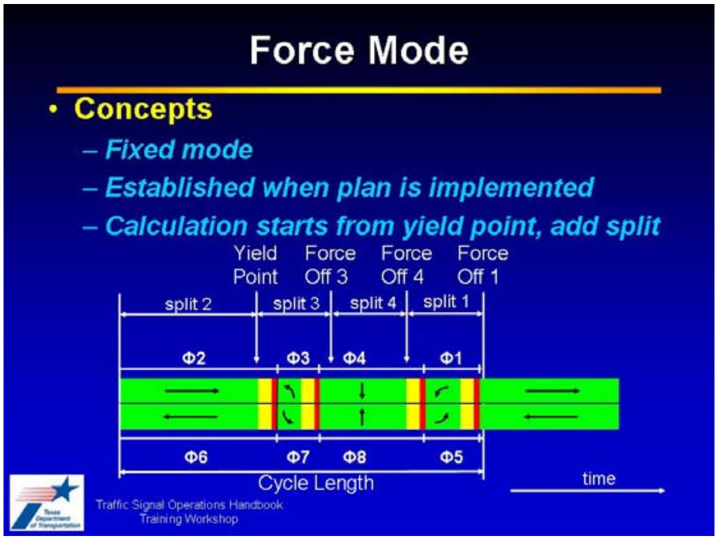


Key Message:
The force mode determines when non-coordinated phases are terminated to ensure progression on the coordinated phases. The force mode may be fixed or floating.

Interactivity:
Tell: To ensure progression, the coordinated phases must be served at a given time in the cycle. However, there is flexibility in when the non-coordinated phases may be served.

Tell: Phase termination points are called the yield point for the coordinated phase, or force-off points for the non-coordinated phases. These points are computed in the controller using the entered phase splits, and are influenced by the selection of force mode.

Slide 98



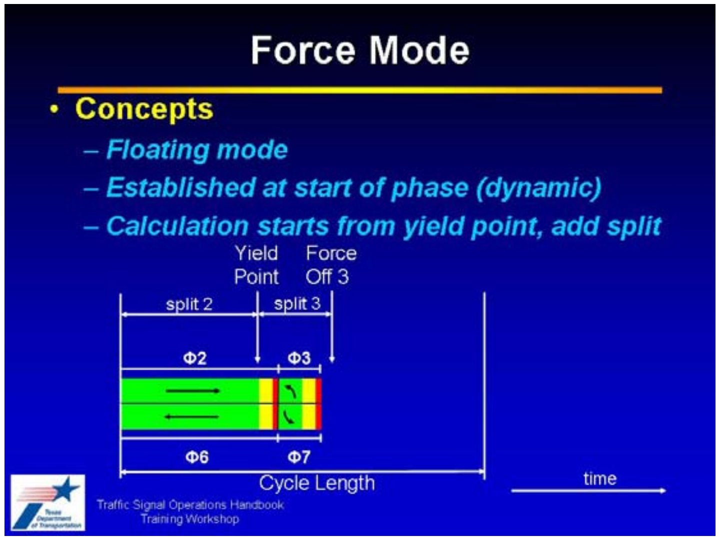
Key Message:
In fixed mode, all of the force-off points are established when the timing plan is implemented. The calculation of the force-off points starts from the yield point, and each subsequent force-off point is determined by adding the preceding phase split.

Interactivity:
Tell: The yield point is the point at which the coordinated phase green ends. In this illustration, the coordinated phase is phase 2.

Tell: The force-off points for phases 3, 4, and 1 are determined in advance by adding the programmed phase splits to the yield point.

Click: Each non-coordinated phase may terminate sooner than its force-off point. In this example, phase 3 terminates sooner than its force-off point. This allows phase 4 to run longer than its split, though it is terminated at its force-off point. Phase 1 also ends sooner than its force-off point, resulting in a somewhat early return to green for phase 2.

Slide 99

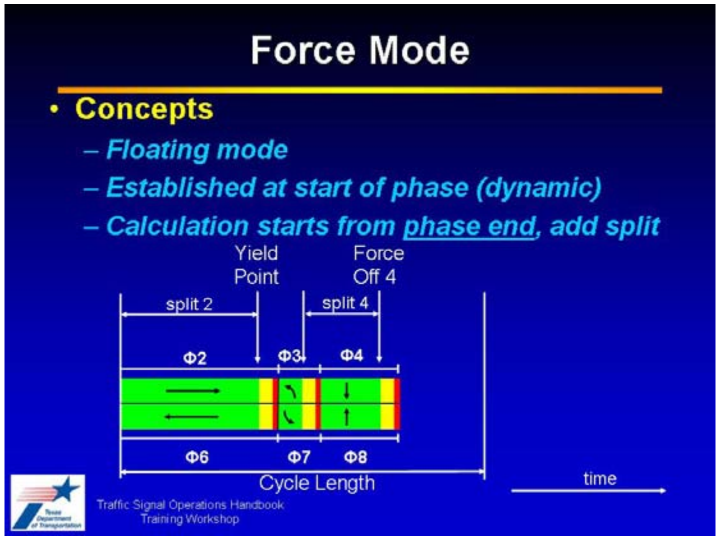


Key Message:
In floating mode, each force-off point is established at the start of its phase. This mode represents a more dynamic method to compute force-off points.

Interactivity:
Tell: The force-off point for phase 3 is computed as a time duration equal to the phase 3 split after the yield point.

Click: In this example, phase 3 is terminated before its force-off point. This also occurred in the preceding fixed-mode example.

Slide 100

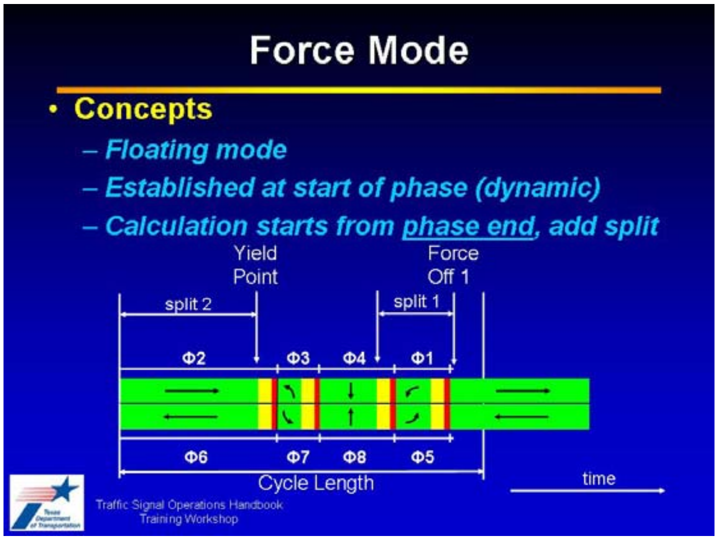


Key Message:
In floating mode, each force-off point is established at the start of its phase. This mode represents a more dynamic method to compute force-off points.

Interactivity:
Tell: Now that phase 3 has ended, the force-off point for phase 4 is computed as a time duration equal to the phase 4 split after the end of the phase 3 split.

Click: In this example, phase 4 is terminated at its force-off point. This also occurred in the preceding fixed-mode example. However, the phase 4 duration is shorter than it was in the fixed-mode example.

Slide 101



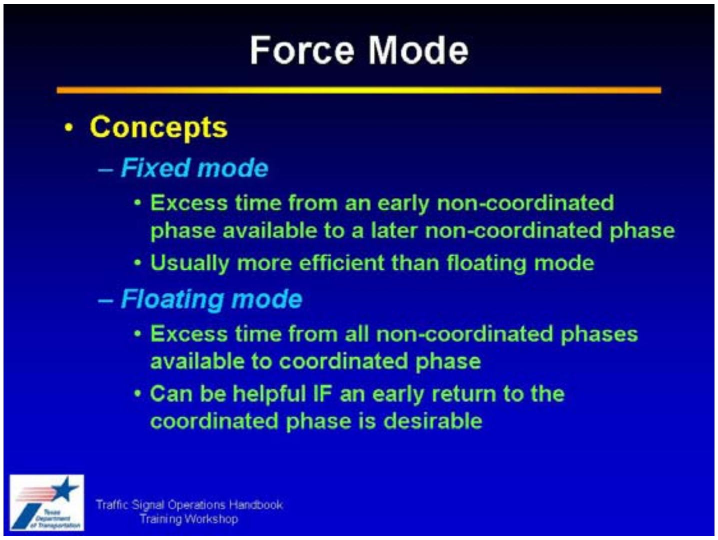
Key Message:
In floating mode, each force-off point is established at the start of its phase. This mode represents a more dynamic method to compute force-off points.

Interactivity:
Tell: Now that phase 4 has ended, the force-off point for phase 1 is computed as a time duration equal to the phase 1 split after the end of the phase 4 split.

Click: In this example, phase 1 is terminated before its force-off point. This also occurred in the preceding fixed-mode example.

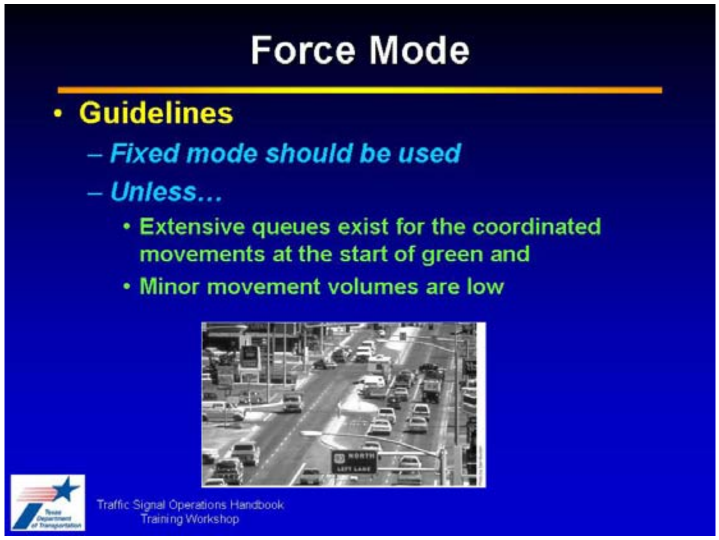
Tell: As was the case in the fixed-mode example, there is an early return to the green for phase 2. However, phase 2 is now starting sooner than it did in the fixed-mode example because less green time was available for phase 4.

Slide 102



Key Message:
Fixed mode gives excess time from early non-coordinated phases to later non-coordinated phases, while floating mode gives excess time from all non-coordinated phases to the coordinated phase. Fixed mode is usually more efficient because it can reduce delay on some non-coordinated phases, but floating mode is helpful if an early return to the coordinated phase is desirable.

Slide 103

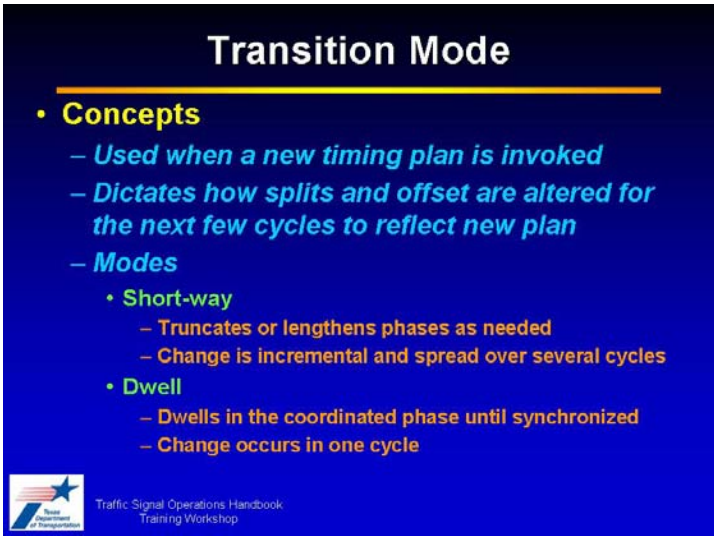


Key Message:
Fixed mode should be used unless the coordinated movements have long queues at the start of their green and minor-movement volumes are low.

Background:
Fixed mode reduces delay on the non-coordinated movements by allowing extra green time to be allocated to these movements. Forced mode allocates unused green time on the non-coordinated movements to the coordinated movement, causing the coordinated movement to return to green earlier.

Early return to green can be problematic because it can encourage drivers to exceed the progression speed and arrive too soon at subsequent intersections, where they would then have to stop. In coordinated-actuated operation, forced mode tends to cause the amount of early return to green to vary from cycle to cycle and from intersection to intersection, making it difficult for drivers to develop expectations about the signal operation.

Slide 104

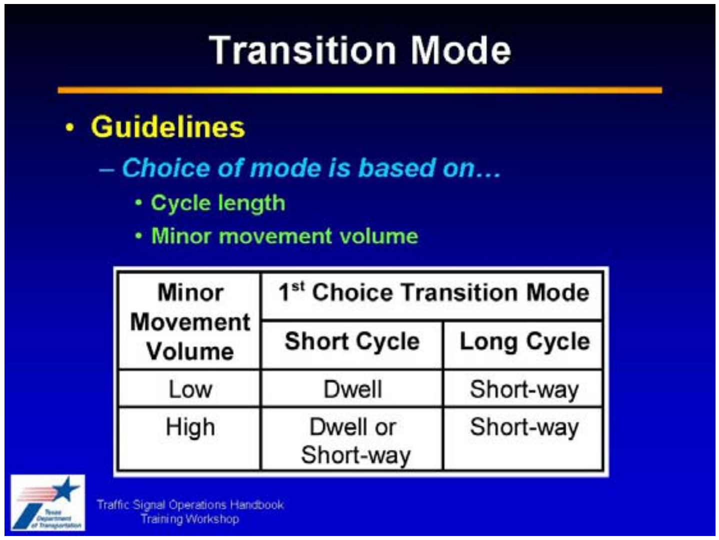


Key Message:
Transitioning occurs when a new timing plan is invoked (e.g., after the evening peak period, the system transitions to off-peak operation). The transition requires splits and offsets to be altered. The change can occur gradually, over several cycles (short-way mode), or quickly, over one cycle (dwell mode).

Interactivity:
Tell: The short-way transition mode truncates or lengthen phases as needed, spreading the timing plan transition over several cycles. This mode spreads delay across all movements.

Tell: The dwell transition mode dwells in the coordinated phase until all the controllers in the system are synchronized with the new timing plan. The transition occurs in one elongated cycle. This mode concentrates delay on non-coordinated movements.

Slide 105

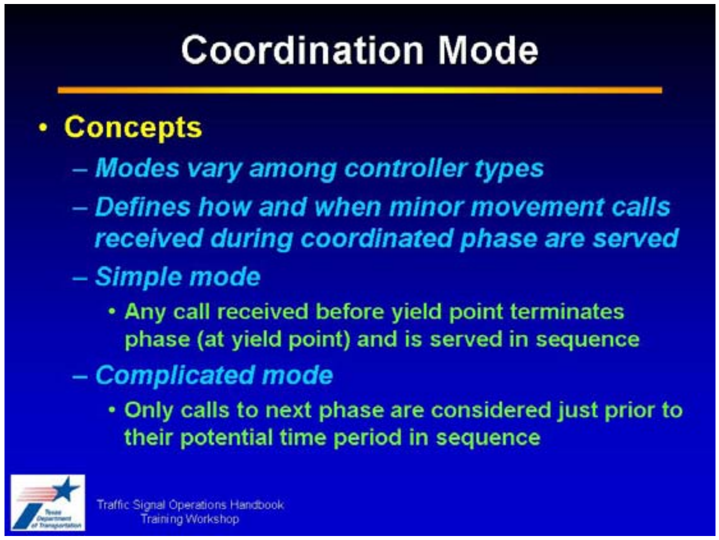


Key Message:
The choice of transition mode is based on the system cycle length and the minor-movement volumes.

Interactivity:
Tell: If the cycle length is long, the short-way transition mode should be used.

Tell: If the cycle length is short, the dwell mode should be used if minor-movement volumes are low. If minor-movement volumes are high and the cycle length is short, either mode can be used.

Slide 106

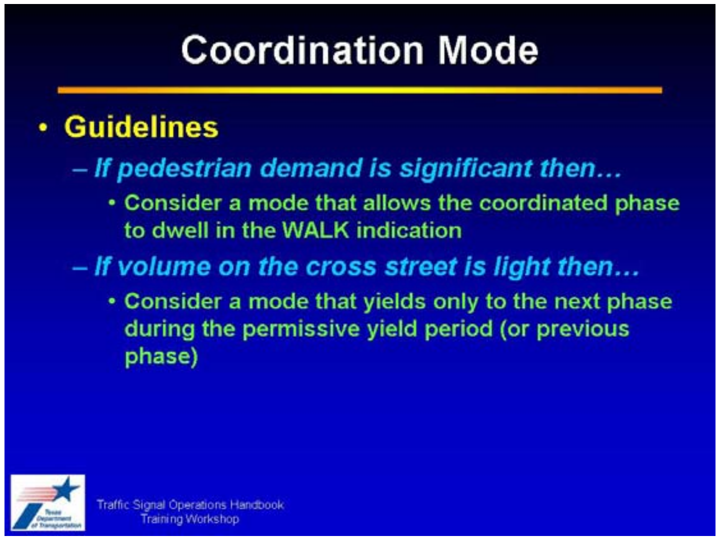


Key Message:
The coordination mode defines the manner in which the coordinated phases are terminated to serve calls on the non-coordinated phases. This mode varies among controller types.

Interactivity:
Tell: The simple mode allows any call received before the coordinated phase's yield point to terminate the coordinated phase at its yield point. The calls are then served in sequence.

Tell: The complicated mode allows calls on only the next phase to be considered, at a time just prior to their time period in sequence. In this mode, the non-coordinated phases each have a sliding window of time called a permissive period when calls can end the coordinated phase.

Slide 107



Key Message:
Because of the variations in coordination mode between controller types, the available coordination modes for the controller being used need to be evaluated carefully before implementation. Two considerations include pedestrian demand and cross-street volumes.

Background:
The variations in coordination mode make it difficult to recommend one mode over another. The *Handbook* guidelines identify two considerations that should influence the choice of coordination mode, but the practitioner still needs to evaluate the coordination modes available for the controller being used.

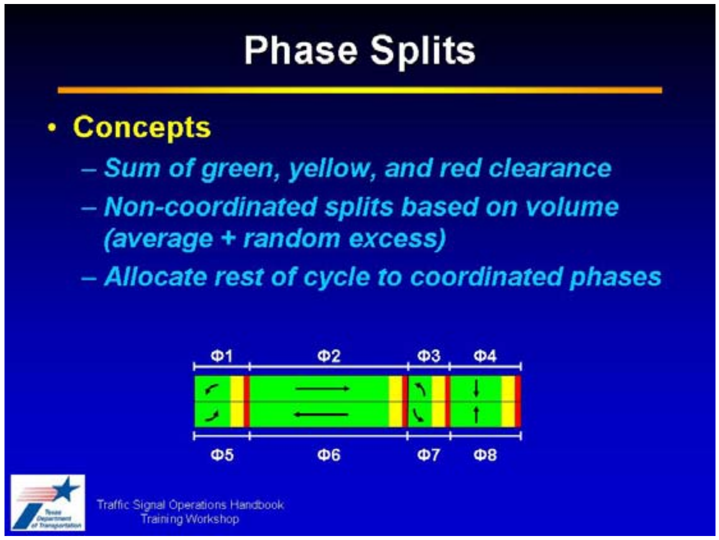
Interactivity:
Tell: If pedestrian demand on the major street is significant, consider a coordination mode that allows the coordinated phase to dwell in the WALK indication.

Tell: If volumes on the cross street is light, then consider a coordination mode that yields only to the next phase during its permissive period.

Slide 108

Key Message:
Settings defining phase operation include phase splits, dynamic splits, and maximum green.

Slide 109



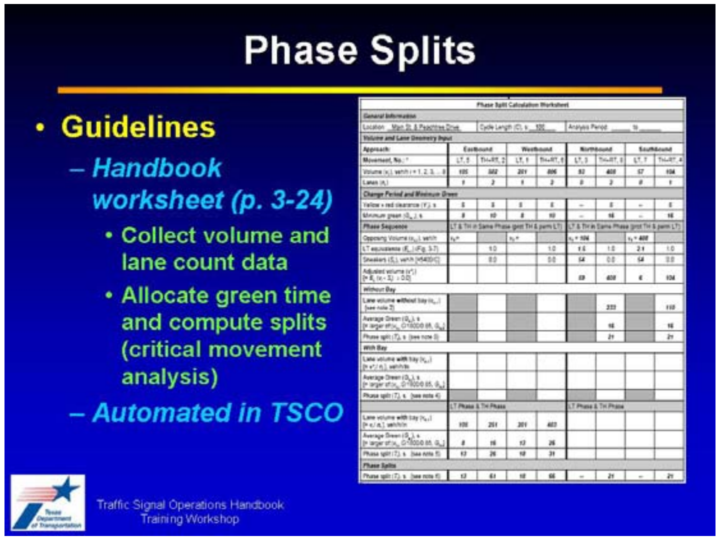
Key Message:
A phase split is the sum of green, yellow, and red clearance times allocated to the phase. Phase split times are based on considerations of volumes for non-coordinated phases and progression bandwidth requirements for coordinated phases.

Interactivity:
Tell: A phase split is defined as the sum of the green, yellow, and red clearance times allocated to a specific phase.

Tell: Phase splits for non-coordinated phases are determined based on considerations of volume. Sufficient time should be provided to serve the average volume for the phase, plus some extra time to serve excess demand that will occur randomly.

Tell: Splits for coordinated phases (typically, phases 2 and 6) are determined based on progression bandwidth requirements. Extra cycle time that was not needed for the non-coordinated phases should also be given to the coordinated phases.

Slide 110

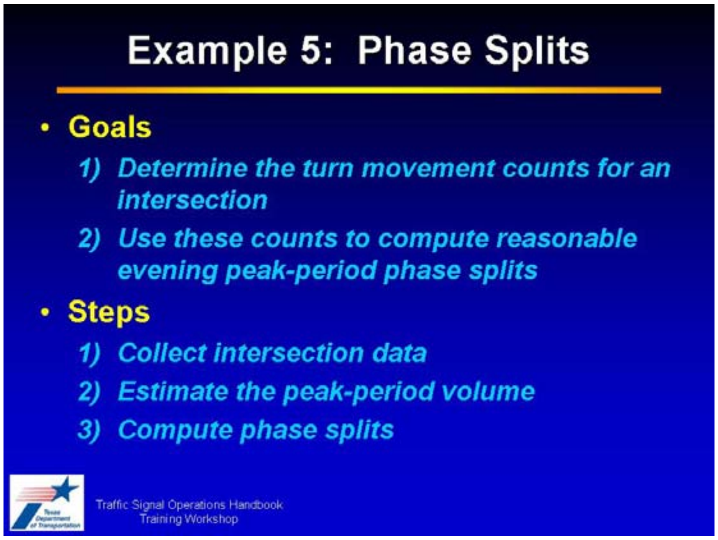


Key Message:
The *Handbook* provides a method to compute phase splits based on the critical movement analysis method. The method requires volume and lane count data, and is automated in the TSCO Splits worksheet.

Interactivity:
Tell: Allocation of cycle time to phases depends on supply (lane count) and demand (traffic volumes). Hence, lane count and volume data need to be collected or estimated.

Tell: The computations can be completed using the phase splits calculation worksheet on page 3-24 of the *Handbook* or automated using the TSCO Splits worksheet.

Slide 111



Key Message:
The TSCO Splits worksheet can be used to compute phase splits for the signalized intersection described by the given data.

Interactivity:
Tell: Go to page 105 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

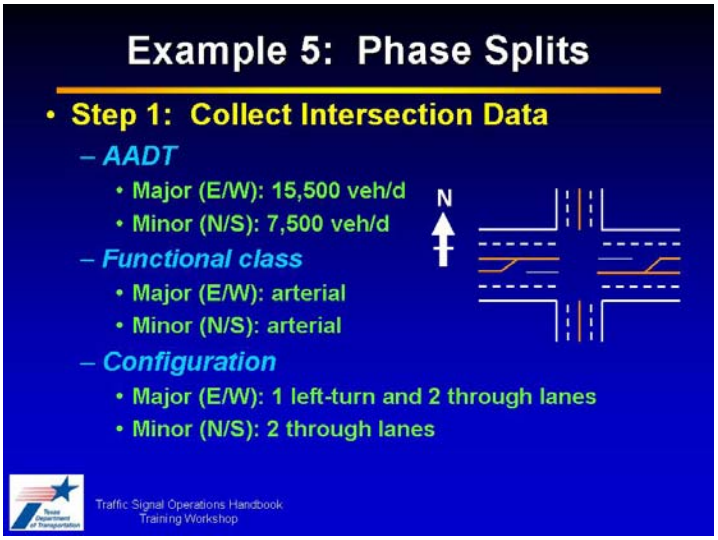
Tell: Our goals are to determine the turn movement counts for an intersection, and use these counts to compute reasonable evening peak-period phase splits.

Tell: The solution is a three-step process: Collect the intersection data, estimate the peak-period volume, and compute the phase splits.

Tell: We will use the Volumes worksheet to obtain turn movement counts, and then use the Splits worksheet to compute the desired phase splits.

Tell: This example is guided. The location of each data input cell will be shown on a screen-shot, and the given data will be reviewed slowly so the participants can enter the data and follow along.

Slide 112

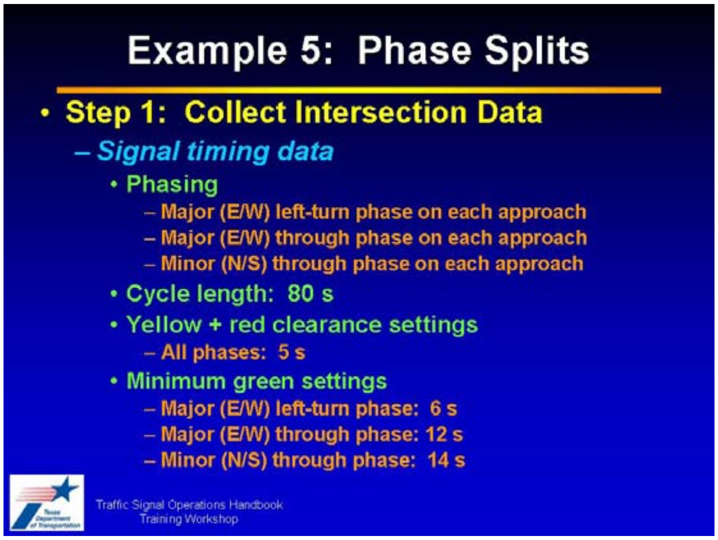


Key Message:
The first step is to collect intersection data. Needed data include traffic volumes, functional class, and lane configuration.

Interactivity:
Tell: The intersection consists of two arterial streets with the illustrated geometry. The major road is the east/west road.

Tell: The AADTs are the same as the numbers from Example 2.

Slide 113



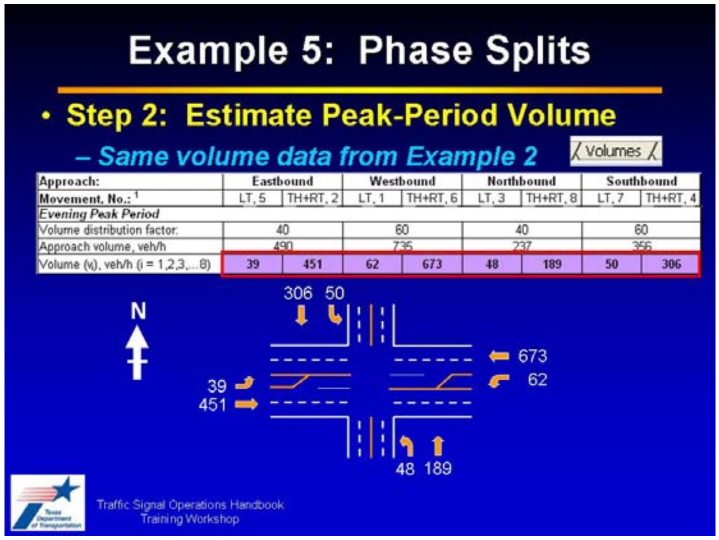
Key Message:
The first step is to collect intersection data. Needed data include signal phasing, cycle length, yellow and red clearance times, and minimum green intervals.

Interactivity:
Tell: Left-turn phases are provided on the major road, but not the minor road.

Tell: The cycle length is 80 s, and every phase has 5 s of yellow and red clearance. To compute phase splits, we need to know only the sum of yellow and red clearance, not the amount allocated to each.

Tell: The minimum green intervals for each phase are given.

Slide 114

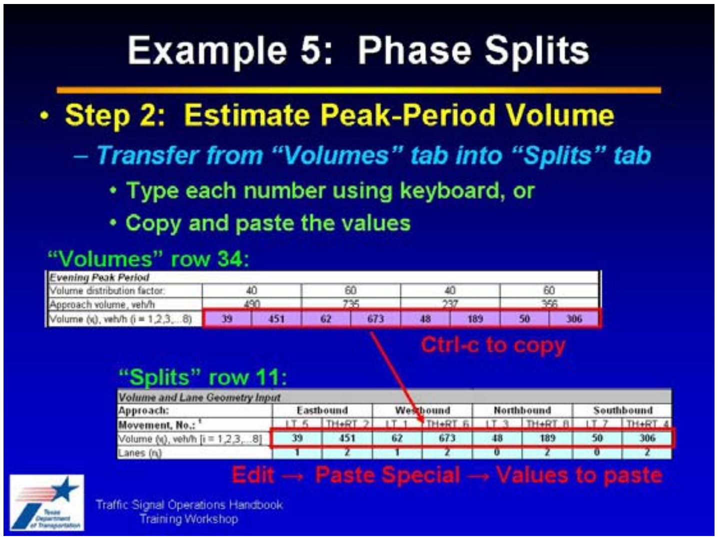


Key Message:
The second step is to estimate the evening peak-period volume. These volumes were estimated in Example 2.

Interactivity:
Tell: We analyzed this same intersection in Example 2. If you no longer have the given data entered into the Volumes worksheet, take a few minutes to do so. Remember that the “Calculate Movement Volumes” button must be clicked if any input data are changed.

Click: The needed evening peak volumes are in row 34 of the Volumes worksheet. The volumes are also shown for each movement in the illustration.

Slide 115



Key Message:
The evening peak-period volumes from the Volumes worksheet need to be transferred to the Splits worksheet.

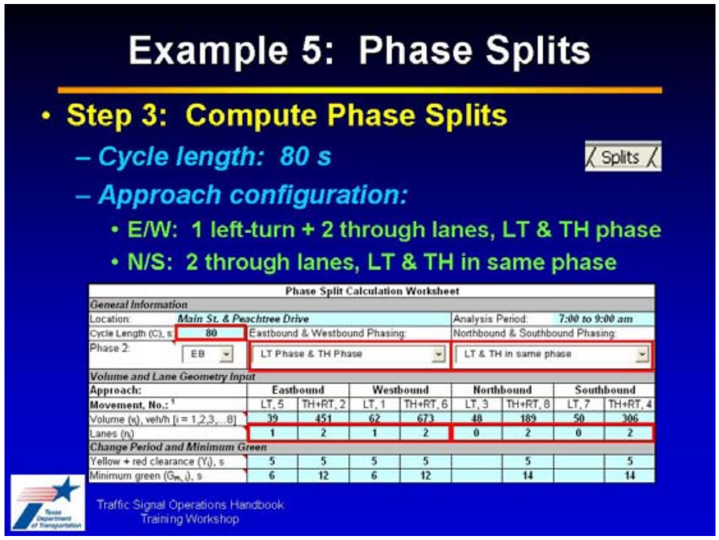
Interactivity:
Tell: The evening peak-period volumes can be typed into the Splits worksheet, or they can be copied and pasted from the Volumes worksheet.

Click: Select the volumes in row 34 of the Volumes worksheet and copy them (control-C or right-click and select "copy").

Click: Select the Splits worksheet.

Click: Place the cursor in cell D11 and paste the volumes. Note that only the values should be pasted (right-click, select "paste special", choose "values", and click OK).

Slide 116



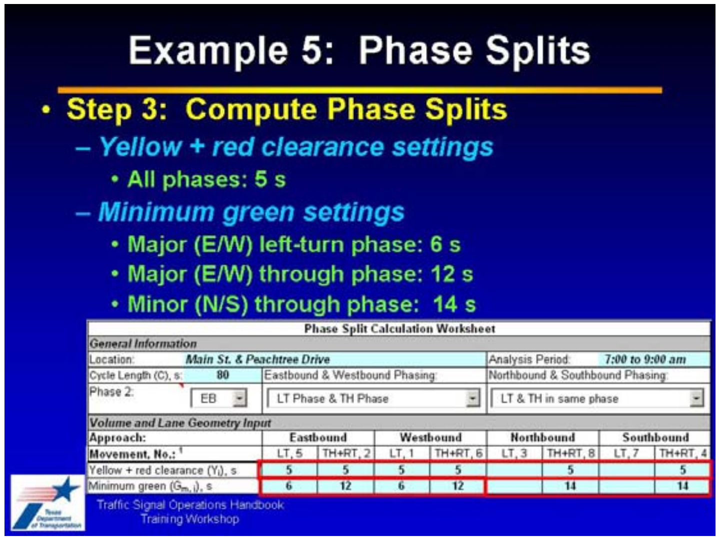
Key Message:
The third step is to compute phase splits. Cycle length and approach configuration data must be entered into the Splits worksheet.

Interactivity:
Click: Enter the cycle length.

Click: Enter the approach configuration data for the east/west road. Put the lane counts in row 12 and choose the phasing from the drop-down menu

Click: Enter the approach configuration data for the north/south road.

Slide 117



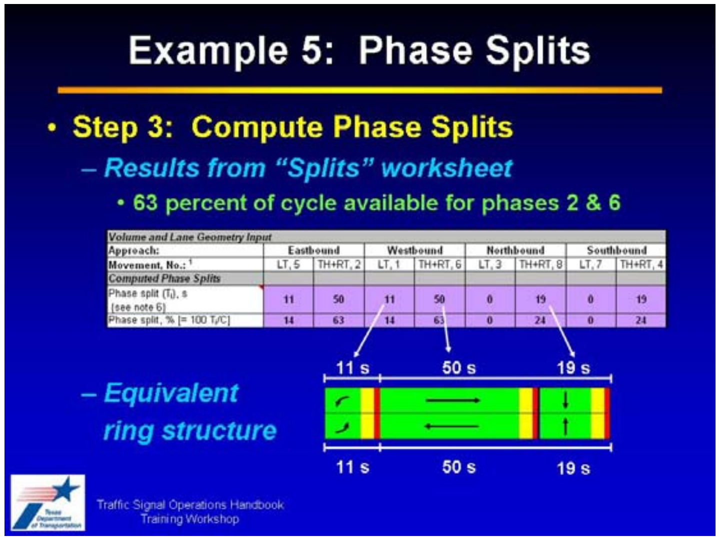
Key Message:
Yellow, red clearance, and minimum green intervals must also be entered into the Splits worksheet.

Interactivity:
Click: Enter a 5-s yellow plus red clearance time for all phases.

Click: Enter the minimum green intervals for the east/west road.

Click: Enter the minimum green intervals for the north/south road.

Slide 118

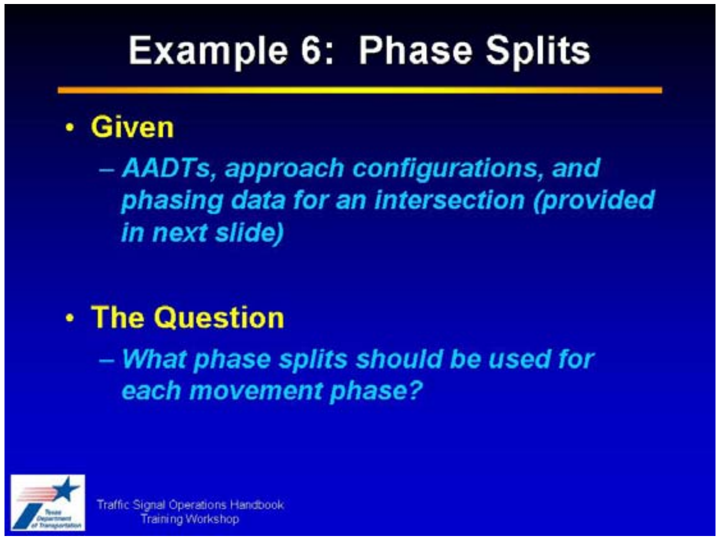


Key Message:
Once the given data are entered, TSCO provides the needed phase splits in seconds and percentage of cycle.

Interactivity:
Tell: Sixty-three percent of the cycle is available for phases 2 and 6, the coordinated phases. This amount of time should allow a good amount of progression bandwidth to be obtained through this intersection.

Tell: The equivalent ring structure, with phase splits in seconds, is shown at the bottom of the slide. No time is allocated to phases 3 and 7 because we do not have left-turn phases on the minor road.

Slide 119

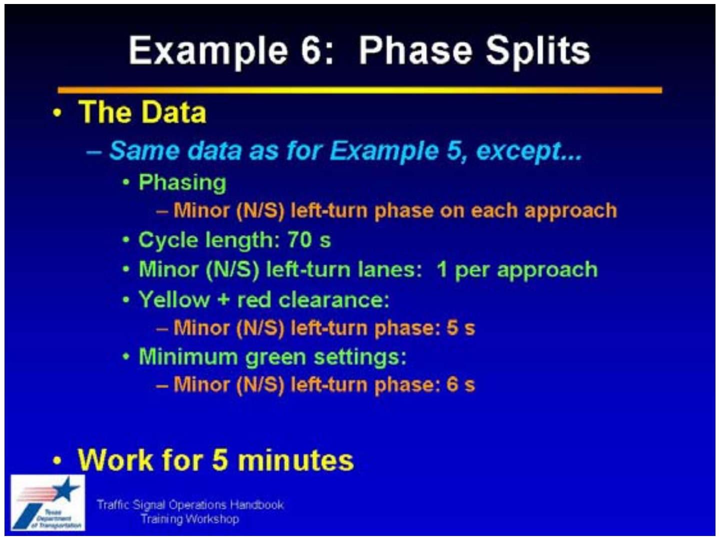


Key Message:
The TSCO Splits worksheet can be used to compute phase splits for the signalized intersection described by the given data.

Interactivity:
Tell: Go to page 106 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Ask: What phase splits should be used for each movement phase?

Slide 120



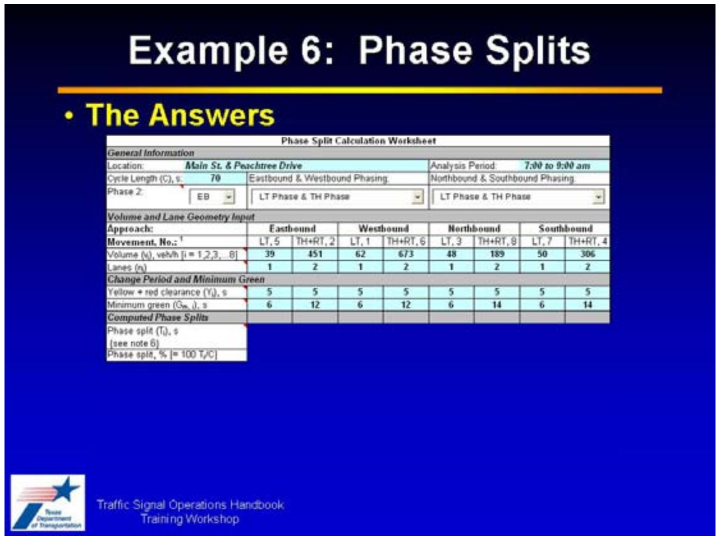
Key Message:
The TSCO Splits worksheet can be used to compute phase splits for the signalized intersection described by the given data.

Interactivity:
Tell: With the exception of the specified changes on the slide, all input data are the same as in Example 5, including the traffic volumes.

Tell: Spend about five minutes entering the given data into TSCO Splits worksheet.

Follow up: Leave the instructor's podium and walk around the room as the participants work on the exercise. Offer help to individual participants when needed. When the participants appear to have arrived at the correct answer, return to the instructor's podium and continue the workshop presentation.

Slide 121



Key Message:
When the given data are entered into the Splits worksheet, TSCO provides the desired phase splits.

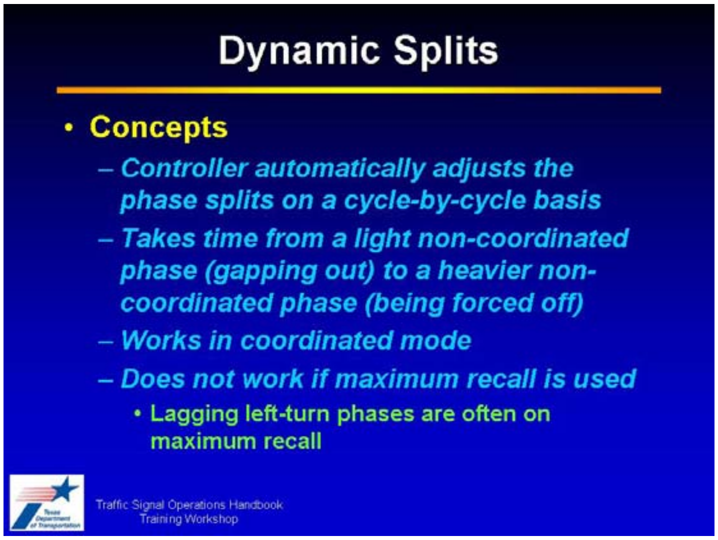
Interactivity:
Click: Reveal the computed phase splits.

Click: Note that minimal time was provided for the newly added left-turn phases. Still, the amount of time available to the coordinated phases has decreased significantly (41 percent of the cycle instead of 63 percent).

Click: Save the TSCO file. The calculations in this example will be re-used later in the workshop.

Tell: The phase split values computed by the Splits worksheet can also be used in the Analysis worksheet. The values cannot be pasted directly because the Analysis worksheet is arranged differently, but they can be entered. The Splits worksheet provides phase splits in percent of cycle because the Analysis worksheet uses these units.

Slide 122



Key Message:
The dynamic splits feature adjusts non-coordinated phase splits on a cycle-by-cycle basis so phases with heavier volumes can be given more green time.

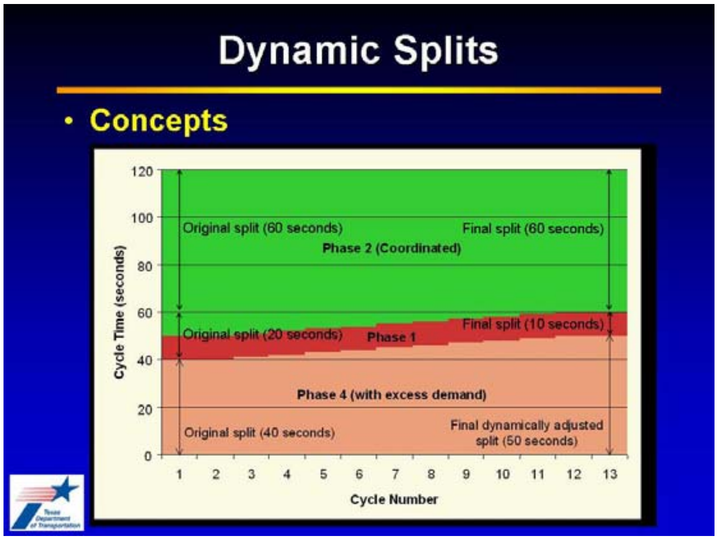
Interactivity:
Tell: The dynamic splits feature adjusts phase splits for non-coordinated movements on a cycle-by-cycle basis. These movements must have detection.

Tell: Time is taken from a light-volume phase that gaps out several times and given to a heavier-volume phase that is being forced off.

Tell: This feature can be used in coordinated mode. It does not affect the coordinated phases.

Tell: The dynamic splits feature does not work if maximum recall is used, as the recall would force the phase to run to its maximum green regardless of volumes. However, lagging left-turn phases on coordinated roads should still be set to maximum recall to preserve the progression bandwidth.

Slide 123



Key Message:
The dynamic splits feature allows cycle time to be reallocated among non-coordinated phases while still providing the needed time for coordinated phases.

Interactivity:
Tell: In this graph, the y-axis is cycle time and the x-axis is cycle number. A total of thirteen 120-s cycles are plotted.

Tell: The arrows on the left side of the graph show the original splits for phases 4, 1, and 2. These phases start with splits of 40 s, 20 s, and 60 s, respectively.

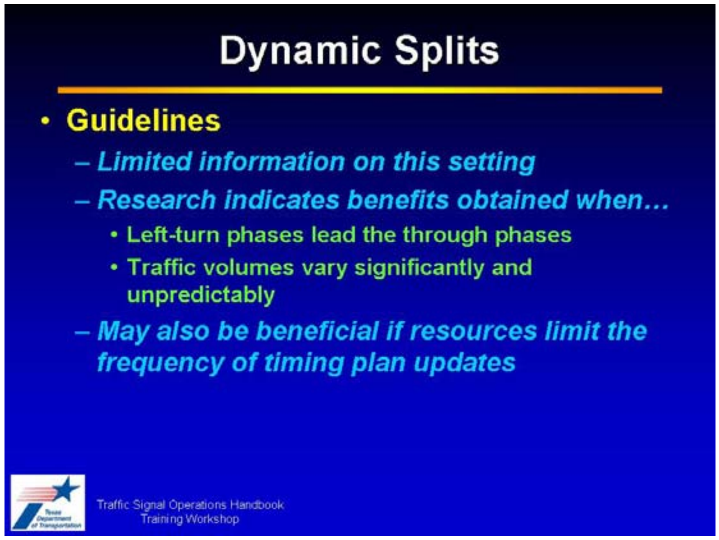
Tell: In this example, phase 4 has excess demand, phase 1 has excess capacity, and phase 2 is coordinated.

Tell: The colors represent the time that each phase is actually served. In cycle 1, phase 4 maxes out, phase 1 ends early, and phase 2 starts early.

Tell: After phase 4 maxes out on cycles 1 and 2, the controller starts extending phase 4 by one second per cycle. As a result, phase 1 gets served later in the cycle and the early return to phase 2 green is reduced.

Tell: By cycle 12, phase 4 has been extended as long as possible while still honoring the split for phase 2. We end with dynamically-adjusted splits of 50 s for phase 4 and 10 s for phase 1. The phase 2 split is still 60 s.

Slide 124

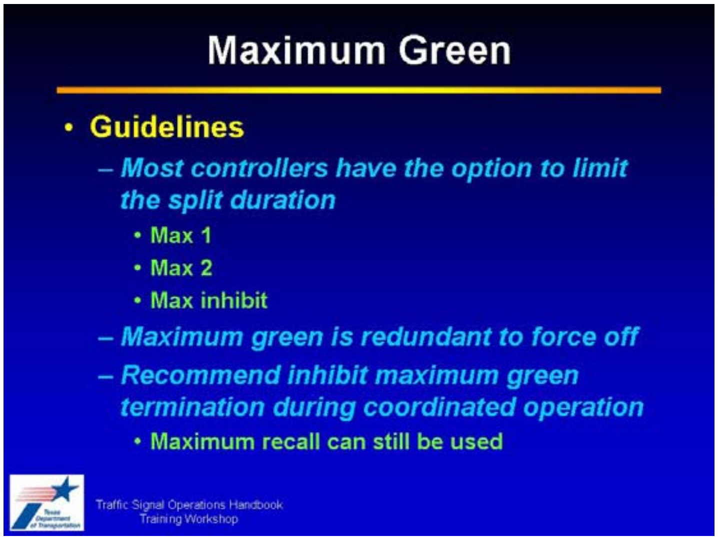


Key Message:
The dynamic splits feature can yield benefits when left-turn phases lead through phases and traffic volume variability is significant and unpredictable. It can also reduce the need to update timing plans.

Interactivity:
Tell: Limited research has shown that dynamic splits can be beneficial when left-turn phases lead through phases and traffic volumes vary significantly and unpredictably.

Tell: The dynamic split feature can also allow timing plans to be updated less frequently.

Slide 125

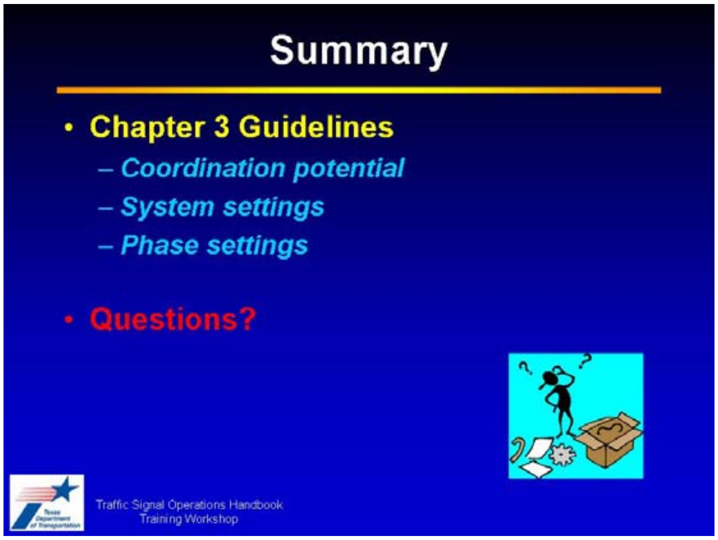


Key Message:
In coordinated signal systems, maximum green should be inhibited for most phases because it is redundant to the force-off settings. It should still be used for lagging left-turn phases on the major road.

Interactivity:
Tell: The maximum green should be inhibited for most phases in a coordinated system because the force-off settings determine when phases should be ended.

Tell: Maximum green should still be used for lagging left-turn phases on the major road to preserve progression bandwidth.

Slide 126


Summary
• Chapter 3 Guidelines
– Coordination potential
– System settings
– Phase settings
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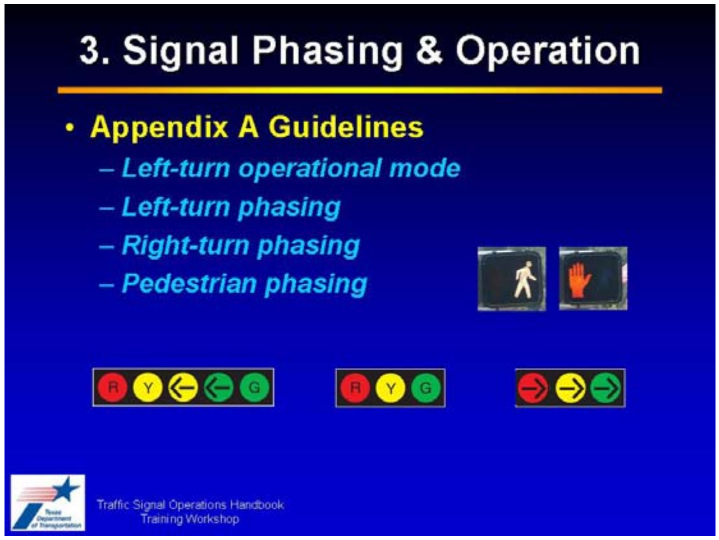
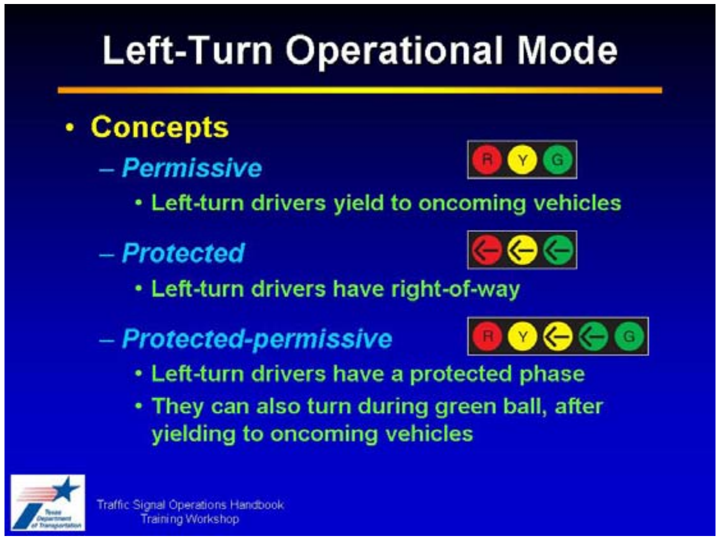
Slide 127



Key Message:
This lesson covers Appendix A of the *Handbook*. Appendix A focuses on signal phasing and operation for left turns, right turns, and pedestrians.

Slide 128



Key Message:
The three common modes for left turn operation include permissive, protected, and protected-permissive.

Interactivity:
Tell: In permissive mode, left-turning drivers turn during the green ball indication. They must yield to opposing through and right-turning vehicles and wait for a safe gap to turn.

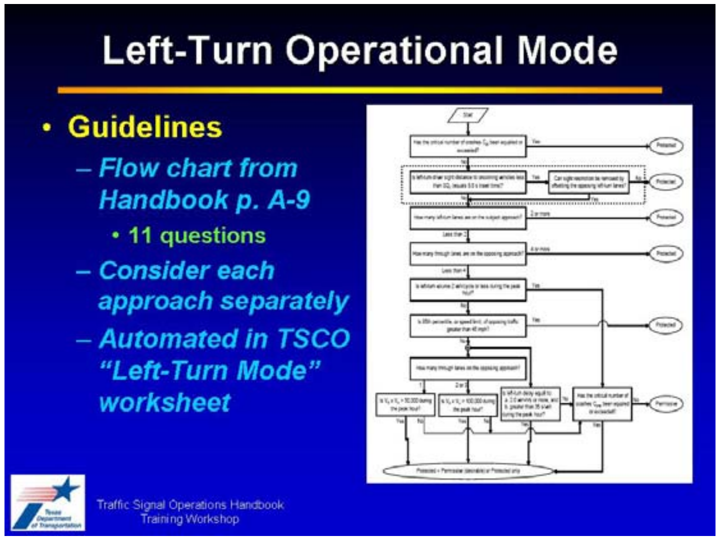
Tell: In protected mode, left-turning drivers can turn only when they have a green arrow indication. They have right-of-way when presented with the green arrow.

Tell: In protected-permissive mode, left-turning drivers have a choice. They can turn during the protected phase, when they have right-of-way, or they can turn during the permissive green ball phase, when they must yield to opposing vehicles.

Slide 129

Key Message:
A variety of factors influence the selection of left-turn operational mode, including traffic volumes and speeds, lane configuration, cycle length, sight distance, and crash history.

Slide 130



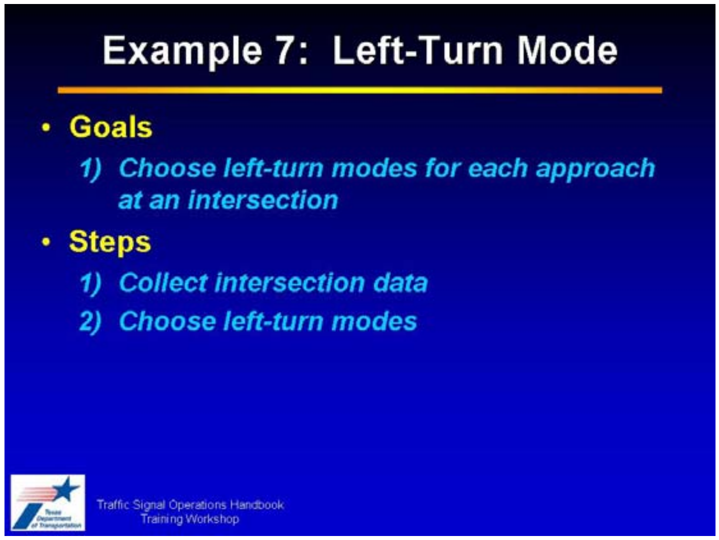
Key Message:
All of the factors influencing the selection of left-turn operational mode are incorporated in a flow chart in the *Handbook*. The flow chart is also automated in the TSCO Left-Turn Mode worksheet.

Interactivity:
Tell: To address the various factors influencing the selection of left-turn operational mode, page A-9 of the *Handbook* contains a flow chart that incorporates eleven questions.

Tell: Each intersection approach should be considered separately. The need for a protected left-turn phase on one intersection approach does not necessarily suggest that a left-turn phase is also needed on other approaches. It is not necessary to use the same operational mode on all approaches.

Tell: Implementation of the flow chart is automated in the TSCO Left-Turn Mode worksheet.

Slide 131



Key Message:
The TSCO Left-Turn Mode worksheet can be used to choose left-turn modes for the intersection approaches described by the given data.

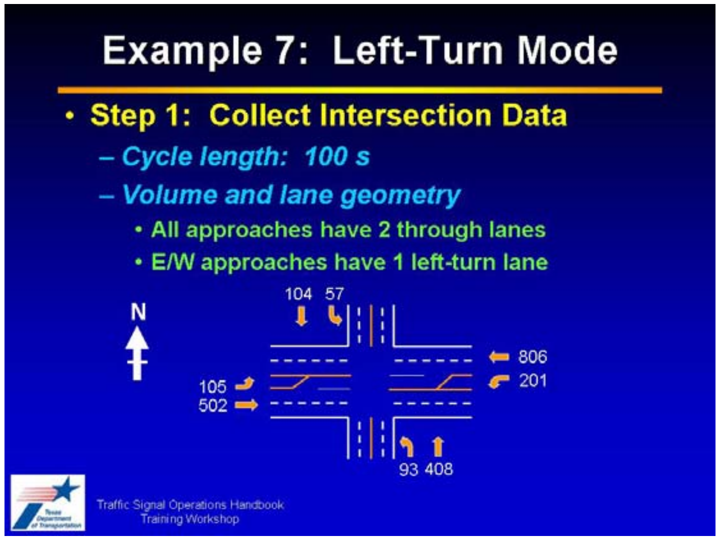
Interactivity:
Tell: Go to page 107 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: Our goal is to choose the left-turn operational mode for all four approaches to the example intersection.

Tell: We will use the Left-Turn Mode worksheet to choose the left-turn mode for each approach.

Tell: This example is guided. The location of each data input cell will be shown on a screen-shot, and the given data will be reviewed slowly so the participants can enter the data and follow along.

Slide 132



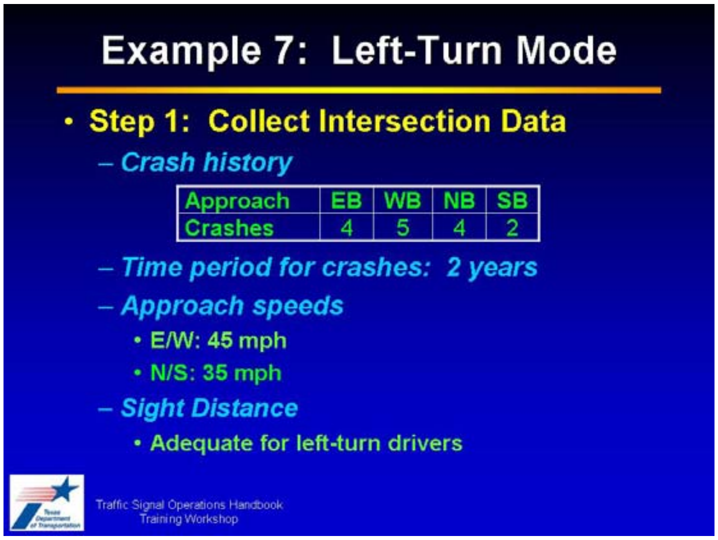
Key Message:
The first step is to collect intersection data. Needed data include cycle length, volumes, and lane geometry.

Interactivity:
Tell: The cycle length is 100 s.

Tell: All approaches have two through lanes. The approaches on the east/west road have one left-turn lane.

Tell: The volumes are shown in the diagram. These are the default volumes that are already entered into TSCO when it is loaded.

Slide 133



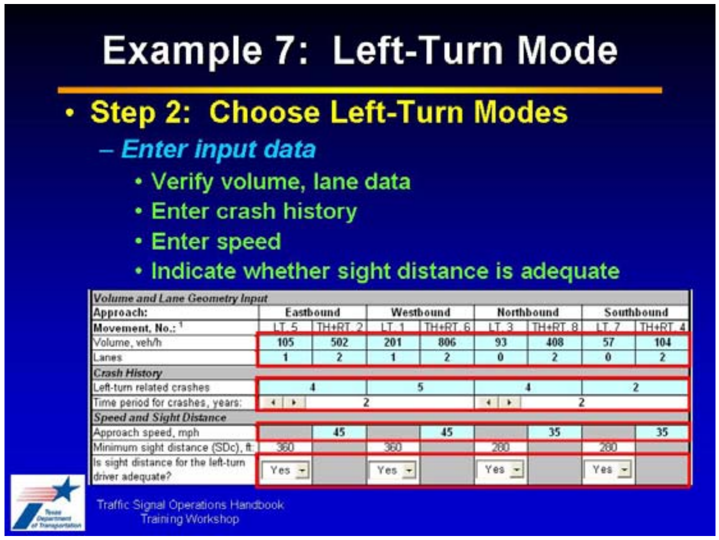
Key Message:
The first step is to collect intersection data. Needed data include crash history, approach speeds, and sight distance adequacy.

Interactivity:
Tell: The crash history is given in the table. These crashes include all left-turn related crashes of any severity.

Tell: The approach speeds are 45 mph on the east/west road and 35 mph on the north/south road.

Tell: The sight distance was determined to be adequate for all left-turn drivers.

Slide 134



Key Message:
The second step is to enter the given data.

Interactivity:
Click: Enter the data into the appropriate cells.

Tell: The volumes are already entered into row 11.

Tell: Enter the lane counts into rows 12.

Tell: Enter the crash counts into row 14.

Tell: Use the slider buttons to adjust the crash history time periods in row 15.

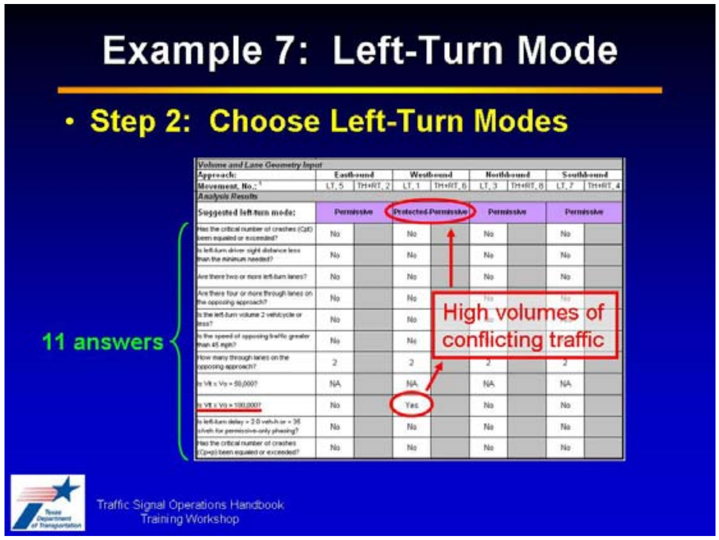
Tell: Enter the approach speeds into row 17.

Tell: We were told that the sight distance for each approach is adequate. Use the drop-down menus in row 19 to indicate that the sight distances are adequate.

Tell: Row 18 computes required sight distances based on the approach speeds. These numbers can be used to determine sight distance adequacy.

Tell: An alternative method to assess sight distance adequacy is to face in the direction of the subject left-turn movement, watch as a vehicle in the adjacent through lanes passes by, identify a landmark next to the vehicle after a count of 5.5 s, and determine whether the opposing lanes next to that landmark are visible.

Slide 135



Key Message:
Once the given data are entered, the left-turn mode can be determined for each approach.

Interactivity:
Tell: The recommended left-turn modes are found in the purple cells in row 22. Below the purple cells, each row contains an answer to one of the eleven questions that are found in the flow chart. This portion of the worksheet reveals the rationale for the recommended left-turn modes.

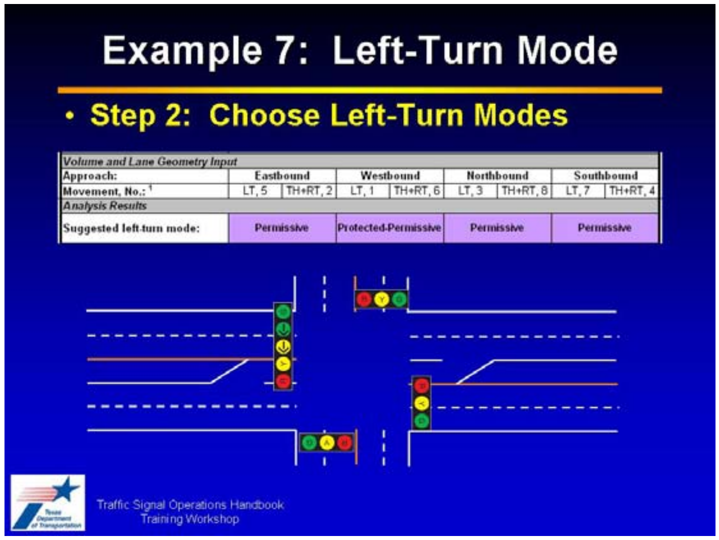
Tell: Notice that only one of the approaches, the westbound approach, was determined to need a protected left-turn phase. A review of the answers in the rows below the purple cells can reveal why.

Click: One of the questions relates to the product of the left-turn volume and the opposing through volume. The westbound approach has a volume product greater then 100,000.

Click: This approach has more than the threshold volume product of 100,000 for requiring a protected left-turn phase.

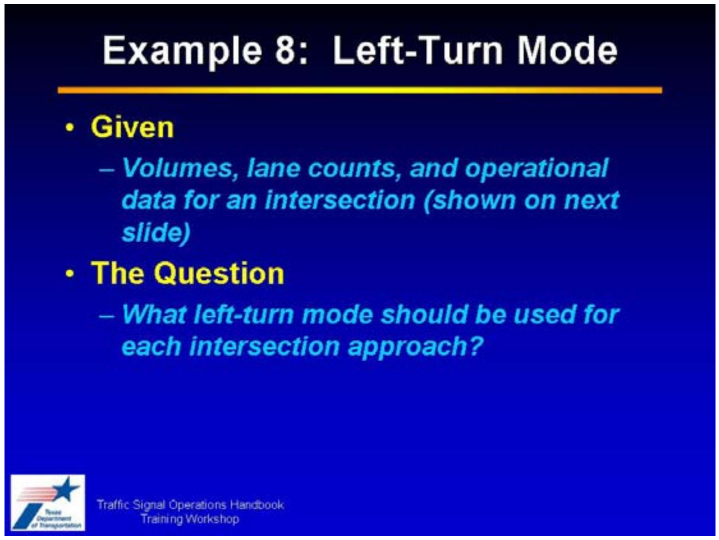
Click: As a result, the approach should have protected-permissive phasing.

Slide 136



Key Message:
Once the given data are entered, the left-turn mode can be determined for each approach.

Slide 137

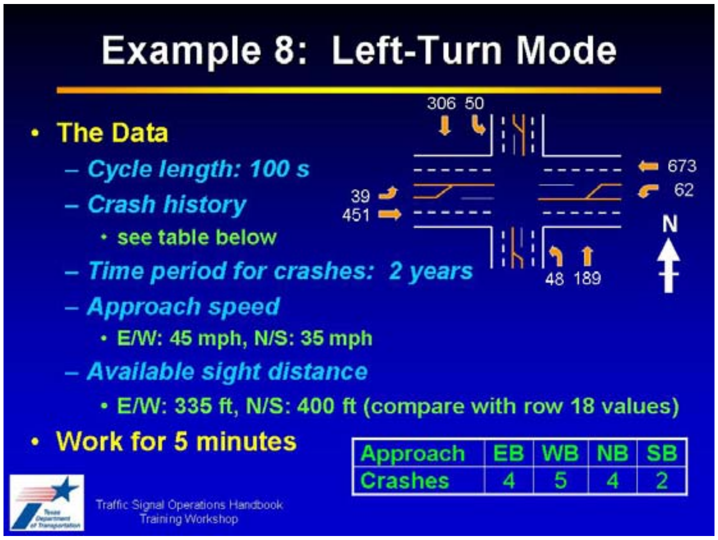


Key Message:
The TSCO Left-Turn Mode worksheet can be used to choose left-turn modes for the intersection approaches described by the given data.

Interactivity:
Tell: Go to page 108 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Ask: What left-turn mode should be used for each intersection approach?

Slide 138



Key Message:
The TSCO Left-Turn Mode worksheet can be used to choose left-turn modes for the intersection approaches described by the given data.

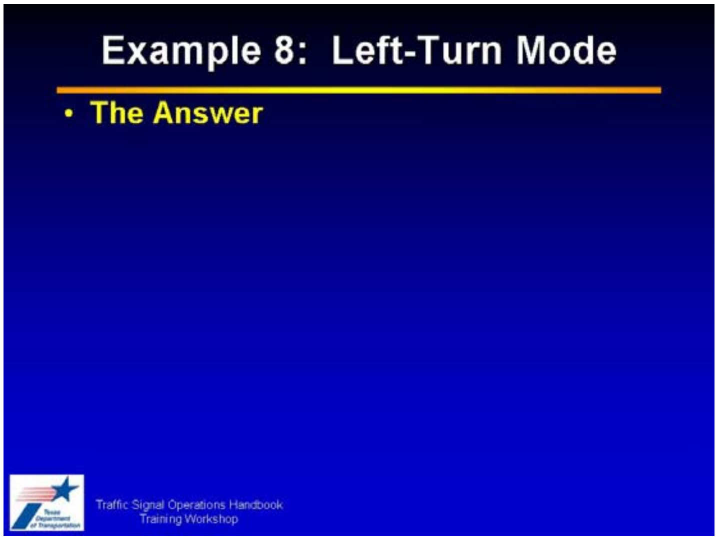
Interactivity:
Tell: The traffic volumes are the same as those from Examples 2, 5, and 6.

Tell: For this example, numbers are given for the sight distances for each approach. It will be necessary to compare the given sight distances with the required sight distances computed in row 18.

Tell: Spend about five minutes entering the given data into TSCO Left-Turn Mode worksheet.

Follow up: Leave the instructor's podium and walk around the room as the participants work on the exercise. Offer help to individual participants when needed. When the participants appear to have arrived at the correct answer, return to the instructor's podium and continue the workshop presentation.

Slide 139



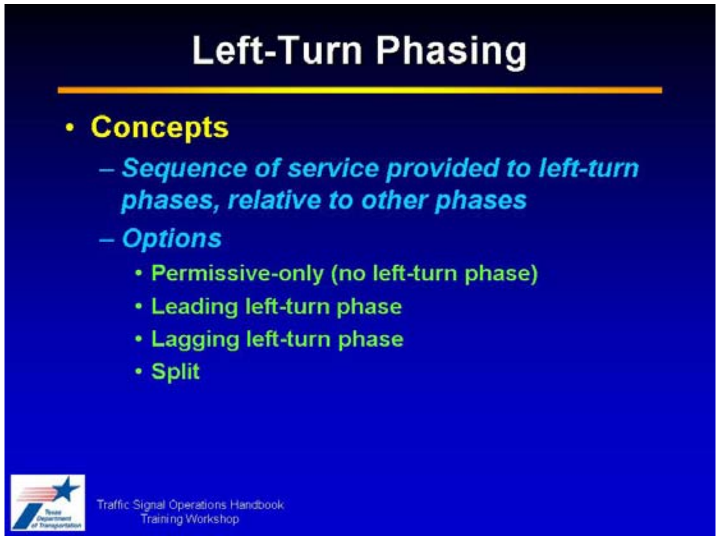
Key Message:
Once the given data are entered, the left-turn mode can be determined for each approach.

Interactivity:
Click: The recommended left-turn mode is protected for the east/west road and permissive for the north/south road.

Ask: Why is protected mode needed for the east/west road?

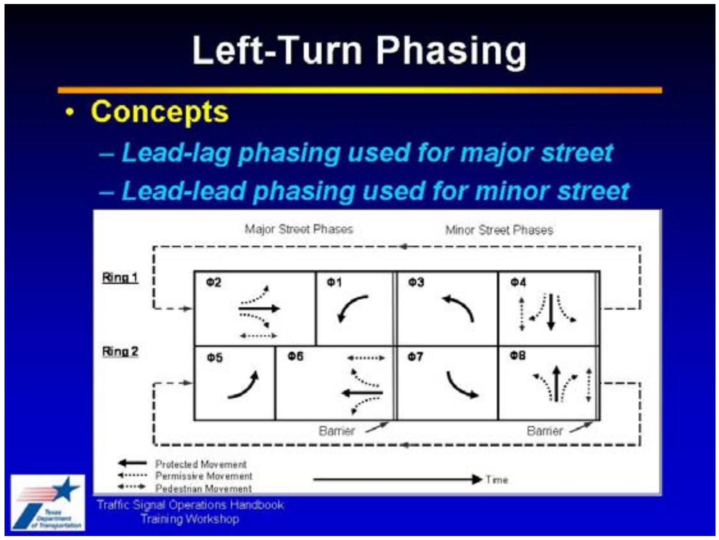
Tell: The east/west approaches do not have adequate sight distance for permissive left-turn maneuvers. The computed numbers in row 18 tell us that 360 feet of sight distance is needed, but according to the given data, we have only 335 feet.

Slide 140



Key Message:
Left-turn phasing refers to the sequence of service provided to left-turn phases, relative to other phases in the cycle. The options include permissive-only (i.e., no protected left-turn phase), leading, lagging, or split.

Slide 141

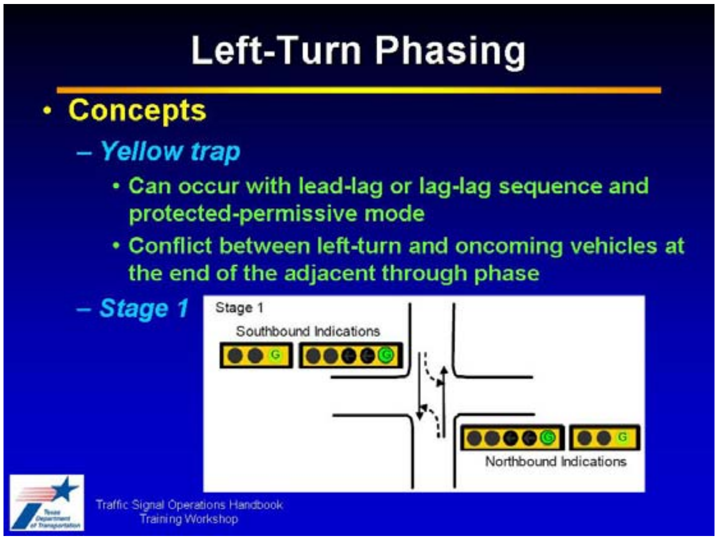


Key Message:
A left-turn phase is said to be leading if it occurs before the opposing through phase, or lagging if it occurs after the opposing through phase.

Interactivity:
Tell: In this example, lead-lag phasing is used for the major street. Note that phase 5 leads phase 6, but phase 1 lags phase 2. This type of phasing is often chosen to facilitate coordination.

Tell: In this example, lead-lead (or "dual lefts leading") phasing is used for the minor street. Both of the left-turn phases occur before their opposing through phase.

Slide 142

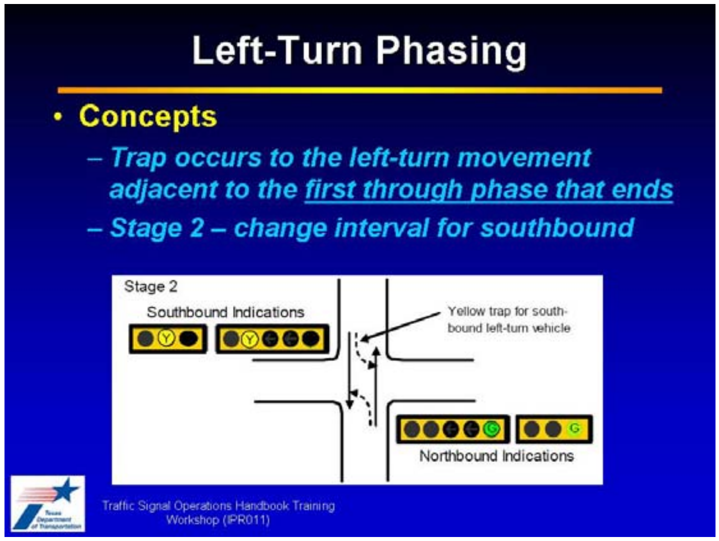


Key Message:
A yellow trap can occur when lead-lag or lag-lag phasing is used with protected-permissive mode. The yellow trap causes a conflict between left-turning and opposing through vehicles when the adjacent through phase ends.

Interactivity:
Tell: In this illustration labeled as stage 1, both through phases are being served, and left-turning vehicles on both approaches can turn permissively.

Tell: All signal heads are displaying a green ball indication.

Slide 143



Key Message:
A yellow trap can occur when lead-lag or lag-lag phasing is used with protected-permissive mode. The yellow trap causes a conflict between left-turning and opposing through vehicles when the adjacent through phase ends.

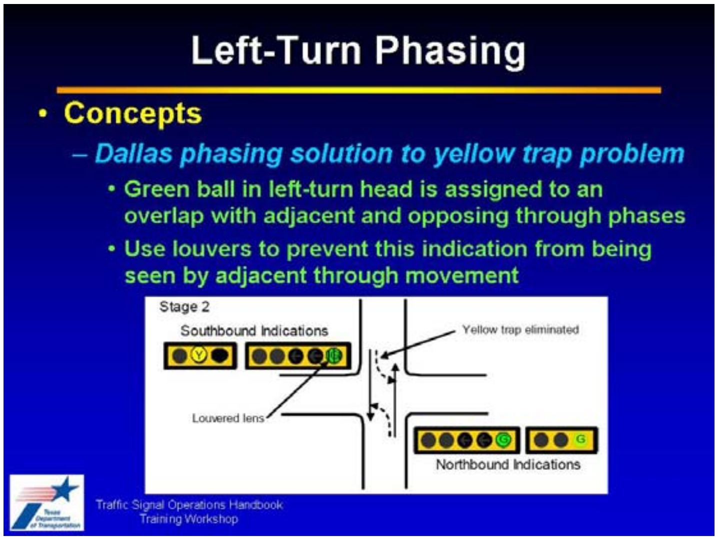
Interactivity:
Tell: In this illustration labeled as stage 2, both southbound signal heads are now displaying a yellow ball because service to the northbound protected left-turn phase is about to begin.

Tell: Drivers waiting to make the permissive southbound left turn just saw all signal indications on their approach go yellow. Under most circumstances (lead-lead protected-permissive phasing or permissive-only phasing), the entire approach is given a yellow ball when service to the perpendicular road is about to begin. In this case, the opposing through vehicles would also be presented with a yellow ball indication.

Tell: A southbound left-turning driver may rationalize that opposing through vehicles are about to stop. In this case, this assumption is wrong. The left-turning driver may choose a gap that is unacceptable because he expects an opposing through driver to decelerate and stop. A crash may occur.

Tell: The yellow trap occurs to the left-turn movement adjacent to the first through phase that ends. In this example, the trap occurs to the southbound left-turn movement.

Slide 144



Key Message:
One solution to the yellow trap problem is to use Dallas phasing.

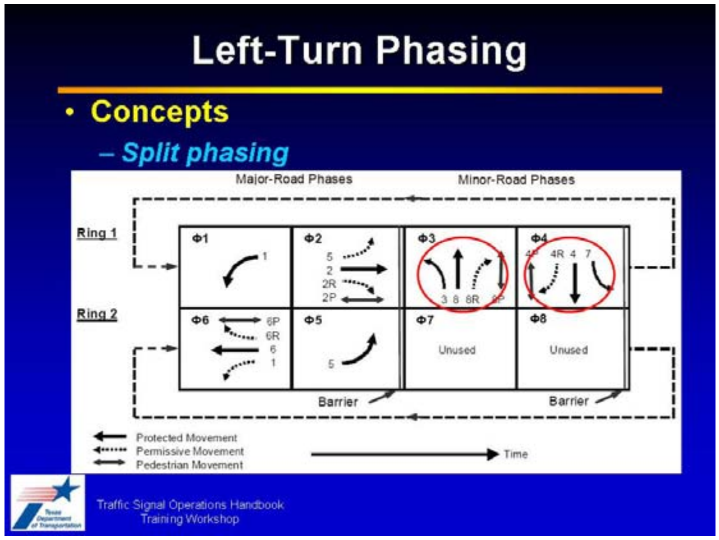
Interactivity:
Tell: We want to continue to allow the southbound left-turning drivers to turn permissively while the northbound through and left-turn phases are being served. Hence, we need to present them with a green ball indication.

Tell: With Dallas phasing, an overlap is used to connect the southbound left-turn green ball to the adjacent *and* opposing through phases. If either of these phases is presented with a green ball, the southbound left-turning drivers also see a green ball.

Tell: To avoid confusing the southbound through drivers (who may see the left-turn green ball displayed at the same time as their own yellow or red ball), it is necessary to louver the green ball so it cannot be seen by the southbound through drivers. With this arrangement, the five-section signal head is an exclusive left-turn signal head, not a shared left/through signal head.

Tell: Dallas phasing allows us to reclaim the most useful portion of the permissive left-turn capacity, which occurs near the end of the opposing through phase when queues are most likely to be dissipated. The left-turning drivers would see a green ball indication during this time if Dallas phasing is used. With traditional phasing, they would see a red ball and would be unable to turn.

Slide 145



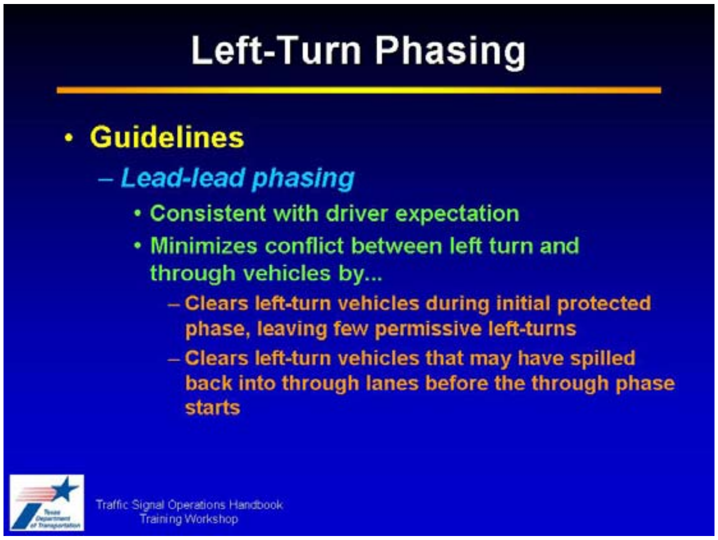
Key Message:
Split phasing is when all movements in one direction (left-turn and through) are served together, followed by all movements in the opposing direction.

Interactivity:
Tell: In this example, the northbound through and left-turning drivers are served at the same time, along with the pedestrians who will not conflict with the northbound left-turning vehicles.

Tell: The southbound through and left-turning drivers are then served, along with the pedestrians who will not conflict with the southbound left-turning vehicles.

Tell: This type of control can be achieved with a single-ring controller.

Slide 146

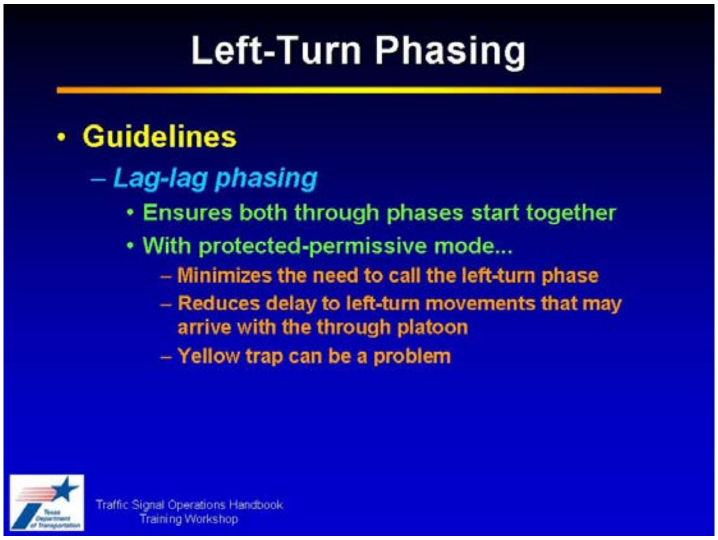


Key Message:
Lead-lead phasing is consistent with driver expectation, and it minimizes conflict between left-turning vehicles and the adjacent through vehicles.

Interactivity:
Tell: Lead-lead phasing is consistent with driver expectation. Historically, it has been the most commonly used phase sequence.

Tell: Lead-lead phasing clears many left-turning vehicles during the initial protected left-turn phase, leaving few vehicles to make permissive left turns. In the case of inadequate left-turn storage length (i.e., the left-turn bay is too short), it also allows left-turning drivers who have spilled back into the adjacent through lanes to clear the through lanes before the through phase starts. Hence, lead-lead phasing helps to reduce conflict between left-turn and adjacent through vehicles.

Slide 147



Key Message:
Lag-lag phasing ensures that both through phases start together. When it is used with the protected-permissive mode, it can also reduce the need to call the protected left-turn phase and reduce delay to left-turning vehicles that arrive with the through platoon.

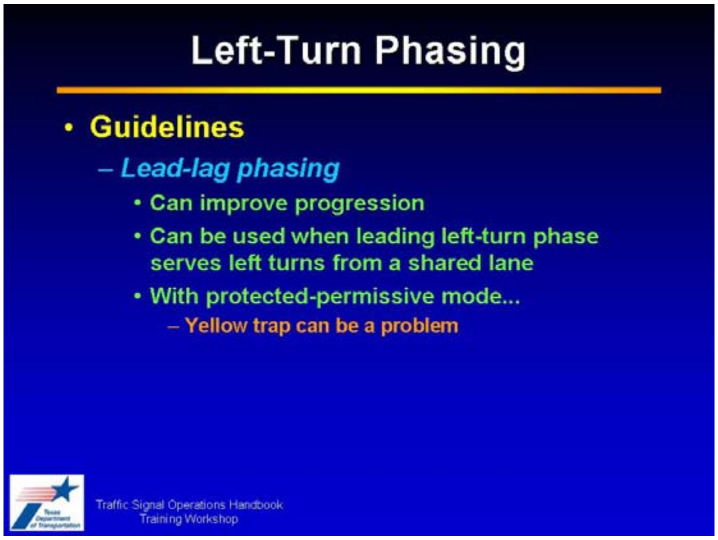
Interactivity:
Tell: When lag-lag phasing is used, the two through phases always start together.

Tell: Lag-lag phasing is sometimes used because it is desirable to avoid calling the protected left-turn phase when it is not needed. If drivers are able to turn left during the permissive period, the protected left-turn phase can be omitted and the time can be given back to the opposing through phase.

Tell: When lag-lag phasing is used in a coordinated system, left-turning drivers who arrive with the through platoon will not have to wait until the next cycle to make their turn, provided that the protected left-turn phase is long enough to serve all of the turning vehicles.

Tell: A yellow trap can occur with lag-lag phasing if the two through phases do not end simultaneously.

Slide 148



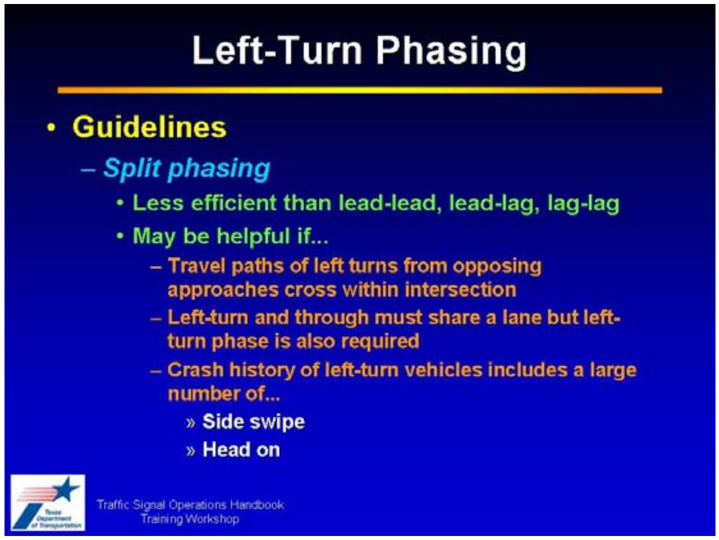
Key Message:
Lead-lag phasing is sometimes used in coordinated systems to increase progression bandwidth. It can also be used when the leading left-turn phase serves turning vehicles from a shared lane. If used with protected-permissive mode, a yellow trap will result.

Interactivity:
Tell: Lead-lag phasing can often improve progression bandwidth in coordinated signal systems. Because signal spacing is seldom ideal for progression, the platoons at a given intersection often tend to arrive at different times for each direction of travel. In these cases, it is desirable to have the green indication begin earlier for the platoon that arrives sooner. The green can be shifted earlier in the cycle by having the adjacent left-turn phase be lagging instead of leading.

Tell: Lead-lag phasing can be used when the leading left-turn phase serves turns from a shared through/left lane.

Tell: When lead-lag phasing is used with protected-permissive mode, a yellow trap will result for the left-turn phase adjacent to the through phase that ends first. This problem can be solved by using Dallas phasing.

Slide 149



Key Message:
Split phasing is usually less efficient than other types of left-turn phasing, but may be helpful if certain geometric constraints are present.

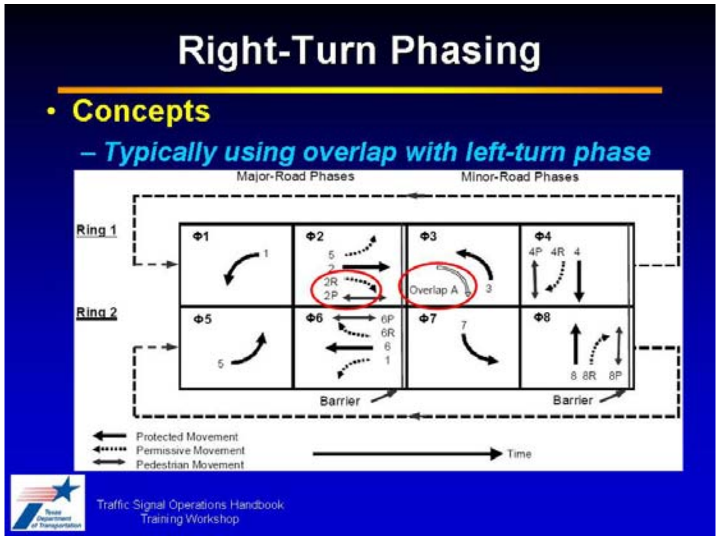
Interactivity:
Tell: For most typical volume conditions, split phasing is less efficient than lead-lead, lead-lag, or lag-lag phasing.

Tell: Split phasing may be useful if certain geometric constraints exist. For example, if the travel paths of left turns from opposing approaches conflict in the intersection, or if a left-turn phase is needed to serve a left-turn movement from a shared lane, split phasing may help.

Tell: Split phasing may also be justified if the crash history of left-turning vehicles at the intersection includes a large number of sideswipe or head-on crashes.

Tell: Generally, split phasing should not be used unless analysis shows that it would improve safety or efficiency, compared to other types of left-turn phasing.

Slide 150

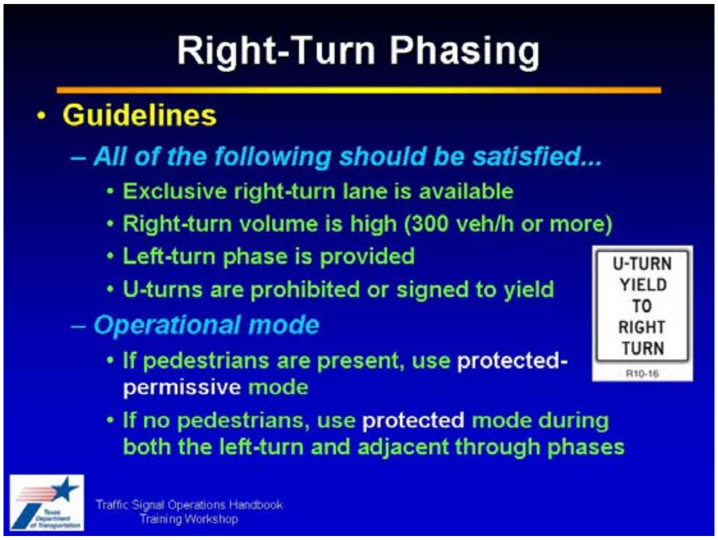


Key Message:
Right-turn phasing can be provided through the use of an overlap with the complementary left-turn phase.

Interactivity:
Tell: In this example, the eastbound right-turn movement is labeled as 2R. This movement is served permissively while phase 2 is served.

Tell: If additional capacity is needed for movement 2R, it can be served with a protected right-turn phase that runs concurrently with phase 3, the northbound left-turn phase.

Slide 151



Key Message:
Right-turn phasing may be used if right-turn volumes are sufficiently high, a turn bay exists to serve the movement, and the potential conflict with complementary u-turn movements is avoided.

Interactivity:
Tell: Right- turn phasing may be used if the right-turn movement is served with a turn bay, the volume is 300 veh/h or more, and the complementary left-turn movement is served with a protected phase.

Tell: Conflicts between right turns and u-turns can occur if right-turn phasing is used. For example, if the right-turn phase serves the eastbound right-turn movement, a conflict will occur if a northbound left-turning driver attempts a u-turn. Hence, u-turns from the complementary left-turn movement must be prohibited or signed to yield (i.e., using sign R10-16).

Tell: If pedestrians are present, operate the right-turn phase in protected-permissive mode. The protected phase occurs concurrently with the complementary protected left-turn phase.

Tell: If pedestrians are not present, operate the right-turn phase in protected mode during both the complementary left-turn phase and the adjacent through phase.

Slide 152

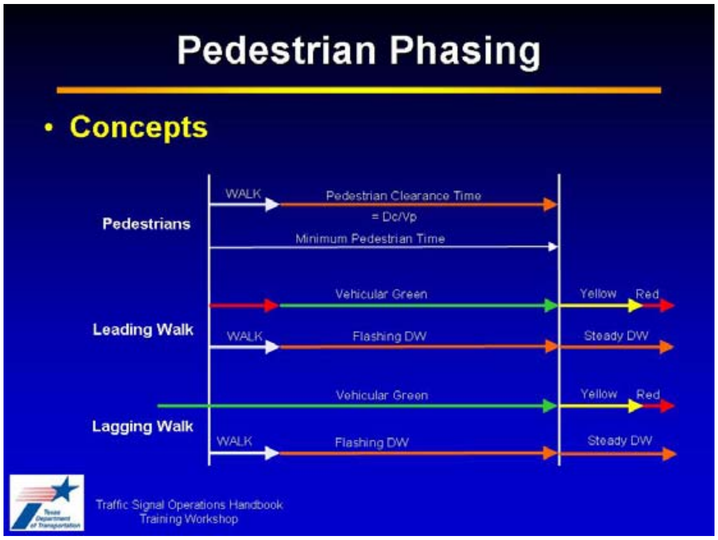
Key Message:
Pedestrians are typically served concurrently with the adjacent through movement. When a significant number of conflicts involving pedestrians occur, several pedestrian phasing options can be considered, including a leading or lagging pedestrian walk or an exclusive pedestrian phase.

Interactivity:
Tell: Pedestrians are typically served concurrently with the adjacent through movement. This phasing potentially puts pedestrians in conflict with turning vehicles. If the conflict is significant, alternative phasing may be considered.

Tell: Two alternative pedestrian phasing options include leading or lagging pedestrian walk. Both still involve pedestrians crossing concurrently with the adjacent through movement.

Tell: A third option is the exclusive pedestrian phase, which is an additional phase to serve only pedestrians. All vehicular movements that conflict with the subject pedestrian crossing are given a red indication. The fullest version of this option is the pedestrian scramble, where all vehicular movements are given a red indication and pedestrians are allowed to cross diagonally.

Slide 153



Key Message:
With a leading walk, pedestrians are allowed to begin crossing before the adjacent through movement is given its green indication. With a lagging walk, the adjacent through movement is given its green indication before pedestrians are allowed to begin crossing.

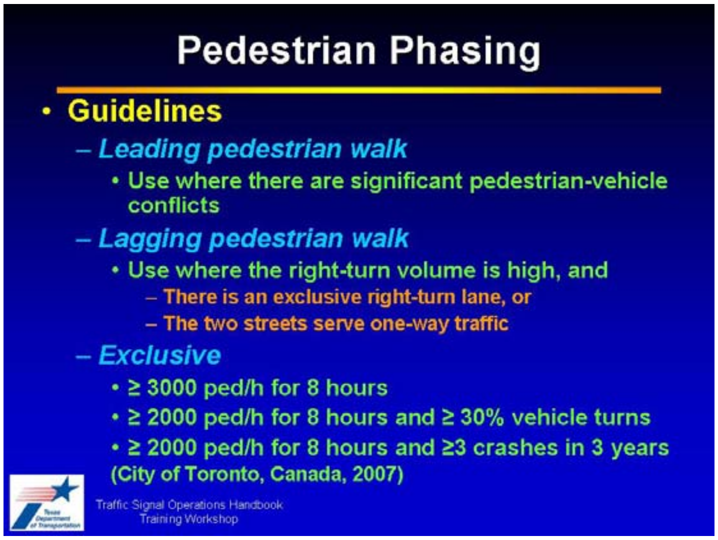
Interactivity:
Tell: The top portion of this diagram illustrates the basic pedestrian timing components—the WALK indication and the pedestrian clearance time. Pedestrian clearance is computed as crossing distance divided by walking speed, and includes the flashing and steady DON'T WALK indications.

Tell: The bottom two portions of this diagram illustrate the timing of the start of the WALK indication with respect to the adjacent through movement's green indication.

Tell: With a leading walk, the WALK indication begins during vehicular red. Pedestrians are allowed to establish a presence in the crosswalk before turning vehicles are given a green indication.

Tell: With a lagging walk, the WALK indication begins several seconds after the start of the green indication. Right-turning vehicles are given an opportunity to clear before pedestrians begin to cross, reducing the potential for conflict between pedestrians and right-turning vehicles.

Slide 154



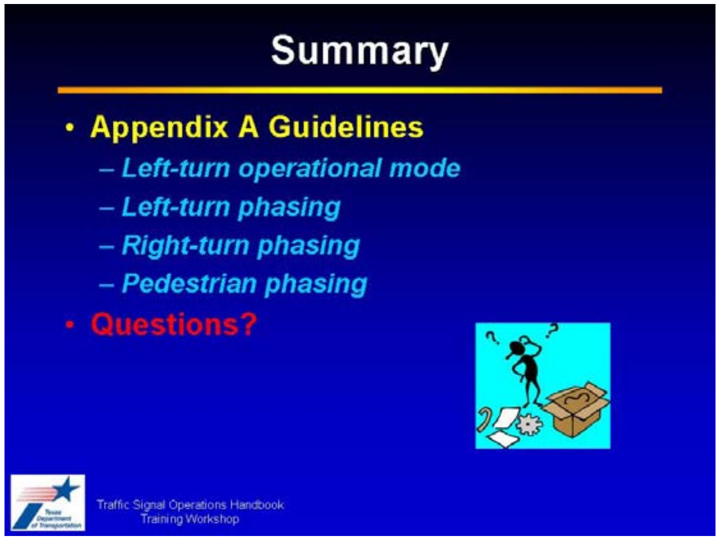
Key Message:
Alternative pedestrian phasing options may be used when justified, based on conflict occurrence and pedestrian and vehicular volumes.

Interactivity:
Tell: A leading pedestrian walk may be used where there are significant pedestrian-vehicle conflicts.

Tell: A lagging pedestrian walk may be used where right-turn volume is high, and either there is an exclusive right-turn lane or the two streets serve one-way traffic.

Tell: An exclusive pedestrian phase should only be considered where there is significant pedestrian volume for eight or more hours of the day, and if a large percentage of the vehicles are turning or the number of pedestrian-involved crashes has occurred.

Slide 155


Summary
• Appendix A Guidelines
– Left-turn operational mode
– Left-turn phasing
– Right-turn phasing
– Pedestrian phasing
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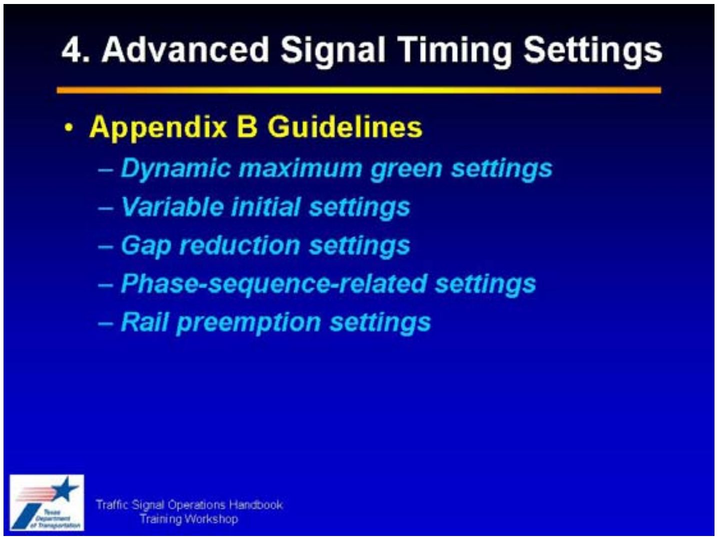
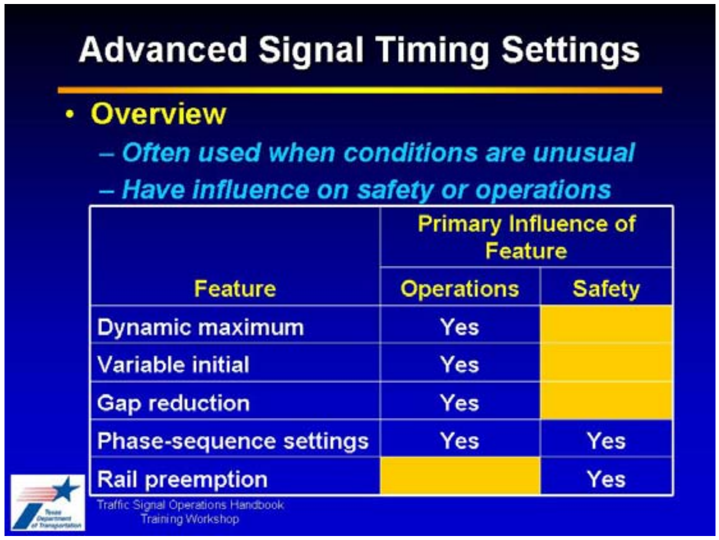


Key Message:
This lesson covers Appendix B of the *Handbook*. Appendix B focuses on advanced signal timing settings, including volume-density functions, phase-sequence-related settings, and rail preemption.

Slide 157



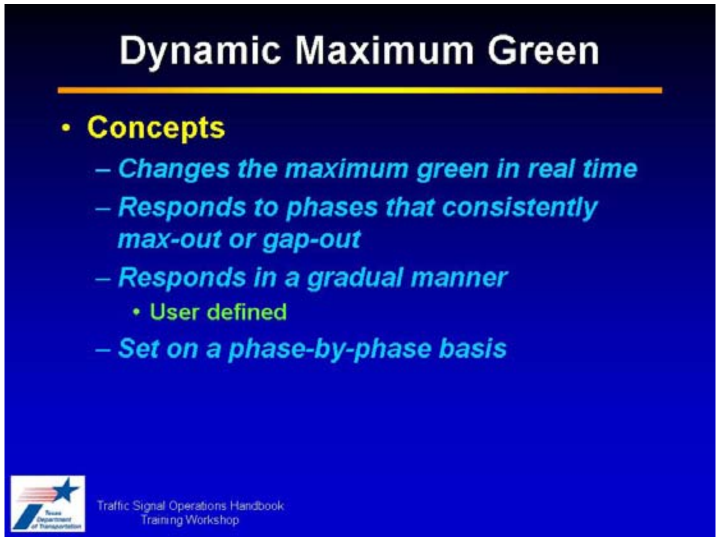
Key Message:
Advanced signal timing settings are often used when traffic or geometric conditions are unusual. The settings influence operations and/or safety, depending on the reason for their use.

Interactivity:
Tell: Dynamic maximum, variable initial, and gap reduction can be used to improve operations at actuated signalized intersections.

Tell: Phase-sequence-related settings (conditional service, simultaneous gap-out, and dual entry) can affect both operations and safety.

Tell: Rail preemption settings influence safety at highway-rail grade crossings.

Slide 158



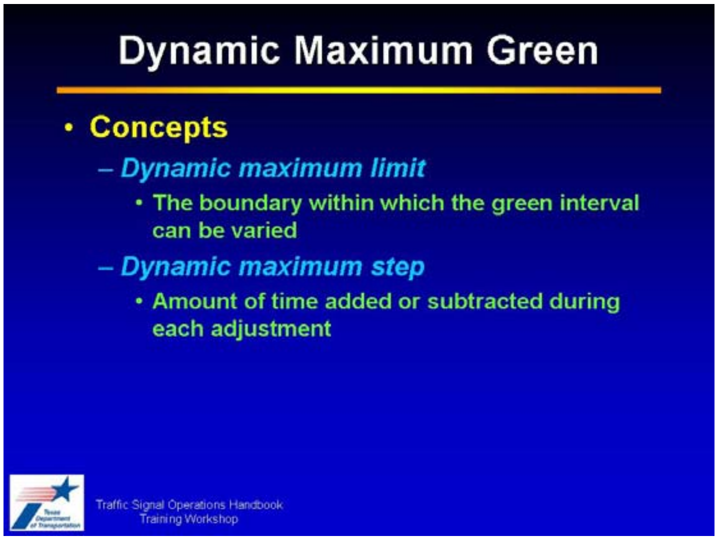
Key Message:
The dynamic maximum green feature increases the maximum green interval in real time, responding to phases that consistently max out or gap out.

Interactivity:
Tell: The dynamic maximum green feature increases the maximum green interval in real time. It responds by increasing the maximum green interval for phases that consistently max out or decreasing the maximum green interval for phases that consistently gap out.

Tell: The feature responds in a gradual manner, using parameters that are set by the user.

Tell: Dynamic maximum green is set on a phase-by-phase basis. It can be used differently for different phases, or used for only some of the phases at an intersection.

Slide 159



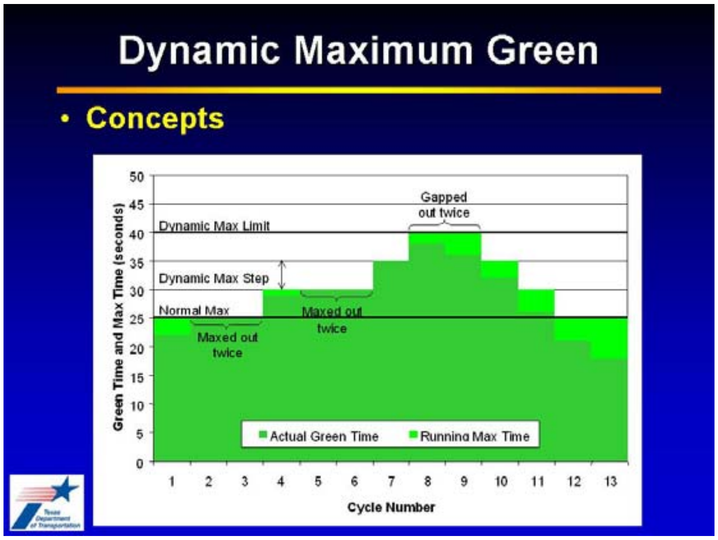
Key Message:
The operation of the dynamic maximum green feature is defined by the dynamic maximum limit and dynamic maximum step settings, which influence the bounds of the maximum green and the amount by which it can change between cycles.

Interactivity:
Tell: The dynamic maximum limit is used in tandem with the normal maximum green interval to define the upper and lower bounds of the maximum green. The longer of the two values is the upper limit, and the shorter of the two values is the lower limit.

Tell: The dynamic maximum step is the amount of time that may be added to or subtracted from the maximum green between subsequent cycles. Larger step values will allow the maximum green to change more rapidly.

Tell: By default, both of these settings are zero. Programming non-zero values invokes the dynamic maximum green feature for the relevant phase.

Slide 160



Key Message:
Adjustments to the maximum green are triggered when the phase maxes out or gaps out in two sequential cycles, and continues every cycle until max-out or gap-out stop occurring.

Interactivity:
Tell: In this graph, the x-axis represents cycle number and the y-axis represents the green time for the phase of interest. The change in maximum green is plotted for 13 cycles.

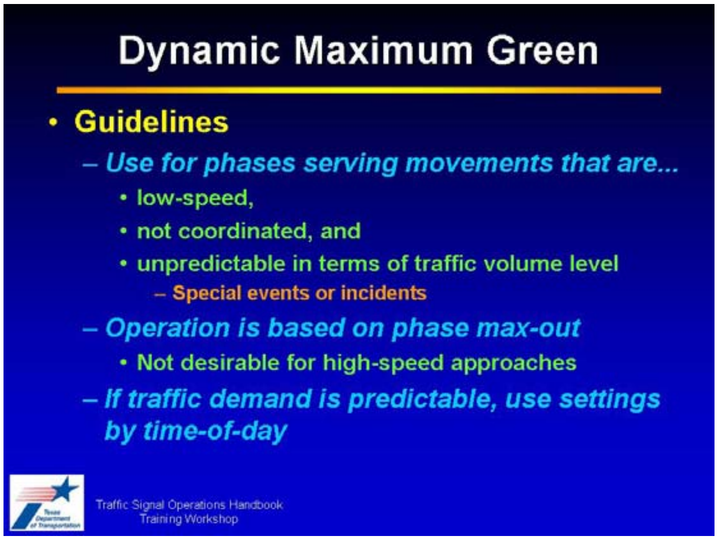
Tell: The two thick horizontal lines represent the normal maximum green interval (25 s) and the dynamic maximum limit (40 s). The dynamic maximum step is programmed as 5 s.

Tell: The dark green represents the actual green time that is observed at the intersection. The light green represents the maximum green for the cycle of interest. Note that both of these values increase, and then decrease, correlating with a traffic volume that increases and decreases with time.

Tell: During cycle 1, the maximum green is 25 s, but the green time only extends to 22 s. During cycles 2 and 3, the green time runs to the maximum of 25 s. The maximum green is then increased to 30 s for cycle 4. Max-out again occurs during cycles 5 and 6, causing the maximum green to increase to 35 s. Max-out again occurs during cycle 7, causing the maximum green to increase to 40 s, which is the dynamic maximum limit.

Tell: Gap-out occurs during cycles 8 and 9. As a result, the maximum green is reduced to 35 s. Gap-out continues to occur for the rest of the cycles, causing the maximum green to be reduced by 5 s each cycle until it reaches its lower bound of 25 s.

Slide 161



Key Message:
Dynamic maximum green is appropriate for phases serving movements that are low-speed, not coordinated, and unpredictable in terms of traffic volume.

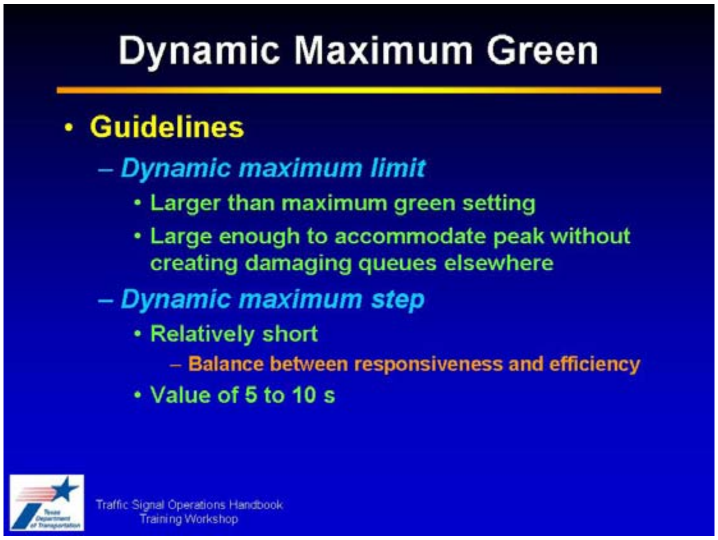
Interactivity:
Tell: Consider dynamic maximum green for movements that are low-speed, not coordinated, and unpredictable in terms of traffic volume. For example, special events or incidents can cause unpredictable changes in traffic volume that could be accommodated through the use of dynamic maximum green.

Tell: The operation of the dynamic maximum green feature depends on the occurrence of phase max-out. Hence, the feature should not be used in situations where max-out is undesirable, such as on high-speed approaches where indecision zone protection is desired.

Tell: If traffic demand is variable but predictable, the maximum green should be adjusted through the use of time-of-day settings rather than the dynamic maximum green feature.

Tell: The dynamic maximum green feature is essentially disabled if frequent max-outs occur, such as if maximum recall is used or a detector fails.

Slide 162



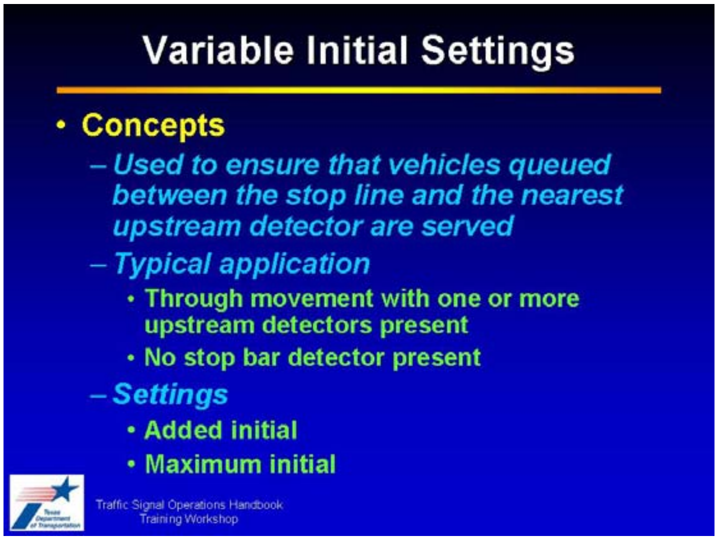
Key Message:
The dynamic maximum limit should be large enough to accommodate traffic volume peaks without causing excessive queuing on other movements. The dynamic maximum step should be relatively short, such that it can yield responsive and efficient operation.

Interactivity:
Tell: Set the dynamic maximum limit larger than the normal maximum green interval. That way, by convention, the dynamic maximum limit always functions as the upper bound for the maximum green.

Tell: The dynamic maximum limit should be large enough to accommodate the "design" peak traffic demand, but not so large that it can induce the formation of excessive queues on other movements. A practical upper limit is 70 s.

Tell: The dynamic maximum limit should be relatively short, such that a balance between responsiveness and efficiency can be achieved. Values of 5 or 10 s will suffice in most cases.

Slide 163

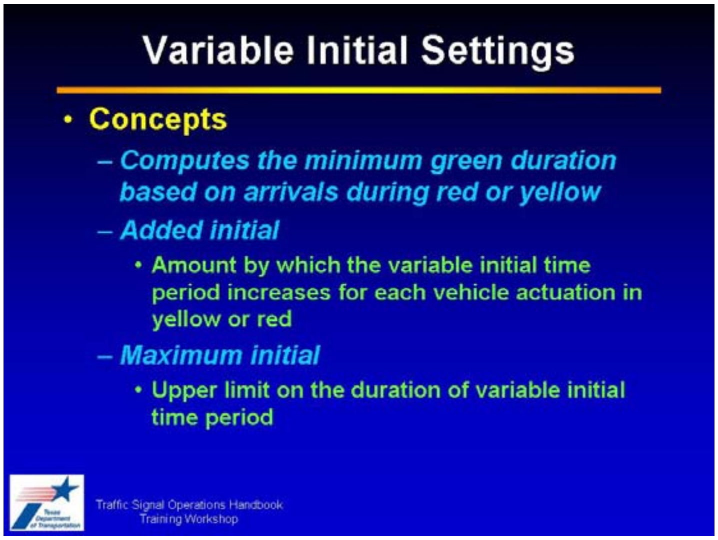


Key Message:
The variable initial feature is used to ensure that vehicles queued between the stop line and the nearest upstream detector are served before the green ends.

Interactivity:
Tell: If no stop line detection is used, the controller cannot detect vehicles stopped between the stop line and the nearest upstream detector. In this case, the phase may prematurely gap out before the initial queue clears.

Tell: Variable initial is set on a phase-by-phase basis by programming the added initial and maximum initial settings.

Slide 164



Key Message:
Variable initial computes the minimum green duration for each cycle based on counts of vehicles arriving during yellow or red.

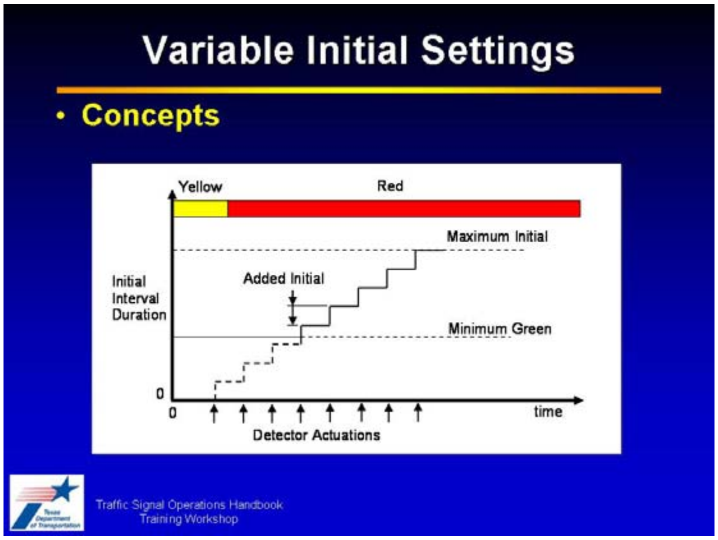
Interactivity:
Tell: Variable initial computes the minimum green duration for each cycle based on counts of vehicles arriving during yellow or red. If enough vehicles arrive on a given cycle, the minimum green duration for the cycle may be longer than the programmed minimum green.

Tell: Added initial is the amount by which the variable initial time increases for each vehicle actuation during yellow or red.

Tell: Maximum initial is the upper limit on the duration of the variable initial time. In other words, it is the upper limit on the minimum green duration.

Tell: By default, the added initial and maximum initial settings for each phase are zero. The variable initial feature is invoked by programming non-zero values.

Slide 165



Key Message:
The operation of the variable initial feature is determined by the setting of the added initial and maximum initial settings.

Interactivity:
Tell: In this graph, the x-axis represents cycle time and the y-axis represents the initial interval duration, or the minimum green duration as it is continually adjusted by the variable initial feature.

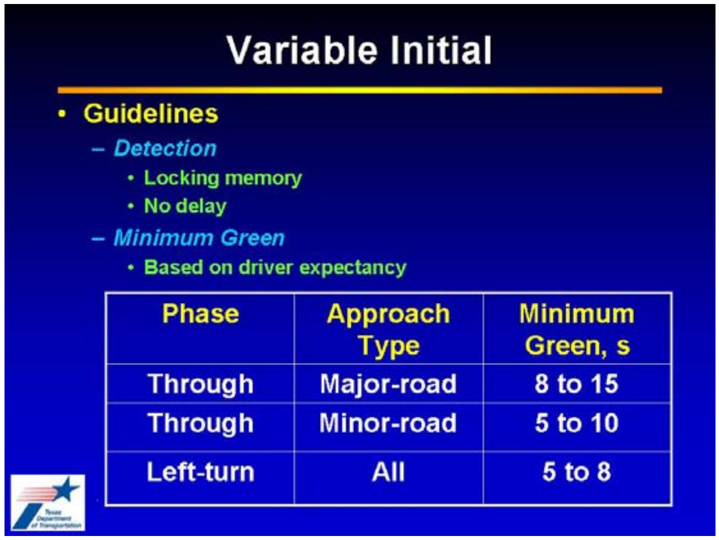
Tell: The time period shown in the graph is the start of yellow through the end of red. Vehicles arrive during this period and stop to wait for the green. The detector actuations that occur with the vehicle arrivals are shown as arrows at the bottom of the graph.

Tell: The two horizontal lines on the graph represent the normal minimum green interval and the maximum initial setting. The initial interval duration can vary between these two values, depending on the number of detector actuations.

Tell: The stair-step line in the graph represents the adjustments being made to the initial interval duration as vehicles arrive. Each detector actuation causes the initial interval to increase by an amount equal to the added initial setting.

Tell: The first three actuations were insufficient to cause the initial interval to increase above the normal minimum green interval. However, each of the next five actuations caused the initial interval to increase until it was capped by the maximum initial setting.

Slide 166

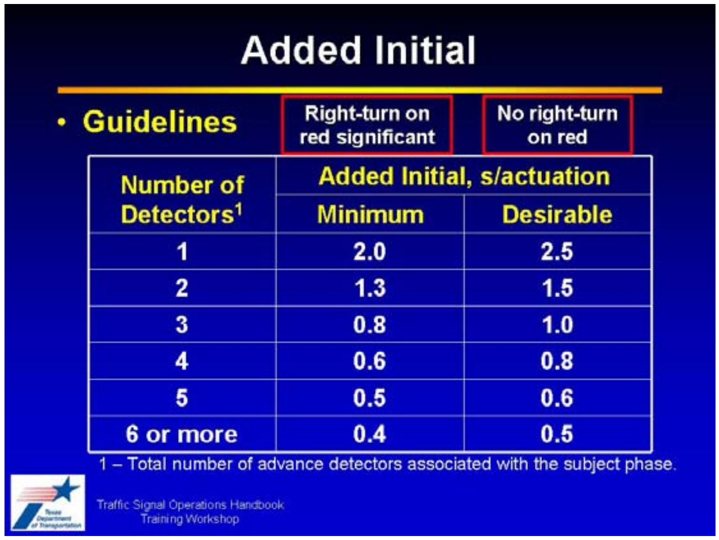


Key Message:
To use variable initial, the detection must have locking memory and no delay. The minimum green interval should be set using the lower end of the values needed to satisfy driver expectancy.

Interactivity:
Tell: For variable initial to work, the detection memory must be locking, and no delay must be used. Otherwise, vehicle arrivals would not be detected.

Tell: When variable initial is used, the minimum green intervals based on driver expectancy should be used. These values were covered in Lesson 1 and are found in Table 2-3 of the *Handbook*. The lower end of the ranges in Table 2-3 should be used because the variable initial feature will increase the minimum green duration as needed.

Slide 167



Key Message:
The added initial setting is influenced by the number of detectors used and the amount of right-turn-on-red volume.

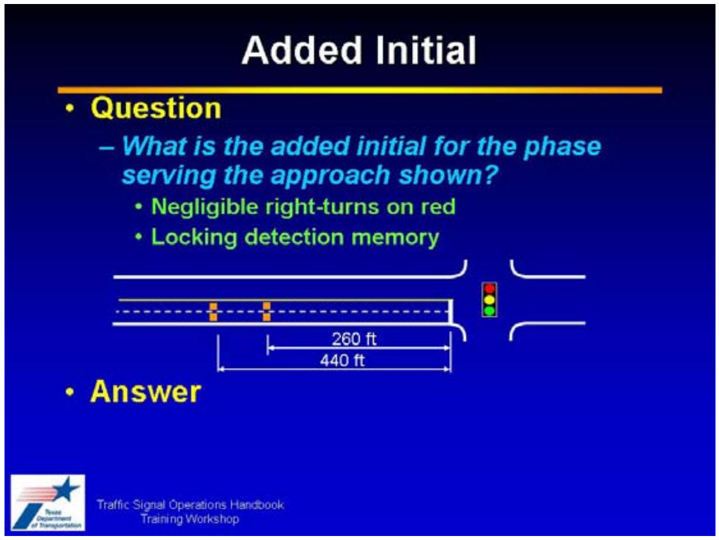
Interactivity:
Tell: Added initial is measured in seconds per detector actuation. If the phase has more detectors, the added initial setting should be smaller because each vehicle will cause more actuations.

Tell: The added initial should be shorter if the phase has a large amount of right-turn-on-red volume. These vehicles depart on red, so it is not necessary to extend the green for them.

Click: Use the minimum values in the table if right-turn-on-red volume is significant.

Click: Use the desirable values in the table if right-turn-on-red volume is negligible.

Slide 168



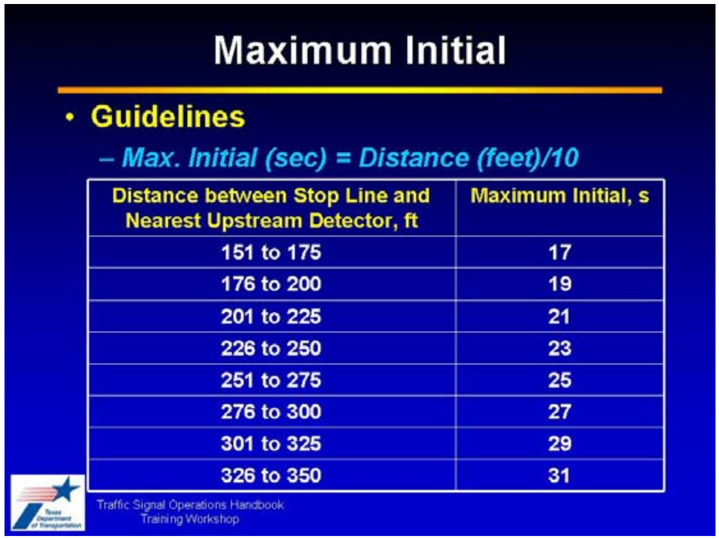
Key Message:
The added initial setting is influenced by the number of detectors used and the amount of right-turn-on-red volume.

Interactivity:
Ask: What is the added initial for the phase serving the illustrated approach?

Tell: Right-turn-on-red volume is negligible. There are four detectors, and they are programmed with locking memory.

Click: The added initial is 0.8 s. That value comes from the "desirable" column in the table.

Slide 169

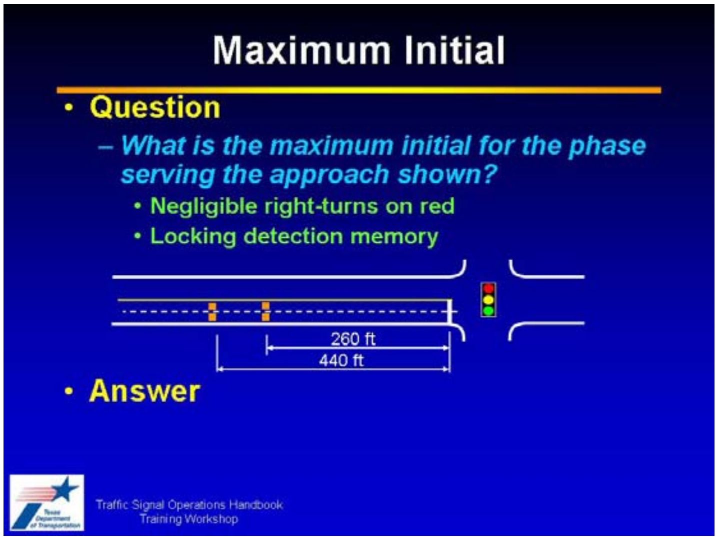


Key Message:
The maximum initial setting is based on the distance between the stop line and the nearest upstream detector. A rule of thumb is to set this value equal to the distance to the detector divided by 10.

Interactivity:
Tell: The maximum initial setting is based on the distance between the stop line and the nearest upstream detector. It should be long enough to allow vehicles queued within this distance to clear before the end of green. Vehicles queued on or beyond the nearest detector can extend the phase through their detector actuations.

Tell: Use the given table to set the maximum initial. A rule of thumb is to set the maximum initial equal to the distance between the stop line and the nearest upstream detector divided by 10.

Slide 170



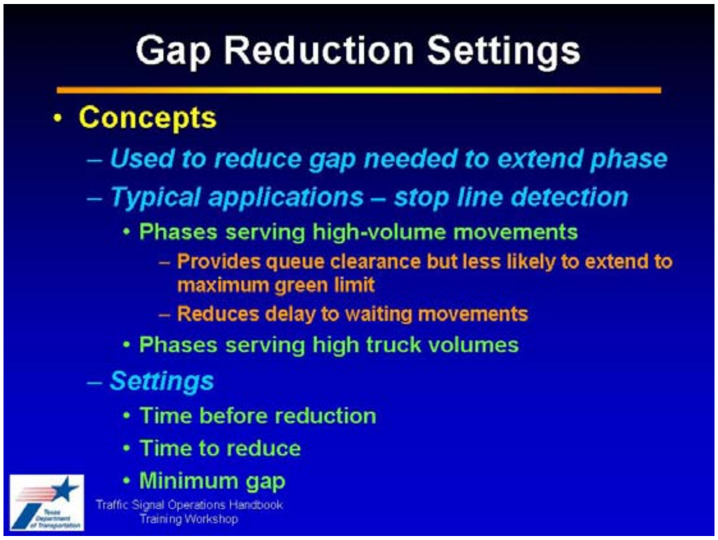
Key Message:
The maximum initial setting is based on the distance between the stop line and the nearest upstream detector.

Interactivity:
Ask: What is the maximum initial for the phase serving the illustrated approach?

Tell: The distances to the detectors are shown on the diagram.

Click: If the table is used, the maximum initial is 25 s. If the rule of thumb is used, the maximum initial is 26 s. This is based on the distance of 260 feet to the nearest detectors.

Slide 171



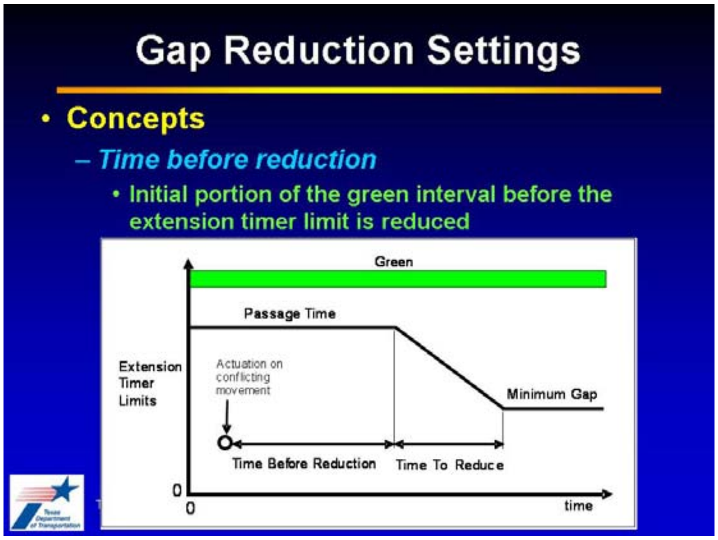
Key Message:
The gap reduction feature is used to reduce the length of the gap that is needed to extend a green indication. It is used on high-volume movements that have stop line detection, and tends to reduce delay to other movements by reducing max-out frequency.

Interactivity:
Tell: Normally, the gap needed to extend a green indication is the passage time (plus the extend time for the detector, if used). On high-volume movements or movements serving many trucks, frequent green extensions will increase delay to waiting vehicles on other movements, and may also increase max-out frequency to unacceptable levels.

Tell: The gap reduction feature makes it possible to reduce the gap needed to extend the green indication to values lower than the passage time. This strategy still allows queue clearance but is less likely to cause max-out.

Tell: Gap reduction is set by programming the time before reduction, time to reduce, and minimum gap settings. These settings are programmed on a phase-by-phase basis.

Slide 172



Key Message:
Time before reduction is the portion of the green interval that elapses before the extension timer limit is reduced.

Interactivity:
Tell: In this graph, the x-axis represents time, starting with the start of the green interval. The y-axis represents the extension timer limit. The extension timer limit is the largest amount of time that may elapse between detector actuations before the green is ended by gap-out.

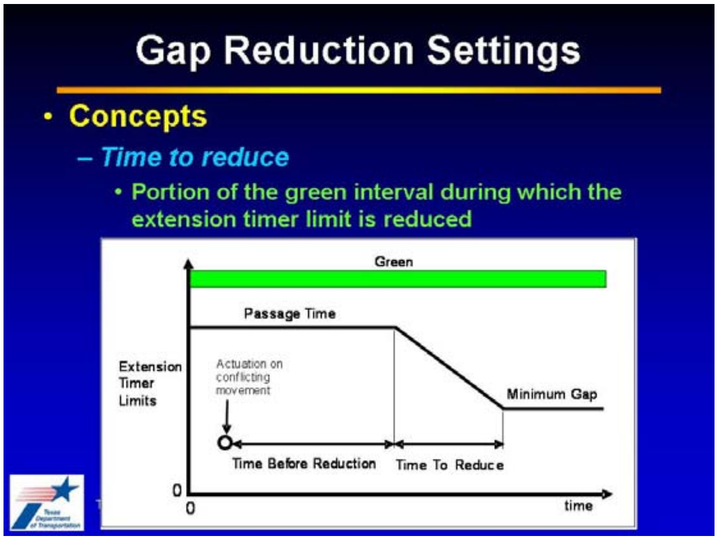
Tell: The extension timer limit begins at a value equal to the passage time before the gap reduction feature begins to reduce the limit.

Tell: Time before reduction is the amount of time that may elapse before the gap reduction feature begins to reduce the extension timer limit. The measurement of time before reduction begins when a detector actuation is received on a conflicting movement.

Tell: In this example, an actuation on a conflicting movement is received shortly after the start of green. The extension timer limit remains equal to the passage time until about the middle portion of the graph. At this point, the time before reduction has elapsed and the extension timer limit begins to increase, making it easier to end the green indication by gap-out.

Tell: The default value for this setting is zero. The gap reduction feature is invoked by programming a nonzero value.

Slide 173



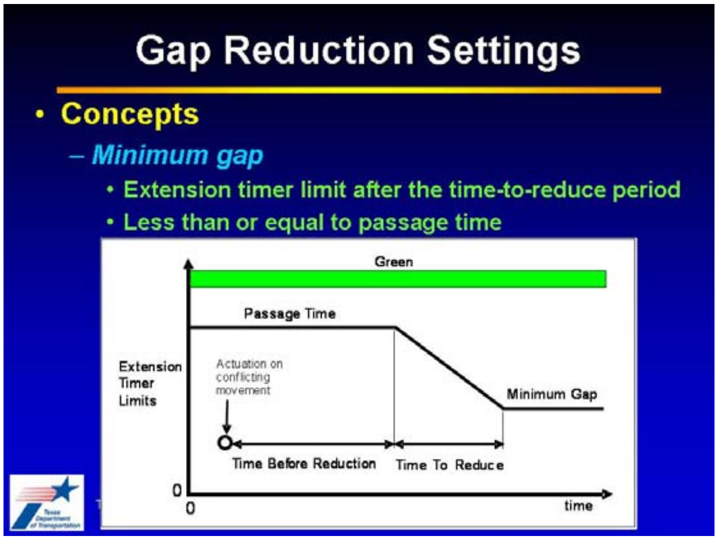
Key Message:
Time to reduce is the amount of time (during the green interval) when the extension timer limit is reduced. The reduction begins when the time before reduction has elapsed.

Interactivity:
Tell: In this example, the time before reduction elapses at the middle of the graph. An actuation on a conflicting movement has been received, but traffic volumes on our phase are high enough that the green has continued to be extended beyond the time before reduction.

Tell: During the time to reduce, the extension timer limit is reduced in a linear fashion until it reaches the minimum gap. Hence, it gradually becomes easier to end the green interval by gap-out.

Tell: The default value for this setting is zero. The gap reduction feature is invoked by programming a nonzero value.

Slide 174



Key Message:
Minimum gap is the extension timer limit after the time-to-reduce period has elapsed. It represents the shortest gap that is considered acceptable to end the green interval.

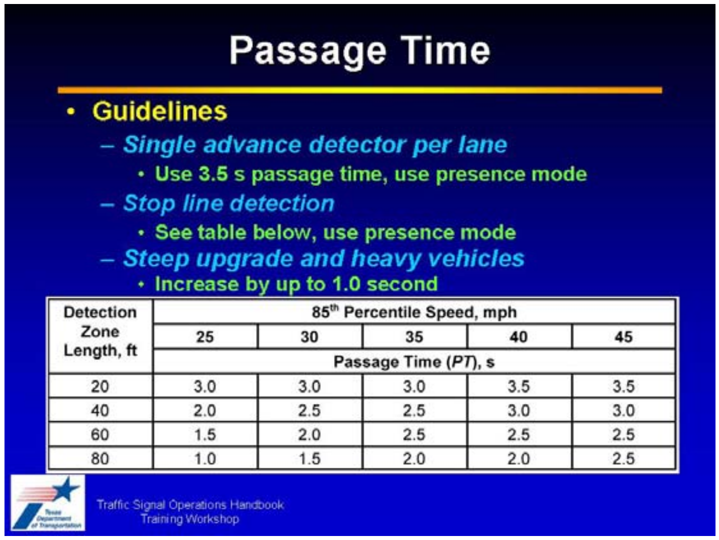
Interactivity:
Tell: In this example, the time to reduce elapses and the green interval still has not been ended. The green interval can still be extended to max-out, but now gaps as short as the minimum gap will be sufficient to end the green interval by max-out.

Tell: The minimum gap can be seen as the horizontal line on the right side of the graph.

Tell: The time to reduce and minimum gap settings determine the slope of the diagonal portion of the line. The extension timer limit will be reduced faster if the time to reduce is shorter or the minimum gap is lower.

Tell: The default value for this setting is the passage time (i.e., the gap is never reduced below the passage time). The gap reduction feature is invoked by programming a value that is less than the passage time.

Slide 175



Key Message:
The gap reduction feature may be used on approaches that have only stop line detection or a single advance detector in each lane. The setting of the passage time is influenced by the detection layout.

Interactivity:
Tell: If there is one advance detector present in each lane, and no stop line detection is used, set the passage time equal to 3.5 s.

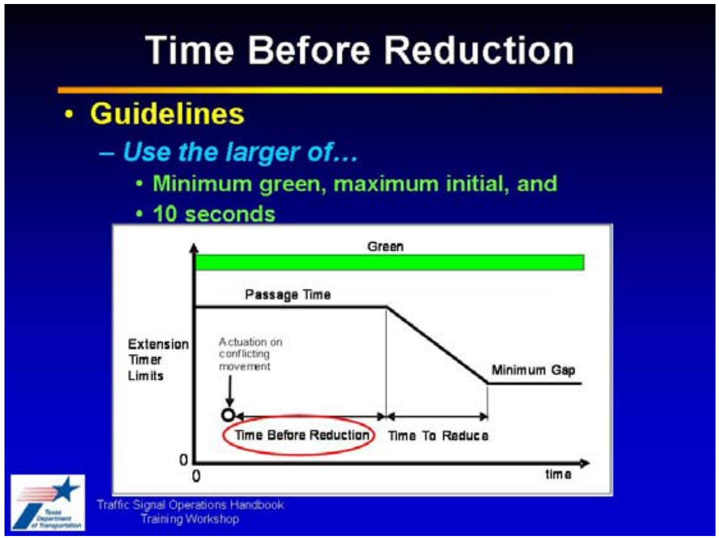
Tell: If only stop line detection is used, set the passage time using Table B-4 in the *Handbook*. Passage time should increase with higher vehicle speeds and decrease with longer detection zones.

Tell: The passage time can be increased by up to 1 s if a steep upgrade and/or a large percentage of heavy vehicles are present.

Tell: To apply this guidance, use presence mode, not pulse mode.

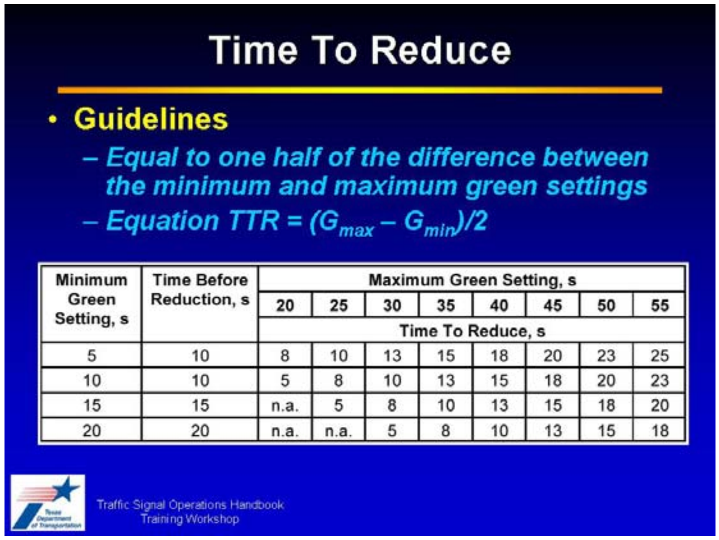
Tell: Gap reduction should not be used on high-speed approaches that have advance detection for indecision zone protection.

Slide 176



Key Message:
The time before reduction should be the larger of the minimum green, the maximum initial (if variable initial is used), and 10 s.

Slide 177

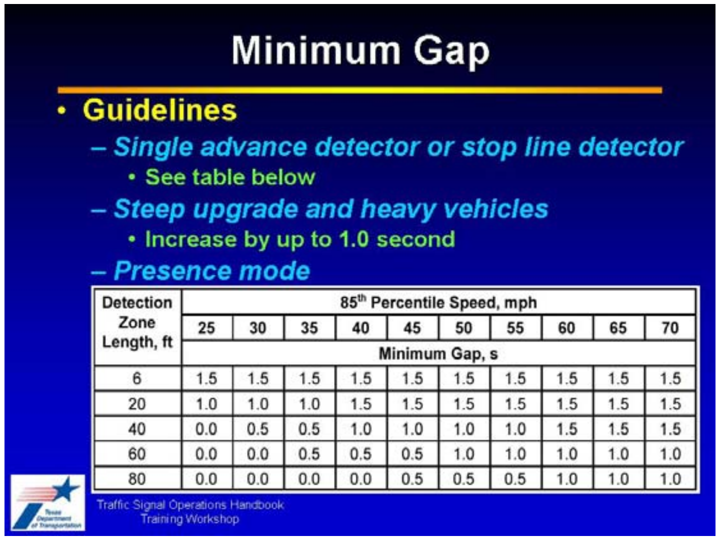


Key Message:
Time to reduce should equal half the difference between the minimum and maximum green intervals.

Interactivity:
Tell: Time to reduce should equal half the difference between the minimum and maximum green intervals. This guidance is shown in the right portion of Table B-5 in the *Handbook*.

Tell: The guidance on time before reduction that was covered in the previous slide is also included in Table B-5.

Slide 178



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

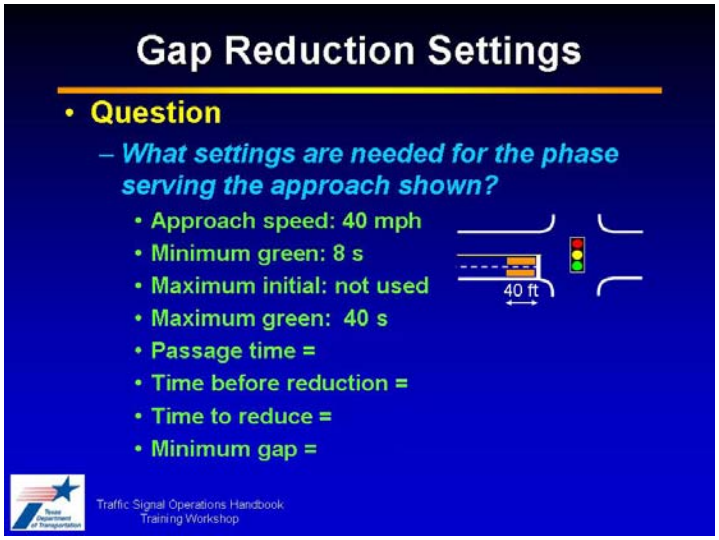
Key Message:
Minimum gap should be set between 0 and 1.5 s, depending on detection zone length and vehicle speeds.

Interactivity:
Tell: If a single advance detector in each lane is used, or if only stop line detection is used, obtain the minimum gap setting from Table B-6 in the *Handbook*.

Tell: The minimum gap can be increased by up to 1 s if a steep upgrade and/or a large percentage of heavy vehicles are present.

Tell: To apply this guidance, use presence mode, not pulse mode.

Slide 179



Key Message:
The guidelines in Appendix B of the *Handbook* can be used to determine the gap reduction settings for the given example intersection approach.

Interactivity:
Ask: What gap reduction settings are needed for the example intersection approach?

Tell: Take a few minutes to use Tables B-4 through B-6 in the *Handbook* to determine the settings.

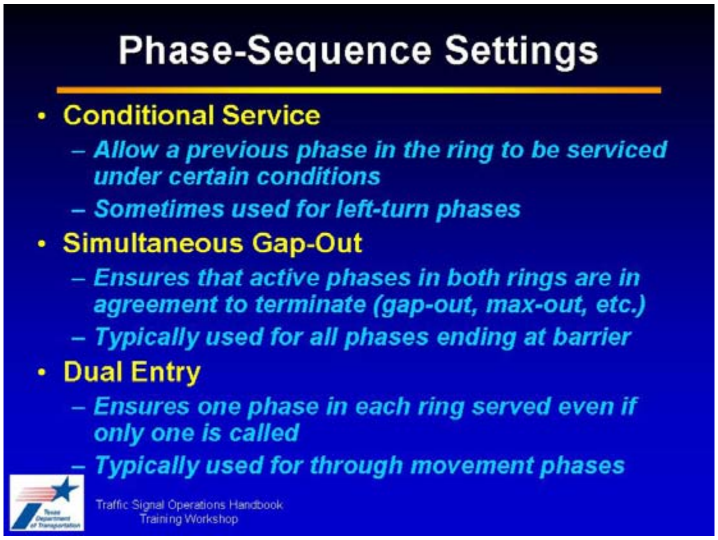
Click: Passage time is 3.0 s (from Table B-4).

Click: Time before reduction is 10 s (from Table B-5).

Click: Time to reduce is 15 s (from Table B-5).

Click: Minimum gap is 1.0 s (from Table B-6).

Slide 180



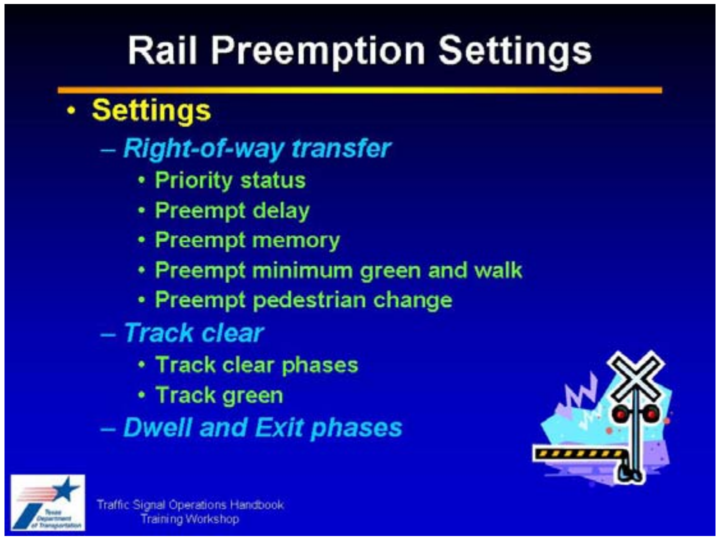
Key Message:
Phase-sequence-related settings are available to improve efficiency and safety.

Interactivity:
Tell: Conditional service allows a phase to be served twice in a cycle. It is sometimes used for left-turn phases that have heavy volumes. For example, if conditional service is enabled for phase 1, it can be served both before and after phase 2.

Tell: Simultaneous gap-out ensures that all active phases in both rings are in agreement to terminate, and then all are terminated at the same time. The reason for termination may differ among the phases. For instance, one phase may be terminating due to gap-out and another may be terminating due to max-out. This feature is typically used for phases that end together at a barrier.

Tell: Dual entry ensures that concurrent phases in both rings are served even if a call is received for only one of the phases. This feature is typically used for through-movement phases. For example, if phases 4 and 8 are set for dual entry, both will be served together, even if a call is received only for phase 4.

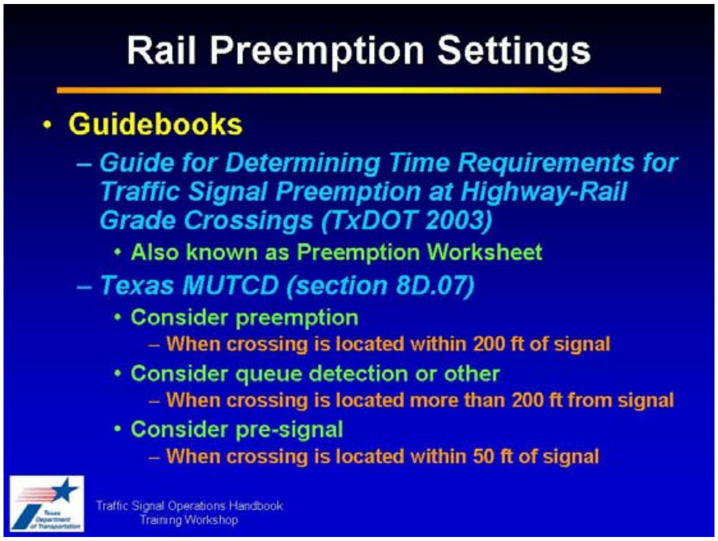
Slide 181



Key Message:
To determine proper rail preemption settings, it is necessary to consider several issues. First, right-of-way must be transferred to the signal phase serving the intersection leg that crosses the tracks. Then, sufficient track clearance green must be provided to allow queued vehicles to clear the tracks. Finally, the dwell and exit phases that run during and after the passing of the train must be programmed.

Background:
The scope of this rail preemption discussion is at-grade highway-rail crossings in close proximity to a signalized intersection. Rail preemption can be thought of as a "supply and demand" analysis, where the "supply" is the right-of-way transfer time and track clearance green time available and the "demand" is the amount of these times needed given the parameters of the site.

Slide 182



Key Message:
The primary guidebook for rail preemption settings is the *Guide for Determining Traffic Signal Preemption at Highway-Rail Grade Crossings* by Engelbrecht et al. This guidebook contains the "preemption worksheet" that is currently used by TxDOT. TSCO has a Preemption worksheet that is a spreadsheet implementation of the preemption worksheet.

Interactivity:
Tell: The graphic on this slide shows the type of intersection to be analyzed in the following slides. The signalized intersection is in close proximity to the rail crossing. The main street runs east/west, and the crossing street runs north/south.

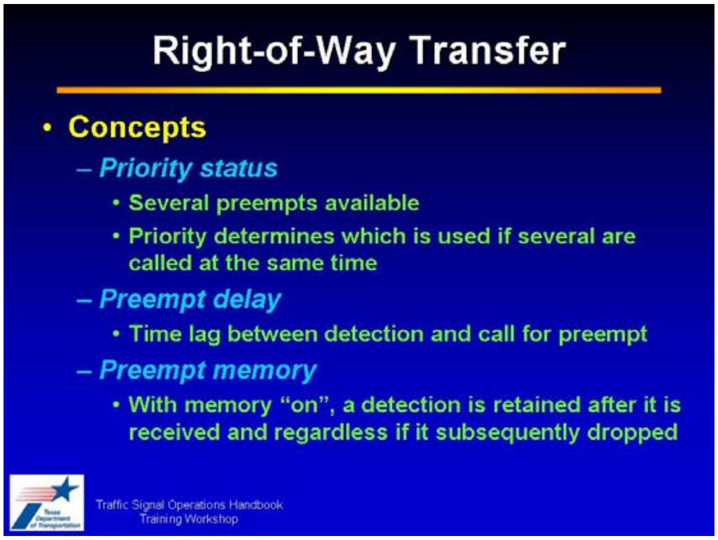
Tell: In the following discussion, we will consider the worst-case scenario—green service had just started on main street, then we received a preemption call from the railroad, and there are queued vehicles on the tracks that need to be cleared before the train arrives.

Tell: Select the Preemption worksheet in TSCO. Look at it occasionally as the following slides are presented, as row and line numbers will be mentioned.

Tell: The Preemption worksheet in TSCO has some green cells. The values in these cells represent "default values". A default value is a recommended value that should describe most conditions, and hence should not need to be changed often.

Notes:
The line numbers and the rows numbers in the TSCO Preemption worksheet differ. The line numbers on the Preemption worksheet conform to the line numbers on the preemption worksheet used by TxDOT. The row numbers come from the spreadsheet itself. Both line numbers and row numbers are included in the following slides' discussion material.

Slide 183



Key Message:
The first consideration in rail preemption timing is right-of-way transfer time, which is the time needed to stop green service on the main street and start serving the track clearance phase. One issue is the type of preempt used.

Interactivity:
Tell: There are several preempt types available, including transit bus preempt, emergency vehicle preempt, and rail preempt. Priority status determines which preempt is used if several are called at the same time.

Tell: Preempts have delay and memory settings, like vehicle detector channels. Delay is the time lag between detection and a preempt call being registered by the controller. When preempt memory is "on" or "locking", a detection is retained even if it is subsequently dropped.

Tell: In TSCO, right-of-way transfer time is computed using lines 1-17 (rows 42-63).

Slide 184

Key Message:
When computing right-of-way transfer time, it is necessary to consider the minimum green, minimum WALK, and pedestrian change intervals needed on the main street. It may be necessary to truncate these times or increase preemption time by obtaining advance preemption time (APT).

Background:
Railroads are required by the TMUTCD to provide 20 s of preemption time. This amount of time may not be sufficient to end service to the main street and clear the crossing-street queue off the tracks. Hence, it may be necessary to truncate green, WALK, or pedestrian change intervals on the main street, or to obtain advance preemption from the railroad (the cost of which is typically paid by the agency responsible for the roads, not the railroad).

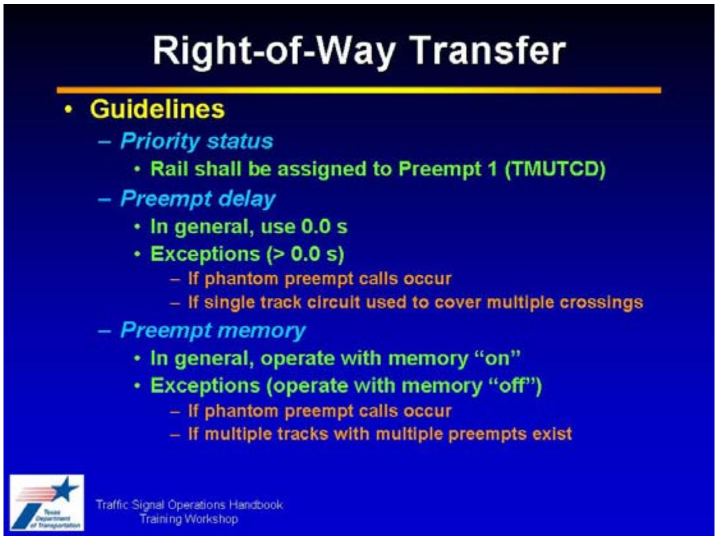
Interactivity:
Tell: For right-of-way transfer time, the worst-case scenario is that a call for rail preemption is received just as green service on the major street has begun. Our goal is to end service on the major street so we can start clearing queues on the crossing street as soon as possible.

Tell: The minimum green and minimum WALK times are the minimum lengths of time that these indications may be displayed prior to starting the preemption sequence.

Tell: The pedestrian change interval is the minimum length of time that can be provided for pedestrian clearance prior to ending service on the main street.

Tell: If the minimum green, minimum WALK, and pedestrian change intervals are collectively long, it may be necessary to obtain APT (i.e., more than the required 20 s of preemption) from the railroad.

Slide 185



Key Message:
Rail preempt should be assigned the highest priority—higher than transit or emergency vehicles. No preempt delay should be used unless phantom preempt calls occur or a single track circuit is used to cover multiple crossings. Preempt memory should be operated in "on" or "locking" mode unless phantom preempt calls occur or multiple tracks with multiple preempts exist.

Interactivity:
Tell: Rail preempt should be assigned the highest priority. It is more important to accommodate a train than a transit bus or an emergency vehicle.

Tell: Normally, use 0.0 s of delay for preempt calls unless phantom preempt calls occur. Regardless of the delay setting, a small amount of delay (about 0.2 s) usually occurs due to the controller's response time to the preempt call.

Tell: An exception can occur if a single track circuit is used to cover multiple crossings—for instance, the crossing being analyzed and the next upstream crossing. In this case, a delay would be needed to account for the time the train takes to advance from the upstream crossing to the crossing being analyzed.

Tell: The preempt memory should usually be operated in the "on" or "locking" mode unless phantom preempt calls occur.

Tell: The preempt memory may need to be operated in the "off" or "non-locking" mode if the crossing consists of multiple tracks with multiple preempts.

Tell: Preempt delay and controller response times are entered into lines 1 and 2 (rows 44 and 45) of the Preemption worksheet.

Slide 186

Key Message:
Minimum green and minimum WALK should be set no shorter than 2 s unless needed to satisfy warning time requirements. The normal pedestrian change interval should be provided if possible, but the TMUTCD allows this interval to be truncated. The amount of truncation exposure incurred by pedestrians should be checked if truncation is considered.

Background:
Truncation exposure is affected by the number of preemption events per day, cycle length, pedestrian volume, and amount by which the pedestrian change interval is truncated. Computation of truncation exposure is detailed in the *Guide for Determining Traffic Signal Preemption at Highway-Rail Grade Crossings* by Engelbrecht et al (project 0-4265).

Interactivity:
Tell: Use minimum green and minimum WALK values no less than 2 s. This allows drivers and pedestrians to see that the signal is cycling, but right-of-way is changing. On freeway ramps with ramp metering, drivers will usually see green intervals of about 2 s.

Tell: It is desirable to provide the normal pedestrian change interval during rail preemption, but Section 4D.13 of the TMUTCD allows this interval to be truncated if needed.

Tell: Preemption time is the time needed to transfer right-of-way and clear the tracks. Warning time is the time available to do the same.

Tell: If the pedestrian change interval is truncated, check the truncation exposure that pedestrians will experience. Values less than or equal to 30 pedestrian-seconds per day were considered acceptable by the project 0-4265 panel.

Tell: Minimum green, minimum WALK, and pedestrian change intervals are entered into lines 4-15 (rows 47-60) of the Preemption worksheet.

Slide 187

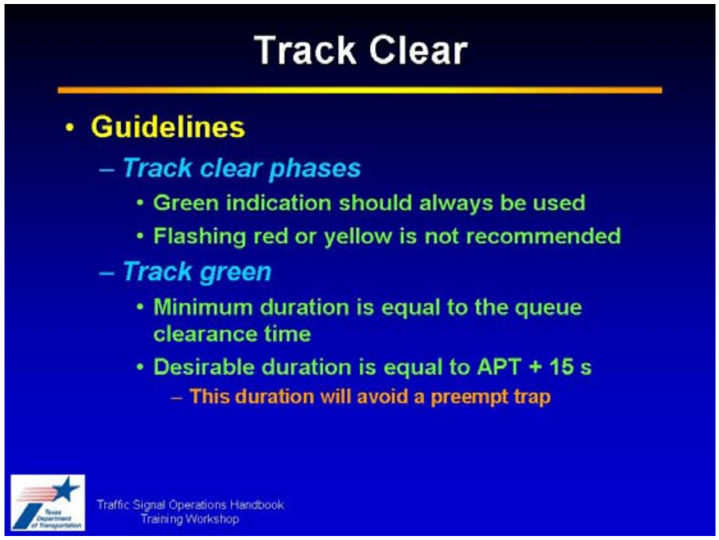
Key Message:
The second consideration in rail preemption timing is track clearance time, which is the time needed to clear queued vehicles off the tracks. The track green is the duration of the green interval for the track clearance phase.

Interactivity:
Tell: For track clearance, the worst-case scenario is that we have a queue of stopped vehicles on the crossing-street approach that crosses the tracks. The queue extends onto and slightly beyond the tracks. Our goal is to clear this queue of vehicles, past the intersection stop line as well as the tracks, before the train arrives.

Tell: Though drivers are trained not to stop on tracks, there are various reasons why some do, including inattention, disrespect for the law, blockage by suddenly-stopping vehicles ahead of the tracks, or failure to realize that the train is wider than the tracks.

Tell: In TSCO, track clearance time is computed using lines 18-25 (rows 64-85).

Slide 188



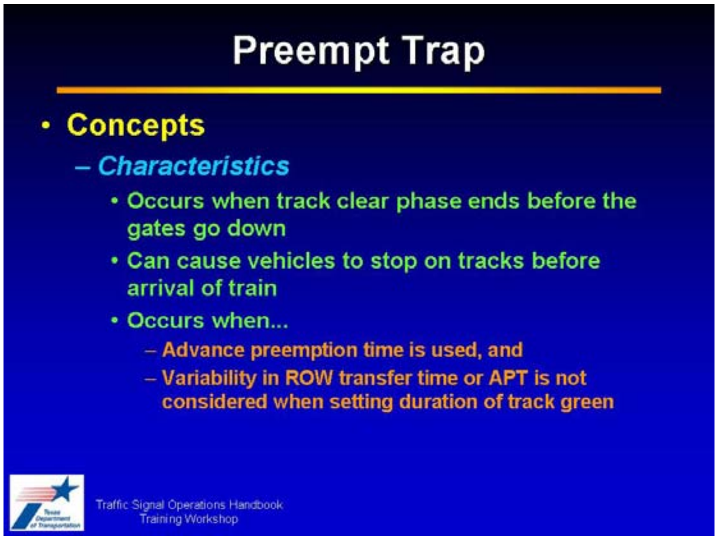
Key Message:
During track clearance, the track clear phase indications should be green, not flashing yellow or red. The track clearance green interval duration is equal to the queue clearance time, and should be equal to the APT (if any exists) plus 15 s to avoid a preempt trap.

Background:
Section 8D.06 of the TMUTCD requires the railroads to provide at least 20 s of warning time when a train is arriving. Section 8D.04 of the TMUTCD requires that the gates be horizontal for at least the 5 s preceding train arrival. Hence, the amount of green time available to clear the tracks is equal to the APT (if any exists) plus 15 s.

Interactivity:
Tell: Use green to clear the tracks, not flashing yellow or red. The goal is to clear the tracks as quickly as possible.

Tell: The track clearance green indication is equal to the queue clearance time. Desirably, it should be equal to the APT (if any exists) plus 15 s, to avoid a preempt trap.

Slide 189

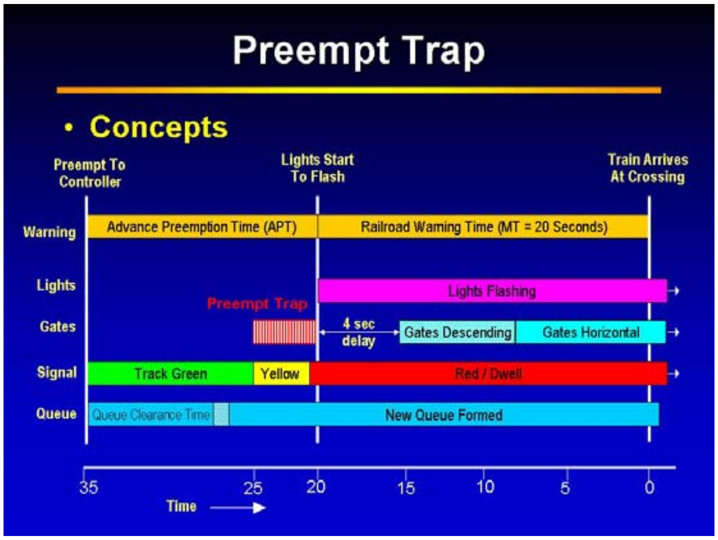


Key Message:
A preempt trap occurs when the track green ends before the gates descend. This can cause vehicles to stop on the tracks before the train arrives.

Interactivity:
Tell: A preempt trap occurs when the track green ends before the gates descend. This can cause vehicles to stop on the tracks before the train arrives. We want the track green to end *after* the gates descend, not *before*.

Tell: A preempt trap can occur when APT is used and variability in right-of-way transfer time or APT is not considered when setting the duration of the track clearance green interval. For example, if the train decelerates after crossing the preemption circuit, it may arrive later than expected.

Slide 190

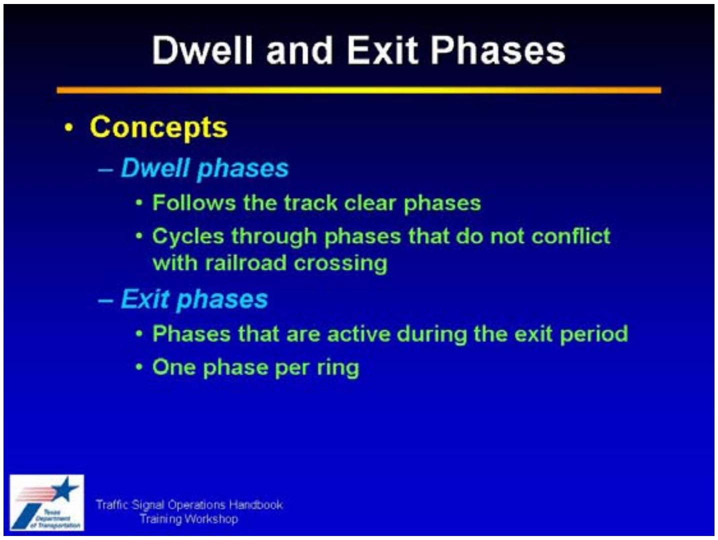


Key Message:
In this diagram, the preempt trap is illustrated as the time between the end of track clearance green and the start of the flashing railroad warning lights.

Interactivity:
Tell: On the top bar of this diagram, the total warning time is shown to have two components—the railroad warning time of 20 s, and APT of 15 s.

Tell: In this example, the track green interval is inadequate. The fourth bar shows that the track green ends before the APT has elapsed. As a result, a new queue begins to form on the crossing street for several seconds before the railroad warning lights begin to flash. This may result in vehicles stopping on the tracks.

Slide 191

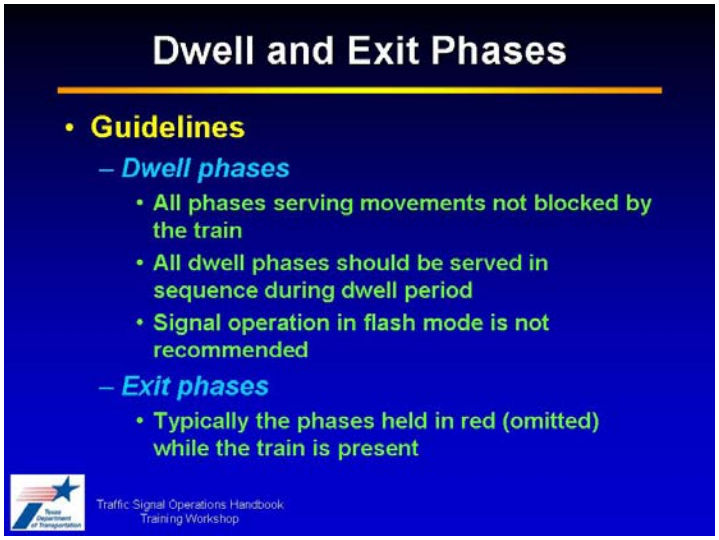


Key Message:
Dwell phases are the phases that follow the track clear phases and do not conflict with the railroad crossing. Exit phases are the phases that are active after the train leaves, for the purpose of clearing the queues that accumulated while the train was present.

Interactivity:
Tell: Service to the dwell phases begins after track clearance. These phase include all that do not conflict with the railroad crossing, and hence can be served while the train is present.

Tell: Significant queues may grow while the train is present. Hence, after it leaves, the queues are flushed by serving one exit phase on each ring, corresponding to movements that had to be stopped for the train.

Slide 192

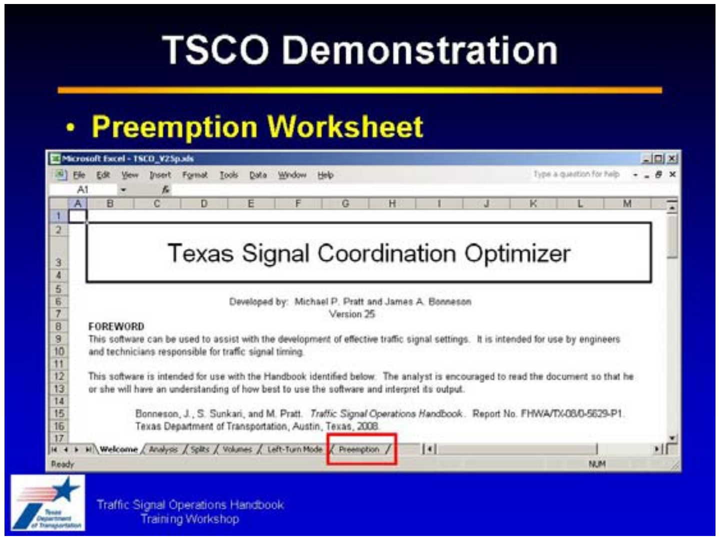


Key Message:
The dwell phases should continue to be served in sequence during the dwell period. The exit phases should be held in steady red while the train is present.

Interactivity:
Tell: The dwell phases should continue to be served in sequence during the dwell period. Be efficient and keep as many vehicles moving as possible, especially if detection has been installed at the intersection. Operating the signal in flash mode is not recommended.

Tell: The exit phases should be held in steady red while the train is present.

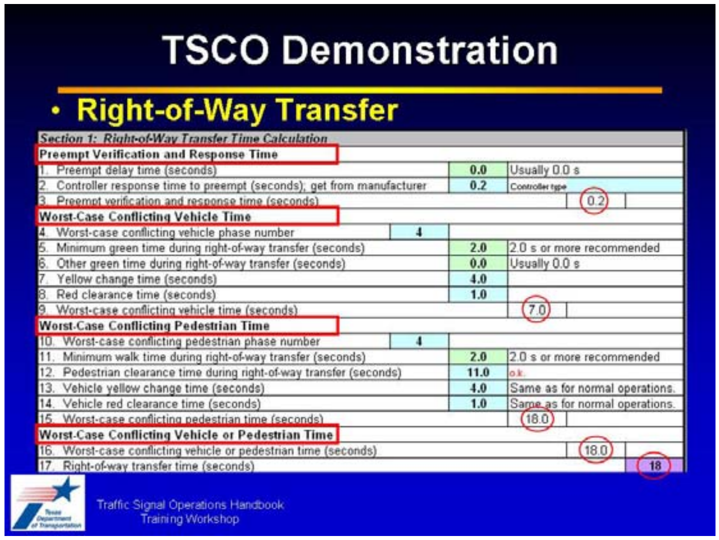
Slide 193



Key Message:
TxDOT's "preemption worksheet" is implemented in spreadsheet form in TSCO.

Interactivity:
Tell: If you have not done so already, open TSCO and select the Preemption worksheet.

Slide 194



Key Message:
TSCO computes right-of-way transfer time as the sum of verification and response time and the worst-case conflicting vehicle or pedestrian time.

Background:
Section 4D.13 of the TMUTCD forbids the truncation or omission of yellow or red clearance during transition to preemption, but allows the truncation of minimum green, WALK, and pedestrian change interval.

Interactivity:
Tell: This screen shot shows lines 1-17 of the Preemption worksheet (rows 42-63).

Click: One component of right-of-way transfer time is the verification and response time, which is the sum of the delay setting and the controller response time.

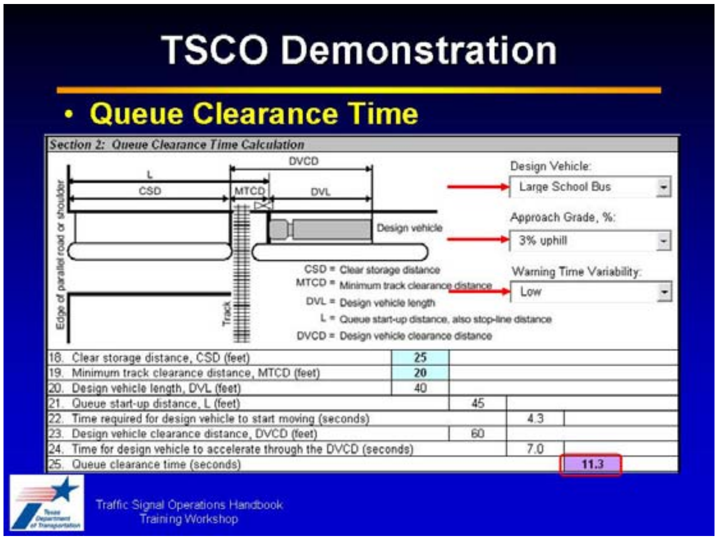
Click: The worst-case conflicting vehicle time is the amount of time it takes to end vehicular service to the major street and start serving the track clearance phase. This time can be reduced by truncating the minimum green interval. Yellow and red clearance may not be truncated.

Click: The worst-case conflicting pedestrian time is the amount of time it takes to end pedestrian service to the major street. This time can be reduced by truncating the WALK and/or pedestrian clearance times.

Click: TSCO computes the right-of-way transfer time as the sum of the preempt verification and response time and the longer of the worst-case conflicting vehicle or pedestrian times.

Notes:
The tenths digit is not displayed in the purple cell on line 17 (row 63), but the tenths digit is retained in the spreadsheet's calculations.

Slide 195



Key Message:
Queue clearance time is the time needed for the design vehicle to start moving and clear the tracks. It is influenced by site characteristics, preemption warning time variability, and the choice of the design vehicle.

Background:
Figure 8B-6 of the TMUTCD shows pavement markings for an example highway-rail grade crossing. The figure includes optional solid white lines that denote the location of the train dynamic envelope. They are located six feet away from each rail.

Interactivity:
Tell: This screen shot shows lines 18-25 of the Preemption worksheet (rows 64-85).

Tell: In the illustrated diagram, the design vehicle is stopped at the stop line for the gates. Our goal is to allow the design vehicle to clear the tracks and before the end of the track green.

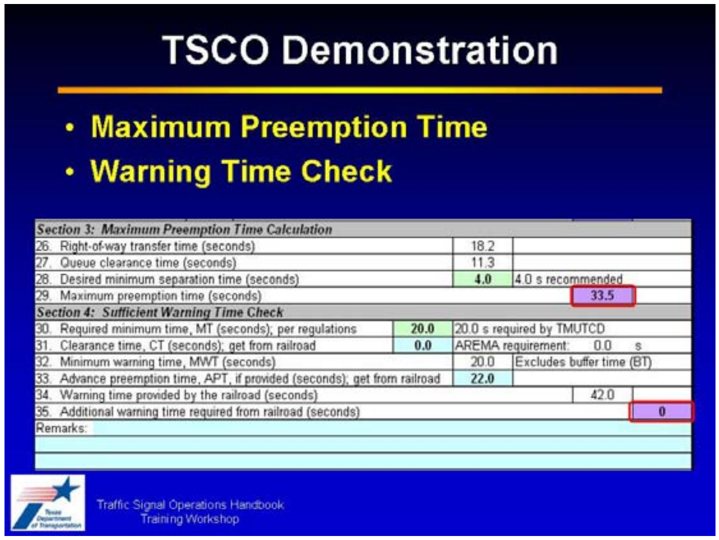
Tell: Queue clearance time is affected by the acceleration characteristics of the design vehicle and the grade of the approach where the vehicle is stopped. The vehicle type and approach grade are specified using the first two drop-down menus.

Tell: The third drop-down menu is used to specify the amount of warning time variability that typically occurs at the crossing. If variability is high, more track clearance green is needed because the train may arrive later than expected.

Tell: The clear storage distance (CSD) is the distance from the edge of the train dynamic envelope (the actual swept path of the train) to the intersection. The minimum track clearance distance (MTCD) is measured from the CSD to the stop line for the gates.

Tell: The queue clearance time is computed in the purple cell in line 25 (row 85).

Slide 196



Key Message:
Maximum preemption time is the sum of right-of-way transfer time, queue clearance time, and the desired separation time between queue clearance and train arrival. It represents the "demand" or total time needed. The maximum preemption time must be compared to the "supply", which is the warning time provided by the railroad.

Interactivity:
Tell: This screen shot shows lines 26-35 of the Preemption worksheet (rows 86-100).

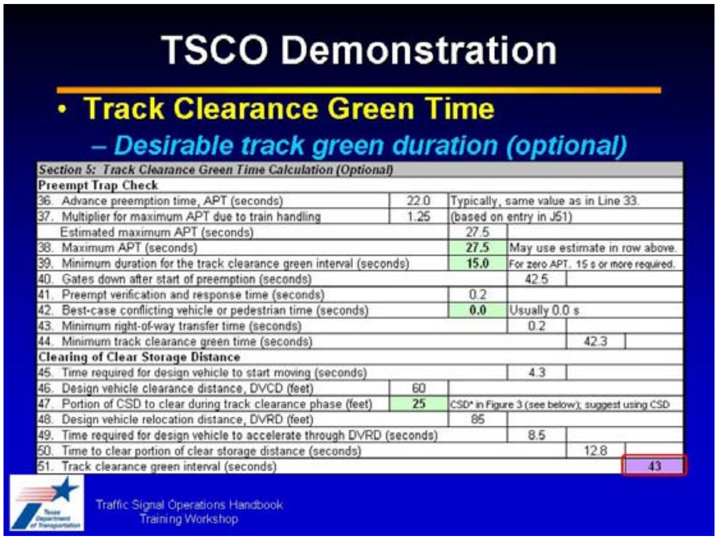
Tell: We have already calculated the right-of-way transfer time and the queue clearance time. We must also determine the desired minimum separation time, which is the elapsed time between the design vehicle leaving the tracks and the train arriving. The default value is 4 s.

Tell: The maximum preemption time is computed as the sum of right-of-way transfer time, queue clearance time, and separation time. This value is computed in line 29 (row 90). It represents our "demand", or the total warning time we need.

Tell: The warning time provided by the railroad is the minimum 20 s that they are required to provide, plus the APT that they provide upon request (and at the expense of the road agency). This value is computed in line 34 (row 96). It represents our "supply", or the total warning time we have.

Tell: If we have insufficient warning time, the value computed in line 35 (row 97) will be greater than zero. We can either obtain more supply by requesting APT, or we can reduce demand by adjusting signal timing parameters or changing the design vehicle.

Slide 197



Key Message:
Additional calculations can determine whether a preempt trap exists and whether the design vehicle is able to leave the clear storage distance before the track green ends. These calculations may suggest the need for increased track green.

Background:
These calculations are optional. A preempt trap cannot occur if the additional warning time amount computed in line 35 (row 97) is zero. It is also acceptable to clear the design vehicle past the tracks but not to the intersection, though the vehicle may have to stop and wait at the intersection stop line, possibly until the train passes and the exit phases are served.

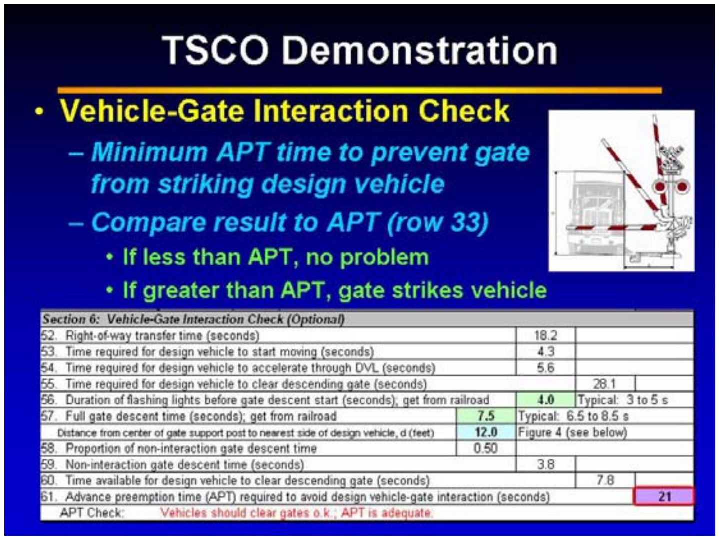
Interactivity:
Tell: This screen shot shows lines 36-51 of the Preemption worksheet (rows 101-120). These calculations are optional.

Tell: In lines 36-44 (rows 102-112), we calculate the minimum track clearance green interval required to avoid a preempt trap. The Preemption worksheet does not allow a green interval shorter than this duration to be used.

Tell: So far, our goal has been to allow the design vehicle to pass the tracks and enter the intersection before the end of track clearance green. However, if we are willing to allow the vehicle to pass the tracks but stop and wait within the clear storage distance (i.e., between the tracks and the intersection), we may be able to use a shorter track clearance green interval. The computation of this potentially shorter track clearance green interval is done in lines 45-50 (rows 113-119).

Tell: The track clearance green interval required to avoid a preempt trap and clear the desired portion of the clear storage distance is provided in line 51 (row 120).

Slide 198



Key Message:
A vehicle-gate interaction occurs if the descending gate hits the design vehicle while it is clearing. It is possible to have sufficient warning time to transfer right-of-way and clear the tracks, but still have a vehicle-gate interaction during queue clearance. It may be necessary to obtain additional warning time or reduce right-of-way transfer time to prevent this interaction.

Background:
The probability of a vehicle-gate interaction is influenced by queue length, design vehicle length, height, and acceleration characteristics; and gate offset from the travel lanes.

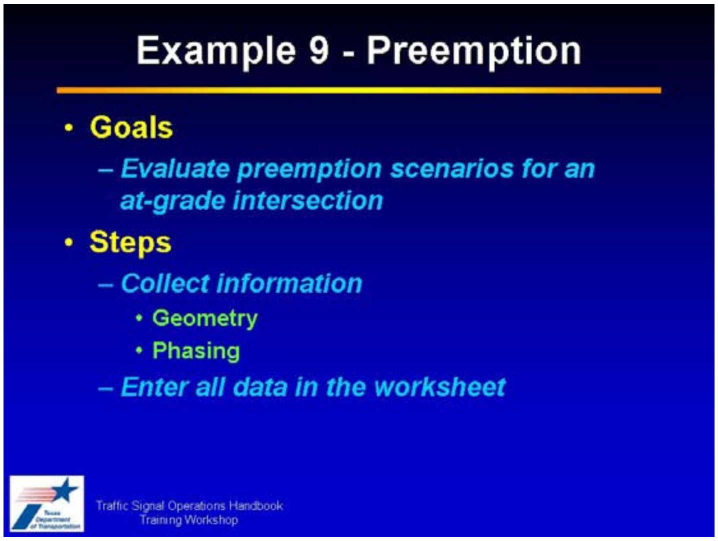
Interactivity:
Tell: This screen shot shows lines 52-61 of the Preemption worksheet (rows 121-133). These calculations are optional.

Tell: Lines 56 and 57 (rows 126-128) can be used to describe the gate operation and its offset from the travel lanes. Only the latter item is likely to change much between sites.

Tell: The amount of APT needed to avoid the vehicle-gate interaction is computed in line 61 (row 132).

Ask: Before we continue to the example problem, are there any questions?

Slide 199



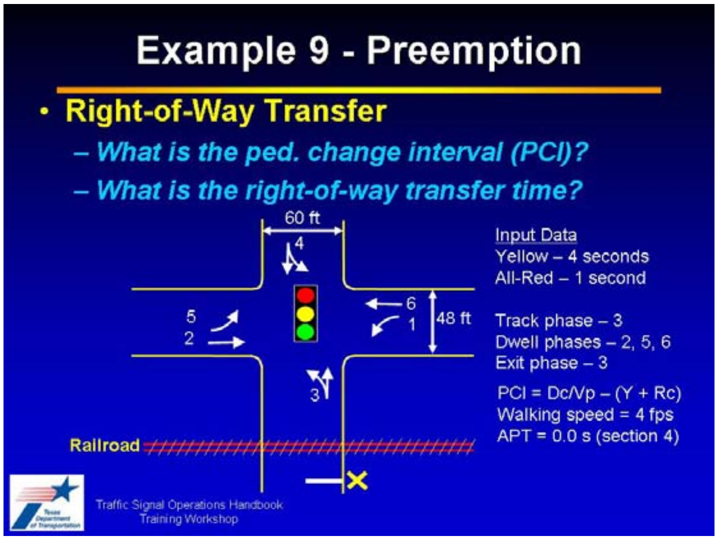
Key Message:
The TSCO Preemption worksheet can be used to evaluate the highway-rail grade crossing described by the given data.

Interactivity:
Tell: Go to page 109 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: This example problem is guided. The example will cover data entry and interpretation of the graph on the top of the Preemption worksheet.

Notes:
At various points during this exercise, it may be beneficial to review the TSCO Preemption worksheet with the participants instead of presenting only from the slides. The graph on the top of the worksheet is particularly useful.

Slide 200



Key Message:
When pedestrians are present, the pedestrian change interval must be calculated. This time becomes one of the components of the right-of-way transfer time.

Interactivity:
Tell: Assume the worst-case scenario—the green service on the main street (east/west in the diagram) just started, and then we received a rail preempt call. We must end service to the main street as quickly as possible so we can begin clearing the tracks.

Tell: The assumed walking speed is 4 ft/s, and we will allow the flashing DON'T WALK to extend into the yellow and red clearance.

Ask: What is the pedestrian change interval?

Click: The pedestrian change interval is 10 s. That is 60 feet (the width of the crossing street) divided by 4 ft/s, minus the 4-s yellow and the 1-s red clearance. Enter the pedestrian change interval into line 12 (row 57) of the Preemption worksheet. Note that the worksheet refers to this time as "pedestrian clearance time during right-of-way transfer".

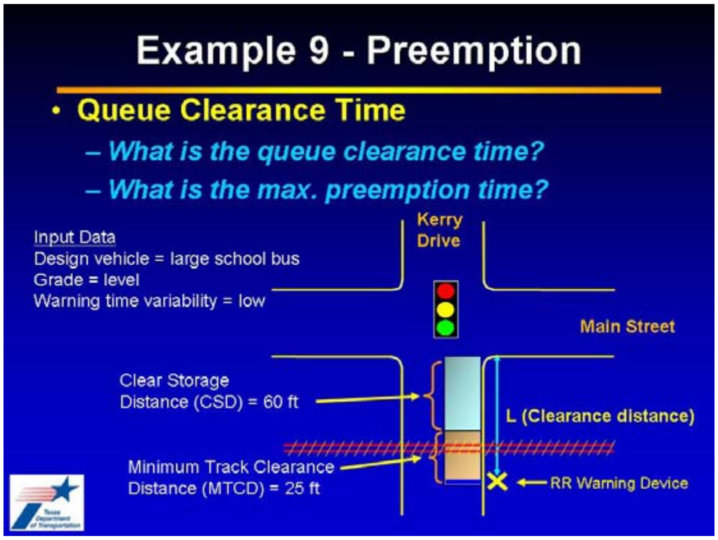
Ask: What is the right-of-way transfer time?

Tell: In addition to the pedestrian change interval we just computed, we need to consider the minimum green and WALK times, yellow, and red clearance. Enter these values where needed in lines 4-14 (rows 48-59). Use 2 s for the minimum green and WALK times.

Click: The right-of-way transfer time is 17 s.

Tell: Note that we do not have APT.

Slide 201



Key Message:
The queue clearance time and maximum preemption time can be computed in TSCO when the given data are entered.

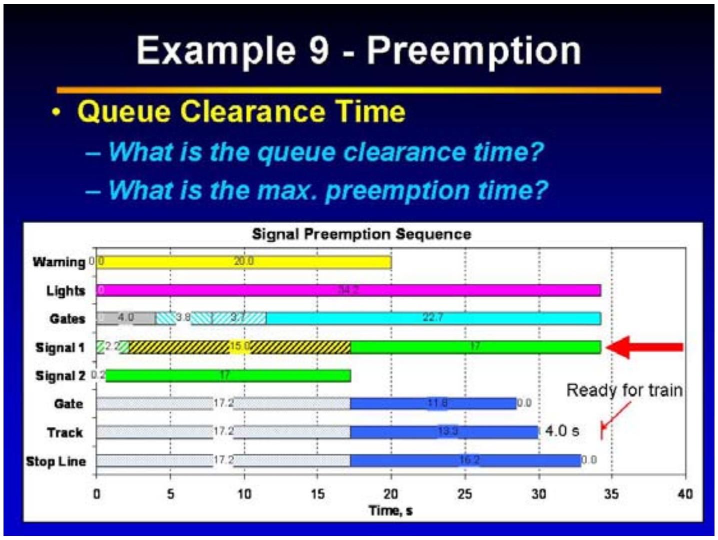
Interactivity:
Ask: What is the queue clearance time?

Tell: We will compute the queue clearance time in TSCO by entering the given data. Use the drop-down menus in rows 65-77 to describe the design vehicle, the approach grade, and the warning time variability. Enter the CSD and MTCD lengths into lines 18 and 19 (rows 78 and 79).

Ask: What is the maximum preemption time?

Tell: The maximum preemption time is the sum of right-of-way transfer time, queue clearance time, and separation time. This represents our “demand”, or the total amount of warning time we need when a train is approaching.

Slide 202



Key Message:
The queue clearance time and maximum preemption time are computed in TSCO.

Interactivity:
Ask: What is the queue clearance time?

Tell: The queue clearance time is the time needed to clear the design vehicle off the tracks. It is illustrated as the blue portion of the "Track" bar on the graph.

Click: The queue clearance time is 13.3 s. It is illustrated on the graph and computed in line 27 (row 88).

Ask: What is the maximum preemption time?

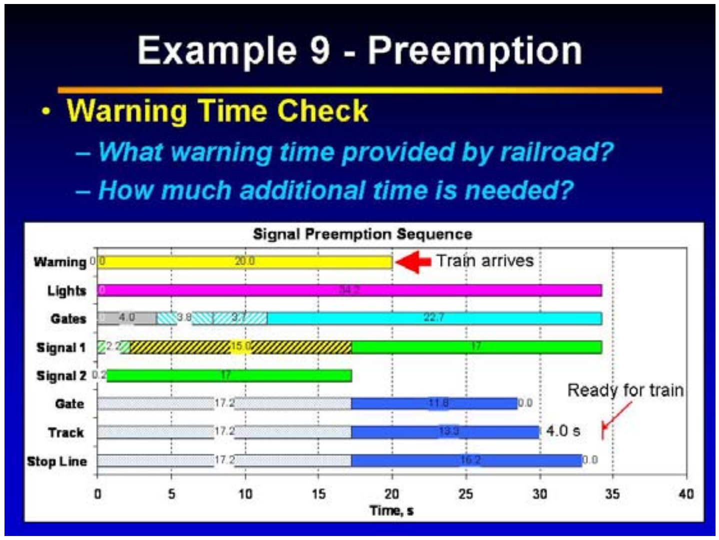
Tell: The maximum preemption time is our total "demand", or the time we need to transfer right-of-way, clear the queue, and have the desired separation time (4 s) between queue clearance and train arrival.

Tell: Separation time occurs after queue clearance time. It is shown as 4 s to the right o the queue clearance time on the slide illustration.

Click: The maximum preemption time is 34.5 s. It is computed in line 29 (row 90).

Notes:
When the given data are entered into TSCO, the graph does not show separation time because none exists. The 4-s separation time shown on the slide was added for illustration purposes.

Slide 203



Key Message:
The Preemption worksheet calculations can indicate whether additional warning time needs to be obtained from the railroad.

Interactivity:
Tell: So far, we have discussed the "demand", or the amount of warning time we need, to transfer right-of-way, clear the design vehicle past the tracks, and have sufficient separation time before the train arrives. Now we assess our "supply", or the warning time we have, and see if it is adequate.

Ask: What warning time is provided by the railroad?

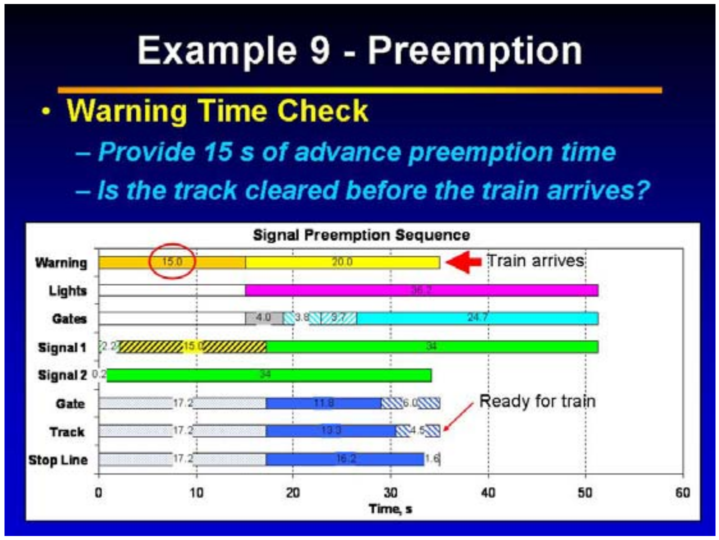
Click: We have only the 20 s that the railroad is required to provide. The train arrives at the end of the 20 s, where the red arrow is located on the slide.

Ask: How much additional warning time is needed?

Click: We need 15 s of additional warning time. This amount is computed in line 35 (row 97). It can also be seen as the horizontal distance between the end of the yellow "Warning" bar and the red line to the right of the blue portion of the "Track" bar.

Notes:
When the given data are entered into TSCO, the graph does not show separation time because none exists. The 4-s separation time shown on the slide was added for illustration purposes.

Slide 204



Key Message:
Adding the needed APT allows the design vehicle to clear the tracks before the train arrives.

Interactivity:
Tell: Provide the needed 15 s of APT. Enter this number into line 33 (row 95).

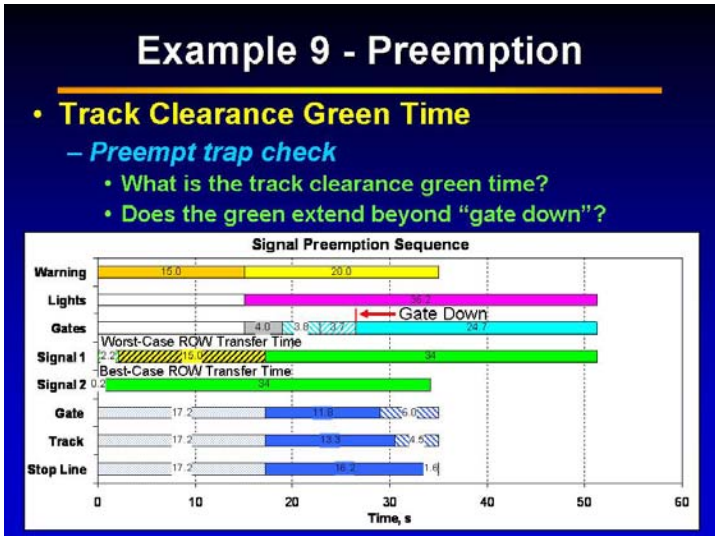
Tell: The advance preemption is shown as the darker portion of the "Warning" bar on the graph. The train still arrives at the end of the time indicated by the "Warning" bar.

Ask: Is the track cleared before the train arrives?

Tell: The blue portion of the "Track" bar still shows 13.3 s of queue clearance time. Now, to the right of the queue clearance time, we have a hatched bar that is 4.5 s in length. The hatched bar shows that we have slightly more than our desired minimum separation time of 4 s that we entered into line 28 (row 89).

Tell: Yes, the track is cleared about 4.5 s before the train arrives.

Slide 205



Key Message:
The Preemption worksheet illustrates that a preempt trap does not occur with the entered settings.

Interactivity:
Ask: What is the track clearance green interval?

Tell: The "Signal 1" and "Signal 2" bars on the graph correspond to the worst-case and best-case right-of-way transfer times, respectively. We are more concerned with the worst case, which is when service on the major street (which runs parallel to the tracks) had just begun when the rail preempt call was received.

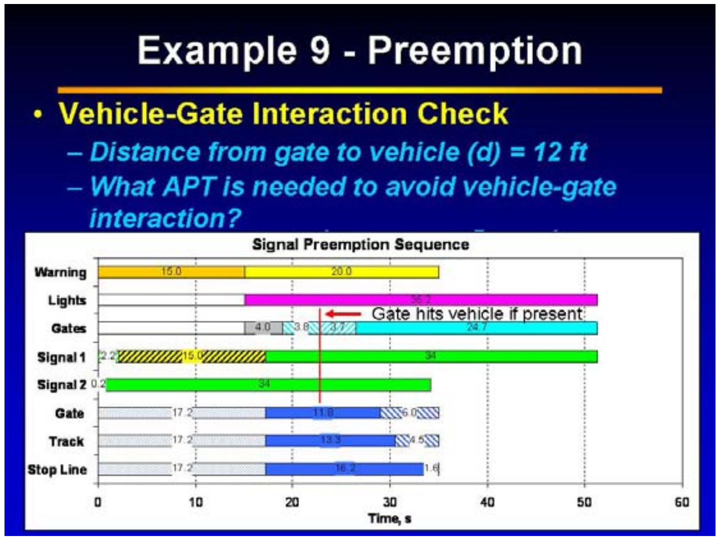
Tell: In both cases, the track clearance green interval is 34 s. This value is illustrated on the graph and calculated in line 51 (row 120) of the worksheet.

Ask: Does the green extend beyond the lowering of the gates?

Tell: The "Gates" bar shows the status of the gates during the preemption sequence. The gates are horizontal at the end of the two hatched portions of the bar. On the slide, this time is labeled as "Gate Down".

Tell: The "Gate Down" time occurs during the track clearance green interval, so the green does extend beyond the lowering of the gates. Hence, there is no preempt trap.

Slide 206



Key Message:
The Preemption worksheet can be used to determine whether a vehicle-gate interaction occurs.

Interactivity:
Tell: The distance between the gate and the design vehicle is 12 feet. Enter this value into row 128 (line 57). The measurement of this dimension is illustrated in Figure 4 at the bottom of the worksheet.

Ask: Does a vehicle-gate interaction occur?

Tell: Once the gate descends beyond a certain point, it can hit the design vehicle if it is present. This portion of the gate descent is shown as the second hatched portion of the "Gates" bar.

Tell: The "Gate" bar illustrates the location of the design vehicle during the preemption sequence. The hatched portion of the "Gate" bar indicates when the design vehicle has cleared the gate.

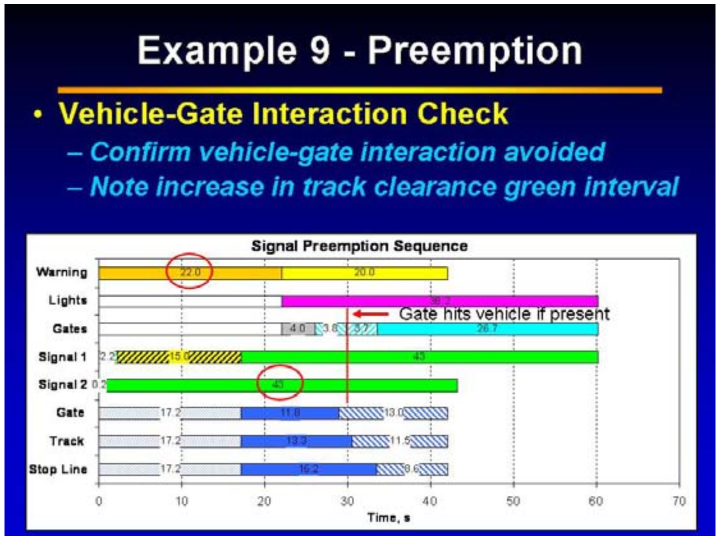
Tell: The vertical red line on the slide is extended from the hatched portions of the "Gates" bar down to the "Gate" bar. The red line does not encounter the hatched portion of the "Gate" bar. Hence, a vehicle-gate interaction can occur.

Ask: How much APT is needed to avoid the vehicle-gate interaction?

Tell: According to the red warning message on row 133, we need to increase the APT by 7 s. Hence, we need a total of 22 s, as computed in line 61 (row 132).

Tell: Enter an APT of 22 s into line 33 (row 95).

Slide 207



Key Message:
The Preemption worksheet graph can be used to verify that no vehicle-gate interaction occurs.

Interactivity:
Tell: The darker portion of the "Warning" bar now shows 22 s of APT instead of 15 s.

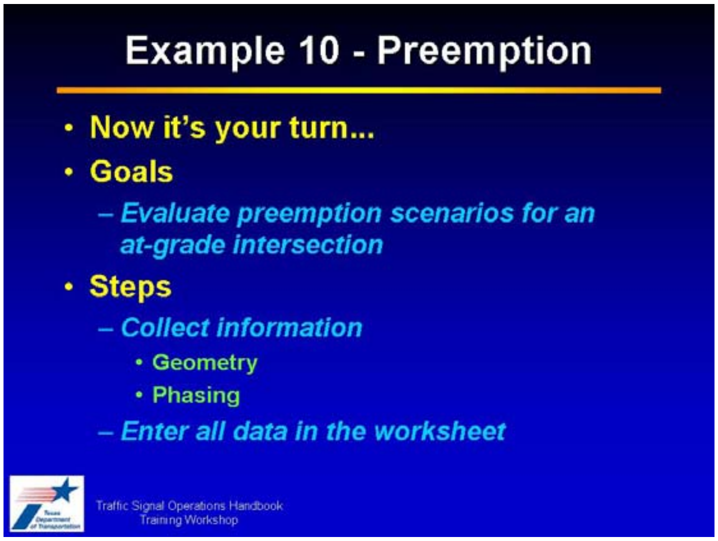
Ask: Is the increase in APT adequate to avoid a vehicle-gate interaction?

Tell: The vertical red line on the slide now meets the hatched portion of the "Gate" bar. Yes, the design vehicle clears the descending gate without getting hit by the gate.

Tell: Increasing the APT also resulted in a longer track clearance green interval.

Ask: Are there any questions?

Slide 208



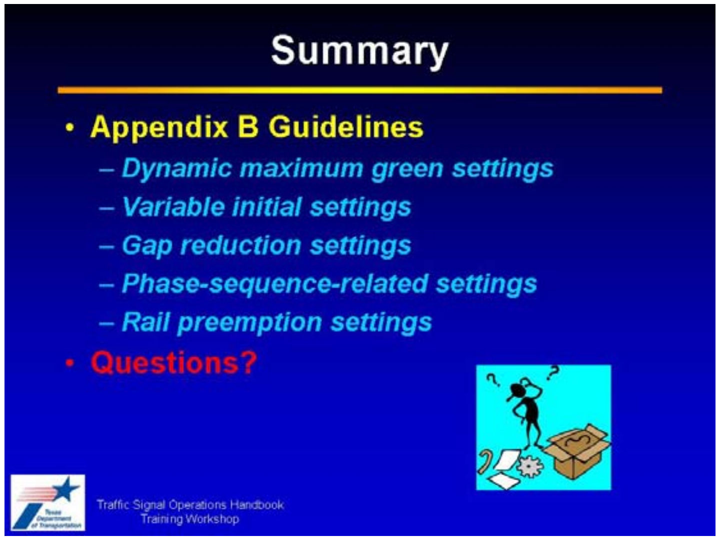
Key Message:
The TSCO Preemption worksheet can be used to evaluate the highway-rail grade crossing described by the given data.

Interactivity:
Tell: Go to page 111 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

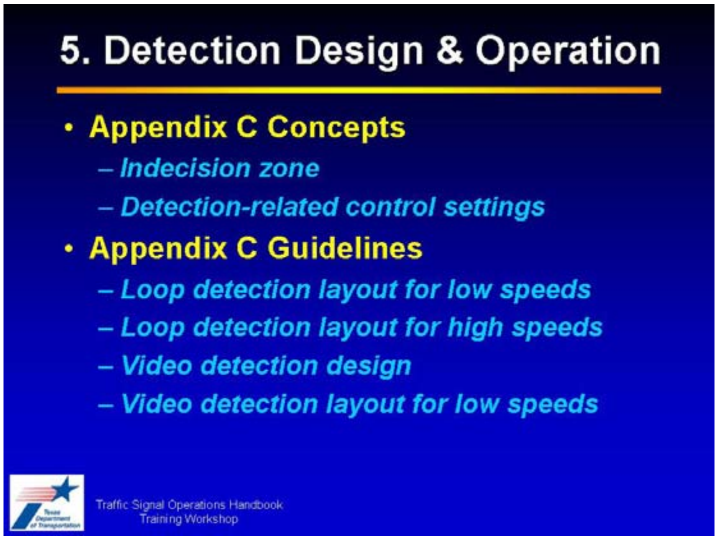
Tell: This example problem is guided. The example will cover data entry and interpretation of the graph on the top of the Preemption worksheet.

Notes:
This exercise is completed with the instructor guiding the participants through TSCO. There are no slides to cover the data entry or results.

Slide 209

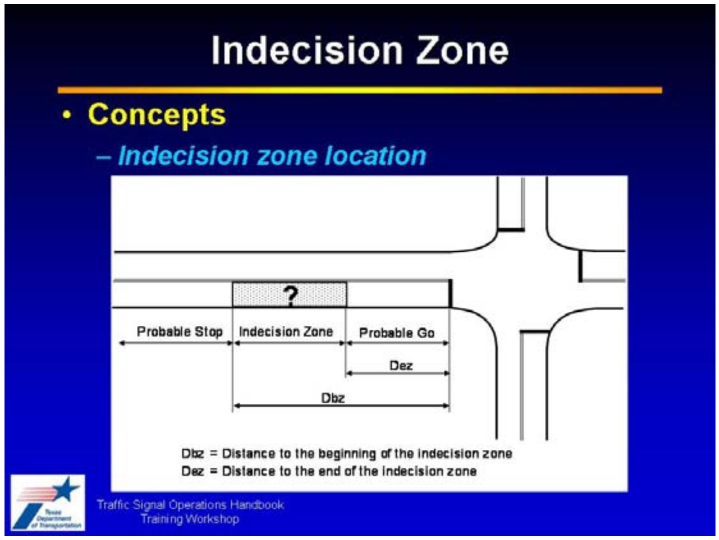

Summary
• Appendix B Guidelines
– Dynamic maximum green settings
– Variable initial settings
– Gap reduction settings
– Phase-sequence-related settings
– Rail preemption settings
• Questions?
Traffic Signal Operations Handbook
Training Workshop

Slide 210



Key Message:
This lesson covers Appendix C of the *Handbook*. Appendix C focuses on detection design and operation, including loop detection layouts for low and high speeds, video detection design, and video detection layout for low speeds.

Slide 211



Key Message:
The indecision zone is a location on a high-speed intersection approach where drivers are collectively indecisive on whether to go or stop if presented with a yellow indication.

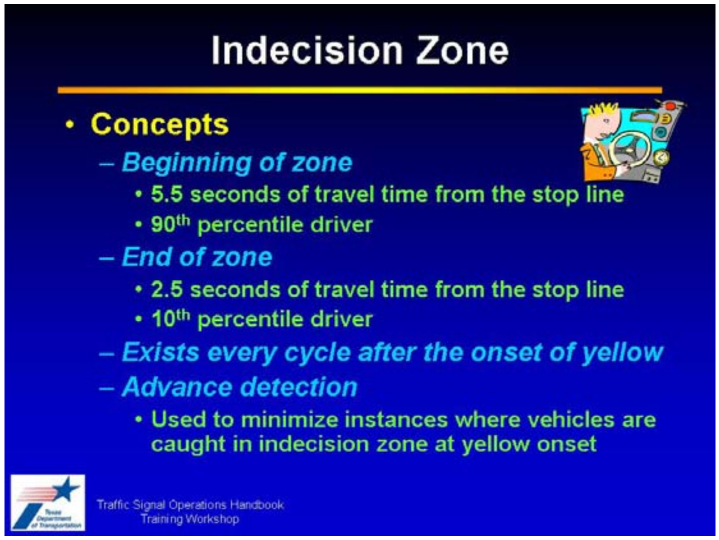
Interactivity:
Tell: When drivers are presented with a yellow indication, they must decide whether to proceed through the intersection or stop. Their decision is based on their speed and their distance to the stop line.

Tell: Though individual drivers are fairly consistent in their decision for a given speed and distance, there is a zone where drivers are collectively indecisive because they tend to reach different decisions. This zone is called the indecision zone. In this location, some drivers will decide to proceed, while others will decide to stop. Rear-end crashes can occur if vehicles are present in this zone at the onset of yellow.

Tell: The indecision zone is sometimes incorrectly called the dilemma zone. A dilemma zone occurs when a vehicle is traveling at a speed that exceeds the speed used to compute the yellow duration, or the driver's reaction time is longer than assumed in the timing of the yellow duration. These drivers will be unable to enter the intersection before the end of yellow or stop before crossing the stop line.

Tell: The dilemma zone can be mitigated by increasing the yellow duration. The indecision zone cannot.

Slide 212



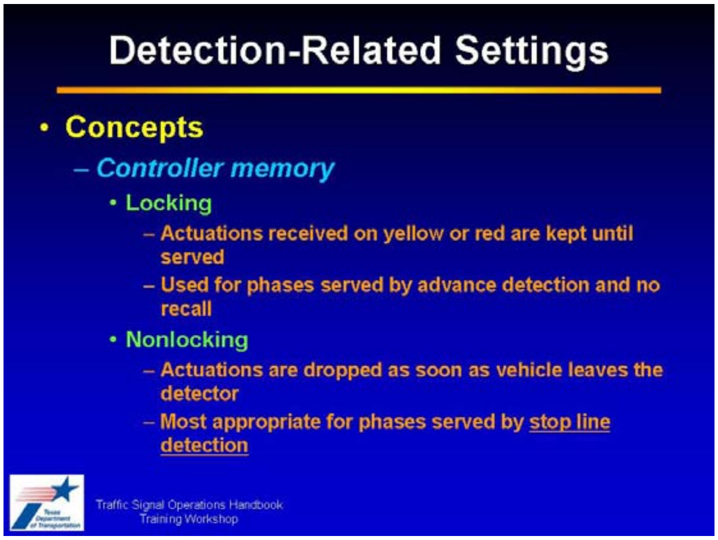
Key Message:
The indecision zone can be defined in terms of travel time to the stop line. It occurs every cycle at the onset of yellow. Its impact can be mitigated by providing advance detection.

Interactivity:
Tell: The beginning of the indecision zone occurs at the location corresponding to about 5.5 s of travel time to the stop line. At this location, about 90 percent of drivers will choose to stop when presented with a yellow indication.

Tell: The end of the indecision zone occurs at the location corresponding to about 2.5 s of travel time to the stop line. At this location, about 90 percent of drivers will choose to proceed when presented with a yellow indication.

Tell: The indecision zone occurs every cycle at the onset of yellow. Advance detection can be placed in the indecision zone and used to extend the green indication when vehicles are present.

Slide 213

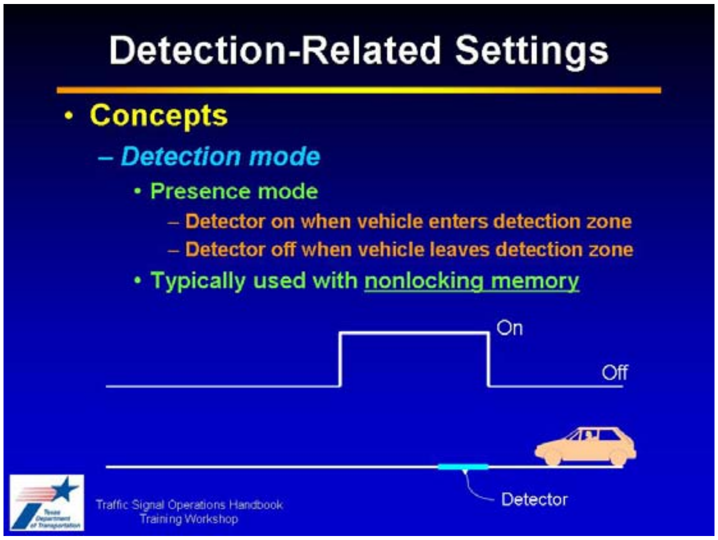


Key Message:
The controller memory for each detection channel can be set to locking or nonlocking, depending on whether it is desired to let detector actuations be dropped when a vehicle leaves the detector.

Interactivity:
Tell: When locking memory is used, detector actuations received on yellow or red are retained until the associated phase is served. This memory setting is used on phases served by advance detection only and lacking a recall.

Tell: When nonlocking memory is used, detector actuations are retained only as long as the vehicle occupies the detector, and dropped when the vehicle departs. This memory setting is used on phases served by stop line detection.

Slide 214



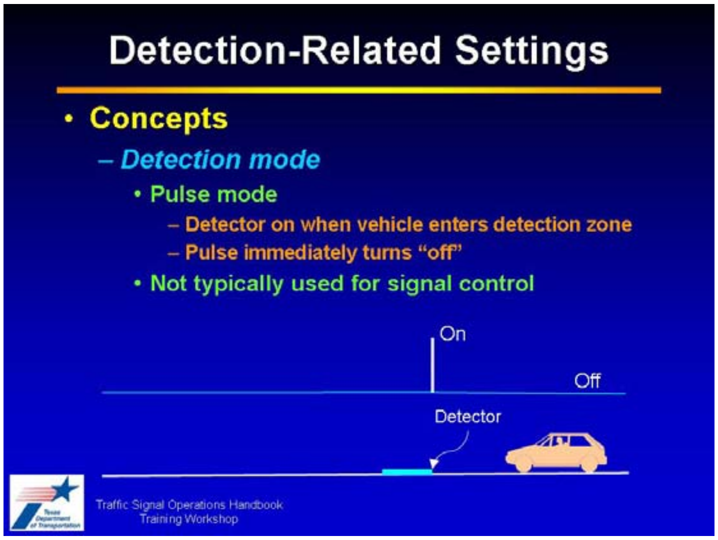
Key Message:
Detection can be operated in presence or pulse mode. In presence mode, the detector remains "on" as long as its detection zone is occupied.

Interactivity:
Tell: Detection can be operated in presence or pulse mode. In presence mode, the detector is actuated as soon as a vehicle enters its detection zone, and remains actuated until its detection zone is no longer occupied.

Tell: Presence mode is typically used with nonlocking memory.

Click: In this example, the detector is actuated as soon as the front of the car passes over it. The actuation ends when the back of the car leaves the detector.

Slide 215



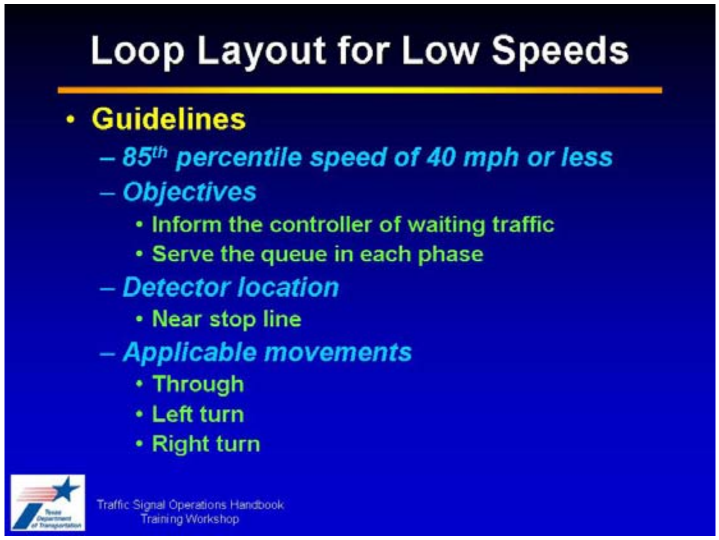
Key Message:
Detection can be operated in presence or pulse mode. In pulse mode, the detector remains "on" for about 0.1 s after a vehicle enters its detection zone, and then turns "off".

Interactivity:
Tell: In pulse mode, the detector is actuated as soon as a vehicle enters its detection zone, but only remains actuated for about 0.1 s.

Tell: Pulse mode is rarely used for signal control applications.

Click: In this example, the detector is actuated as soon as the front of the car passes over it. The actuation ends a short time later, while the car is still present.

Slide 216

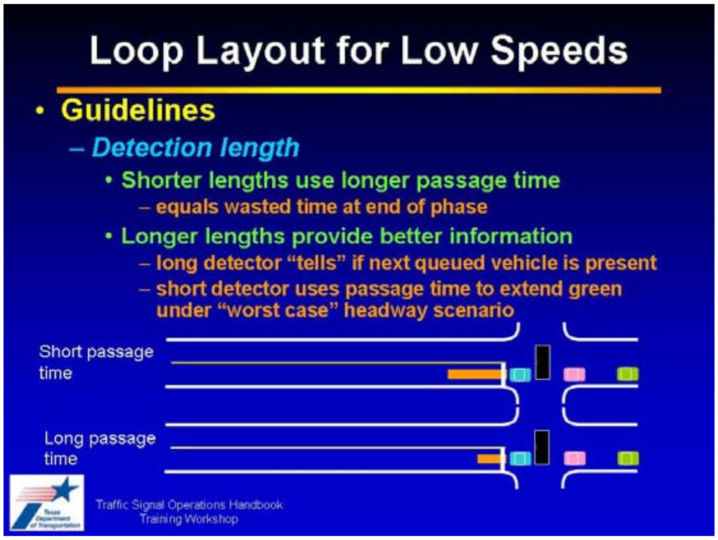


Key Message:
For low speeds (40 mph or less), loops should be placed to inform the controller when waiting traffic is present and to serve queues in each phase.

Interactivity:
Tell: Speeds of 40 mph or less are considered "low" for loop layout purposes. For low speeds, the objectives of loop layout are to inform the signal controller when waiting vehicles are present, and to allow the queue in each phase to be served before its green indication ends.

Tell: To accomplish these objectives, place the detectors near the stop line. All movements require detection—through, left-turn, and right-turn.

Slide 217



Key Message:
Shorter detectors require a longer passage time setting to prevent premature gap-out in cases where an exceptionally long headway occurs within the queue. As a result, use of shorter detectors result in unneeded extension of the green indication for a few seconds after the last queued vehicle has departed.

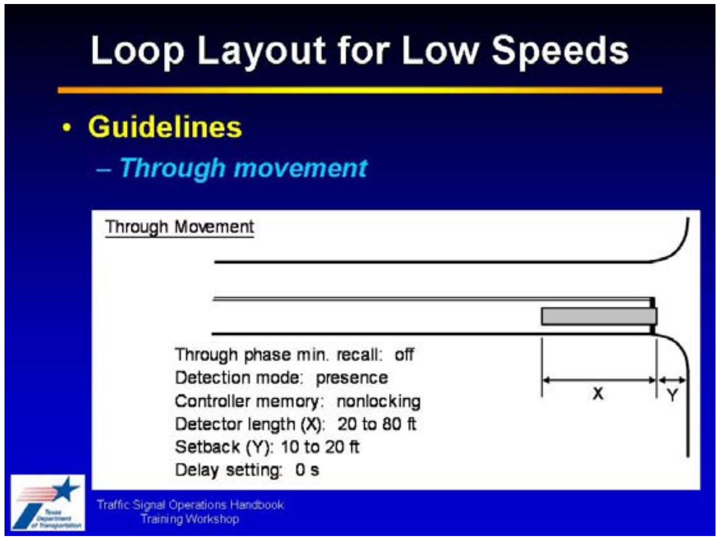
Interactivity:
Tell: For all stop line detector applications, the passage time is set long enough that the green indication will be extended as long as the initial queue is still clearing. This setting is made using assumptions about the lengths of headways that are expected within a queue.

Tell: Shorter detectors require a longer passage time to extend the green when exceptionally long headways occur within the queue. This longer passage time increases the amount of time that the green indication is extended after the last queued vehicle leaves the detector.

Tell: Longer detectors require a shorter passage time, as it is more likely that the next queued vehicle will occupy the detector even in the worst case of an exceptionally long headway. This shorter passage time allows the green indication to be ended sooner after the last queued vehicle departs.

Click: Notice that the signal with the longer detector goes to yellow sooner. The signal with the shorter detector is extended longer because the passage time is still elapsing, and the controller is unaware that the last queued vehicle has departed.

Slide 218

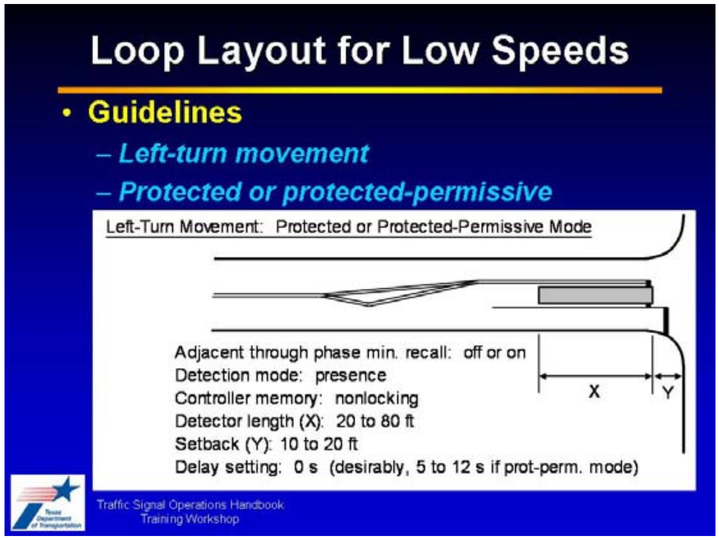


Key Message:
Detectors for through movements should be operated in presence mode, with nonlocking memory, with no phase minimum recall or delay. The detector should be 20-80 feet long, with longer zones being more desirable.

Interactivity:
Tell: Detectors for through movements should be operated in presence mode, with nonlocking memory, with no phase recall or delay.

Tell: The detector should be 20-80 feet long, with longer zones being more desirable. Research has shown that 80 feet is the best length for queue detection, but stop line detectors of this length are seldom used because of their increased maintenance costs. A common and reasonable practice is to use 40-foot stop line detectors.

Slide 219

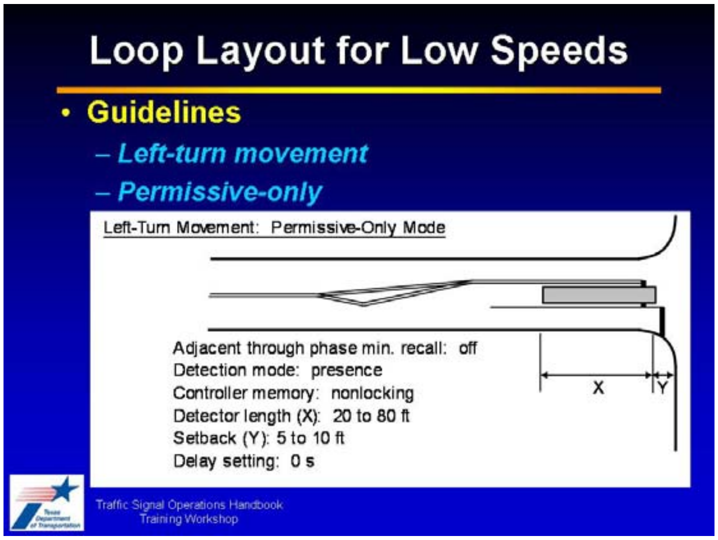


Key Message:
Detection design for protected or protected-permissive left-turn movements should be about the same as that for through movements. A delay of 5-12 s is desirable if protected-permissive mode is used.

Interactivity:
Tell: Generally, the detection design for a left-turn movement is the same as that for a through movement.

Tell: It is desirable to use a delay setting of 5-12 s if protected-permissive mode is used for the left-turn movement, to avoid calling the left-turn phase if the drivers are able to turn permissively. Use delays at the high end of the range if high speeds or volumes exist on the opposing through approach.

Slide 220

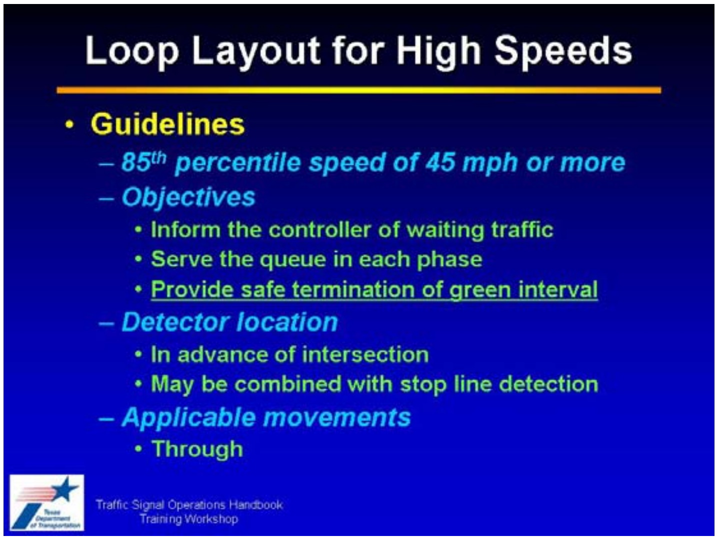


Key Message:
Detection design for permissive left-turn movements should be about the same as that for through movements. The detector should be extended beyond the stop line to avoid stranding turning vehicles in the intersection if the adjacent through phase is not on recall.

Interactivity:
Tell: Generally, the detection design for a left-turn movement is the same as that for a through movement.

Tell: If the adjacent through phase is not on recall, extend the detector beyond the stop line to avoid stranding turning vehicles in the intersection at the end of the phase.

Slide 221



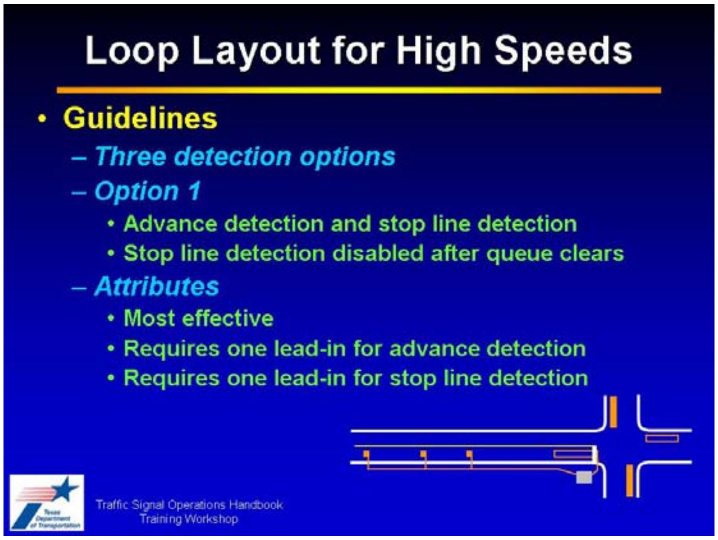
Key Message:
On high-speed approaches (45 mph or greater), loop layout should be designed to provide safe termination of the green interval, in addition to informing the controller of waiting traffic and serving queues in each phase.

Interactivity:
Tell: As was the case with low-speed approaches, loop layout at high-speed approaches should be designed to inform the controller of waiting traffic and allow queues in each phase to be served. Additionally, it is necessary to provide safe termination of the green interval for the high-speed movements.

Tell: To accomplish these objectives, place detectors in advance of the intersection. These detectors may be combined with, or work independently of, the stop line detectors.

Tell: Advance detection is only needed on the through movements that have high speeds.

Slide 222



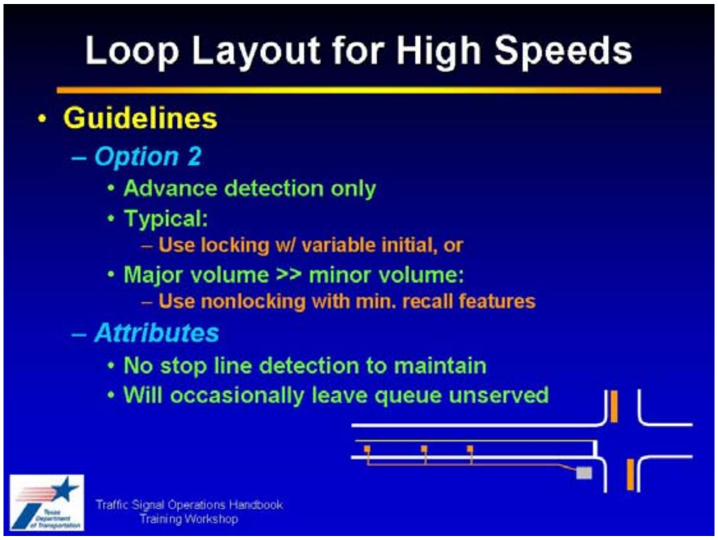
Key Message:
The first of three options for high-speed loop layout is to provide advance detection and stop line detection, and to disable the stop line detection after the initial queue clears.

Interactivity:
Tell: The first option for high-speed loop layout is to provide advance detectors and a stop line detector. The advance detectors provide indecision zone protection. The stop line detector ensures that initial queues can clear, but is deactivated when the queue clears.

Tell: This option is the most effective because it provides the needed detection while avoiding unnecessary green extensions at the stop line after the queue has cleared.

Tell: To deactivate the stop line detector after the queue clears, the stop line detector must not share the same detection channel as the advance detectors.

Slide 223



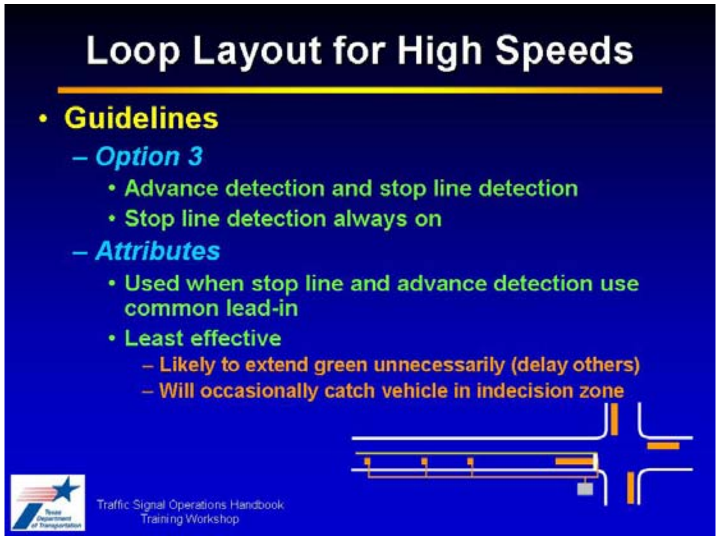
Key Message:
The second of three options for high-speed loop layout is to provide advance detection only.

Interactivity:
Tell: The second option for high-speed loop layout is to provide advance detectors only.

Tell: For typical volumes, the advance detectors would be operated with locking memory and the variable initial feature would be used. If the major-road volume is much greater than the minor-road volume, nonlocking memory can be used along with a minimum recall on the major-road through phases.

Tell: This option eliminates the maintenance issues often associated with stop line loop detectors. However, queues may occasionally be left unserved.

Slide 224

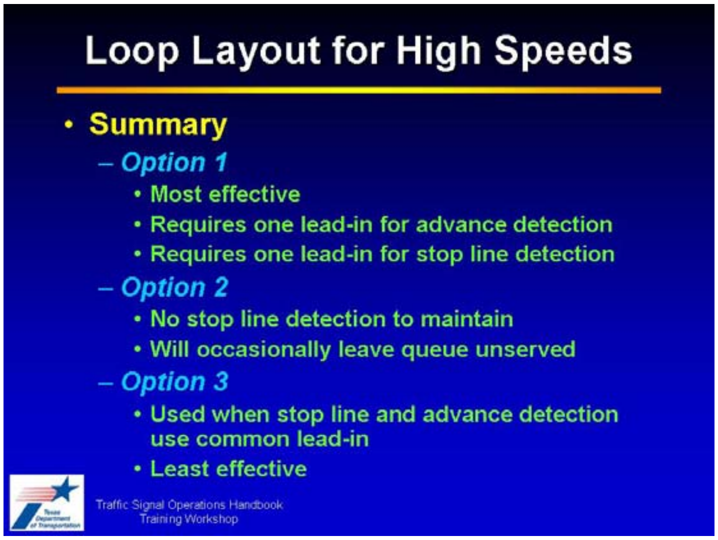


Key Message:
The third of three options for high-speed loop layout is to provide advance detection and stop line detection, and to leave the stop line detection active after the initial queue clears.

Interactivity:
Tell: The third option for high-speed loop layout is to provide advance detectors and a stop line detector. The advance detectors provide indecision zone protection. The stop line detector ensures that initial queues can clear. All of the detectors share the same detection channel.

Tell: This option is the least effective because it extends the green unnecessarily when free-flowing vehicles pass over the stop line detector. As a result, max-out may occur more frequently, which can catch vehicles in the indecision zone.

Slide 225



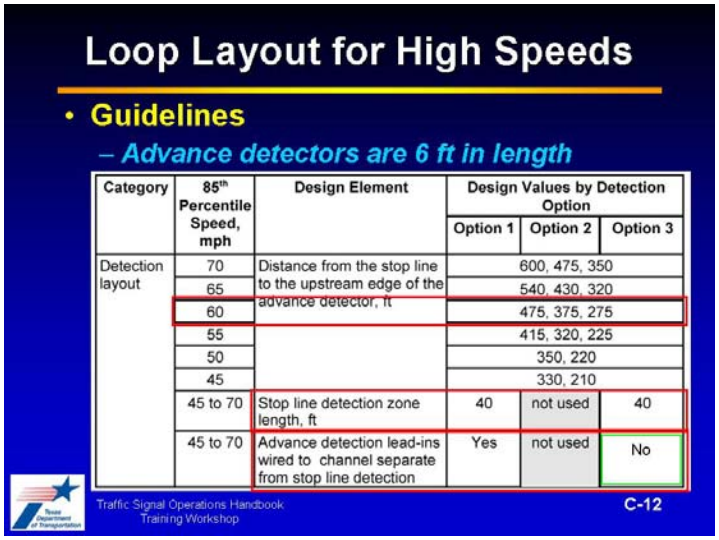
Key Message:
Three options are available for loop layout on high-speed approaches.

Interactivity:
Tell: Option 1 is the most effective, but it requires separate lead-ins for the advance and stop line detectors so the stop line detector can be deactivated after queue clearance.

Tell: Option 2 eliminates the maintenance issues associated with stop line detection, but occasionally leaves queues unserved.

Tell: Option 3 is used when the advance and stop line detectors share the same lead-ins. It is the least effective option.

Slide 226



Key Message:
Detection design guidelines for high-speed approaches are summarized in Table C-3 of the *Handbook*.

Interactivity:
Tell: Table C-3 is found on page C-12 of the *Handbook*. The top half of the table addresses detection layout. Three design elements are covered: Distance to advance detectors, stop line detection zone length, and detection lead-in wiring.

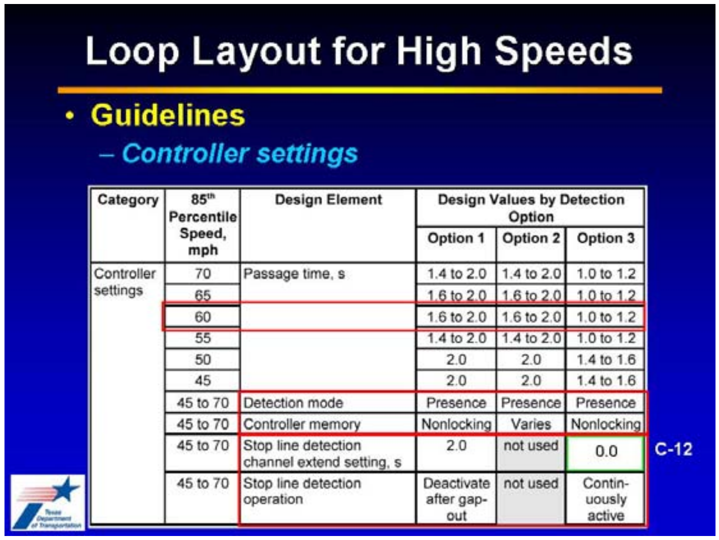
Click: For an approach with an 85th percentile speed of 60 mph, the three advance detectors should be placed 475, 375, and 275 feet from the stop line.

Click: If options 1 or 3 are used, the stop line detector should be 40 feet long. No stop line detector is used with option 2.

Click: The details for the detection lead-in wiring are provided for the three options.

Tell: An erratum for this table is boxed in green. For option 3, the cell describing the detector lead-in wiring should read “No” instead of “Not necessary”.

Slide 227



Category	85th Percentile Speed, mph	Design Element	Design Values by Detection Option		
			Option 1	Option 2	Option 3
Controller settings	70	Passage time, s	1.4 to 2.0	1.4 to 2.0	1.0 to 1.2
	65		1.6 to 2.0	1.6 to 2.0	1.0 to 1.2
	60		1.6 to 2.0	1.6 to 2.0	1.0 to 1.2
	55		1.4 to 2.0	1.4 to 2.0	1.0 to 1.2
	50		2.0	2.0	1.4 to 1.6
	45		2.0	2.0	1.4 to 1.6
	45 to 70	Detection mode	Presence	Presence	Presence
	45 to 70	Controller memory	Nonlocking	Varies	Nonlocking
	45 to 70	Stop line detection channel extend setting, s	2.0	not used	0.0
	45 to 70	Stop line detection operation	Deactivate after gap-out	not used	Contin-uously active

Key Message:
Detection design guidelines for high-speed approaches are summarized in Table C-3 of the *Handbook*.

Interactivity:
Tell: Table C-3 is found on page C-12 of the *Handbook*. The bottom half of the table addresses controller settings. Five design elements are covered: Passage time, detection mode, controller memory, stop line detection channel extend setting, and stop line detector operation.

Click: For an approach with an 85th percentile speed of 60 mph, the passage time should be between 1.6 and 2.0 s if options 1 or 2 are used, or between 1.0 and 1.2 s if option 3 is used.

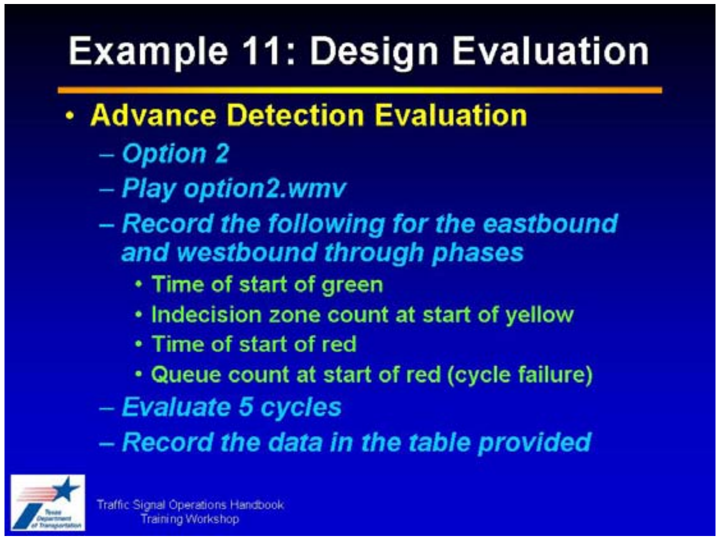
Tell: The passage time ranges for option 3 are shorter to reduce this option's tendency to max out more frequently. However, these shorter passage times may yield less than optimum indecision zone protection for slower vehicles.

Click: The guidelines specify detection mode and controller memory settings for each option.

Click: Extend settings and stop line detection operation are described in the bottom portion of the table.

Tell: An erratum for this table is boxed in green. For option 3, the cell describing the stop line detection channel extend setting should read "0.0" instead of "1.0".

Slide 228



Key Message:
Advance detection can be evaluated by counting vehicles in the indecision zone at the start of yellow and queued vehicles at the start of red.

Interactivity:
Tell: Go to page 111 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: In this example, we are evaluating option 2 for advance detection loop layout. This layout consists of advance detectors but no stop line detectors.

Tell: This example problem is guided. We will extract our data from the option2.wmv file and record it in the AdvDet.xls file.

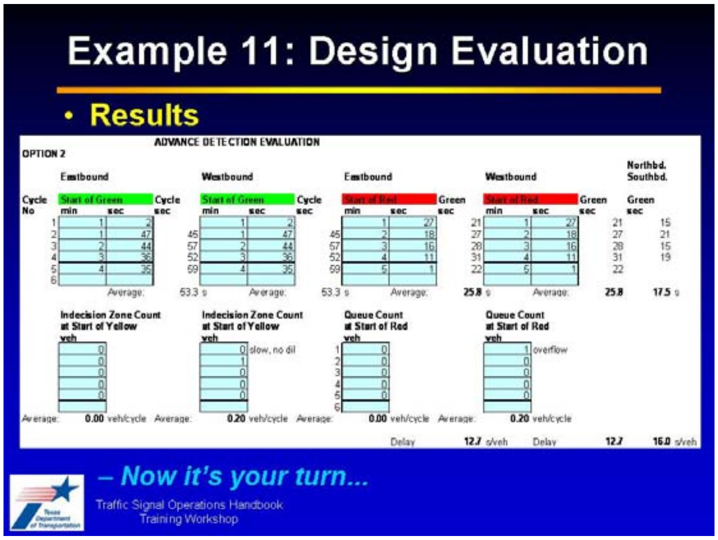
Notes:
After finishing with this slide, switch over to the option2.wmv file on the CD. Play it and show the participants where to look to obtain the following observations:

- Start of green time,
- Start of red time,
- Indecision zone count at start of yellow, and
- Queue count at start of red.

The start of green time and start of red time are extracted from the time clock for the option2.wmv file. The location of this clock may vary depending on which program is used to play the file. The count of vehicles in the indecision zone is done based on the travel time definitions (between 2.5 s and 5.5 s travel time to the stop line).

Do this for one cycle, and then demonstrate how to enter the data into the AdvDet.xls file. Repeat for up to the next four cycles as desired.

Slide 229



Key Message:
In this example, option 2 performed well.

Interactivity:
Tell: The green time calculations show that no max-outs occurred.

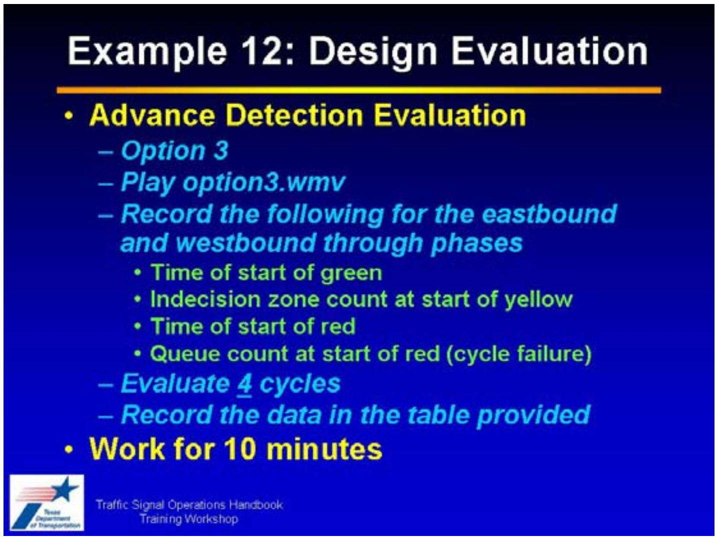
Tell: One vehicle was caught in the indecision zone at the start of yellow, in five cycles observed.

Tell: One of the five cycles had a queued vehicle present at the start of red.

Tell: Overall, option 2 performed well. The average delay to the major-road through movements was 16.0 s per vehicle.

Click: Now it's your turn. Another example follows where we will evaluate option 3.

Slide 230



Key Message:
Advance detection can be evaluated by counting vehicles in the indecision zone at the start of yellow and queued vehicles at the start of red.

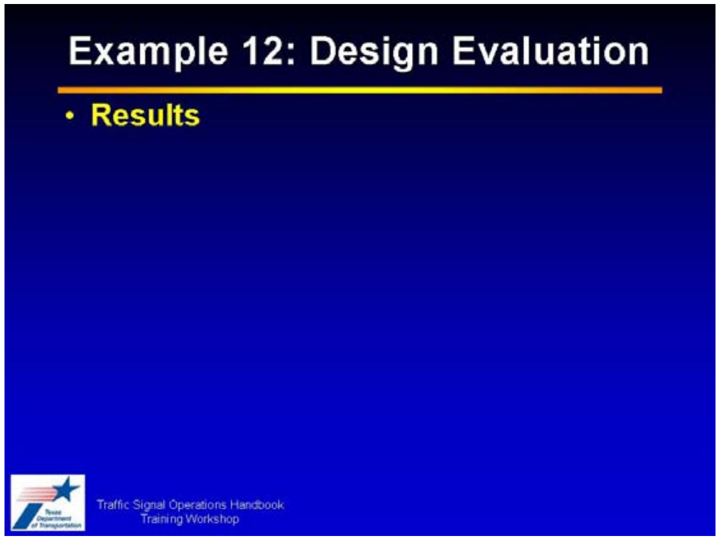
Interactivity:
Tell: Go to page 112 in the Course Notes booklet, where the given data are repeated and space is provided to record answers.

Tell: In this example, we are evaluating option 3 for advance detection loop layout. This layout consists of advance detectors and stop line detectors, with all detectors for each phase sharing the same lead-ins.

Tell: Spend about 10 minutes reviewing the option3.wmv file and entering the needed observations into AdvDet.xls file. Evaluate four cycles.

Follow up: Leave the instructor's podium and walk around the room as the participants work on the exercise. Offer help to individual participants when needed. When the participants appear to have arrived at the correct answer, return to the instructor's podium and continue the workshop presentation.

Slide 231



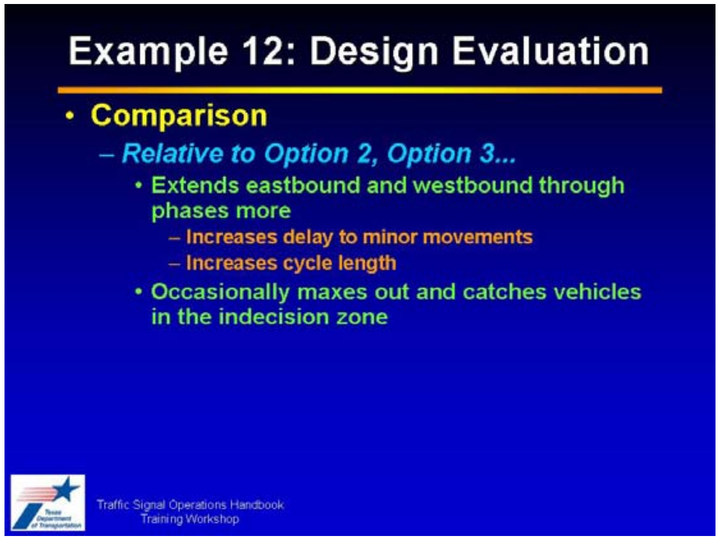
Key Message:
The observations obtained from the footage of option 3's operation can be used to evaluate the advance detection layout.

Interactivity:
Ask: What is the average delay to the eastbound and westbound movements?

Click: The average delay is 25.2 s per vehicle.

Tell: Notice that max-outs occurred in cycles 2, 3, and 4.

Slide 232



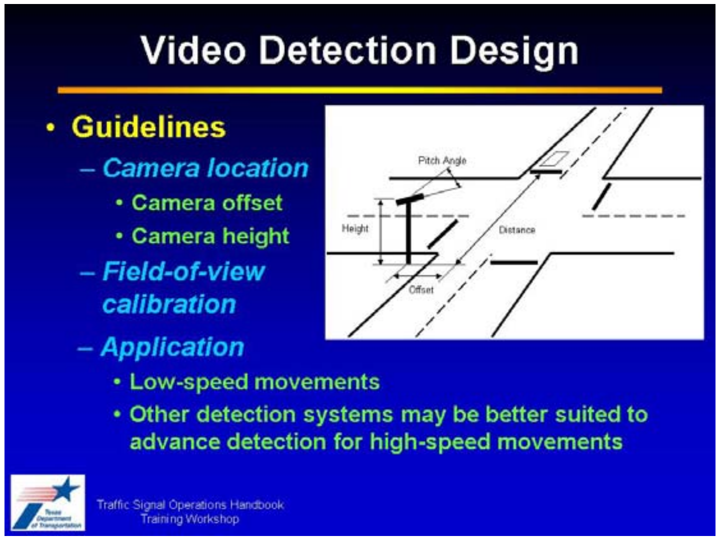
Key Message:
Option 3 caused more frequent max-outs than option 2, and was less effective in protecting drivers from the indecision zone.

Interactivity:
Tell: Because option 3 involves using stop line detectors that remain active after queue clearance, the green indications were extended more than needed, resulting in more frequent max-outs.

Tell: When max-out occurs, the green indication ends arbitrarily, regardless of whether vehicles are present in the indecision zone. Five vehicles were caught in the indecision zone in cycles 2, 3, and 4.

Tell: Max-outs also cause delay increases to minor movements. The average delay was higher for option 3 than for option 2.

Slide 233



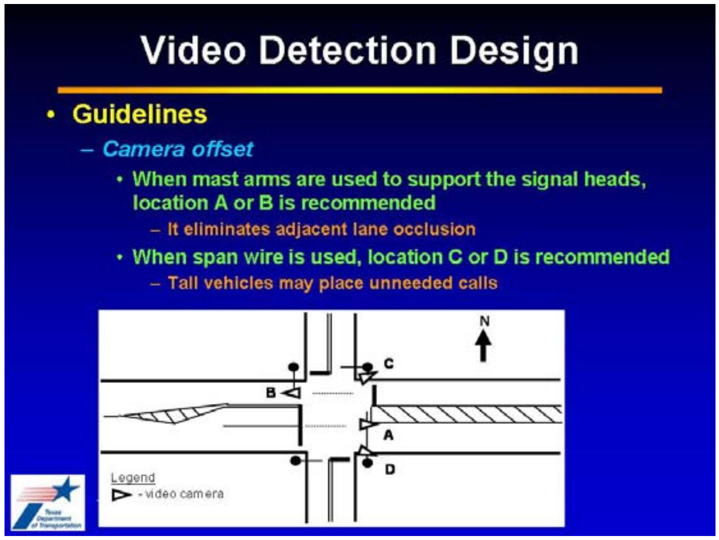
Key Message:
Effective video detection operation is dependent on proper camera placement and field-of-view calibration. Video detection works well for stop line detection applications on low-speed movements. Other systems are better suited to provide advance detection for high-speed movements.

Interactivity:
Tell: The *Handbook* provides guidelines for camera location, including offset and height. Proper camera placement is essential to achieving effective video detection operation.

Tell: The camera field of view is calibrated by adjusting the pitch angle and the lens focal length. Good calibration helps to improve accuracy by minimizing glare from the sun or other lighting sources.

Tell: Video detection is effective for stop line detection on low-speed movements. It should not be used for advance detection on high-speed movements. For advance detection applications, the distances to the detection zones are too great and the size of the detection zones in the camera's field of view are too small to allow accurate operation. Failure to detect high-speed vehicles is unacceptable because it can cause drivers to be caught in the indecision zone.

Slide 234



Key Message:
Cameras should be placed to minimize lane occlusion, but they must be placed on solid support where movement is minimal.

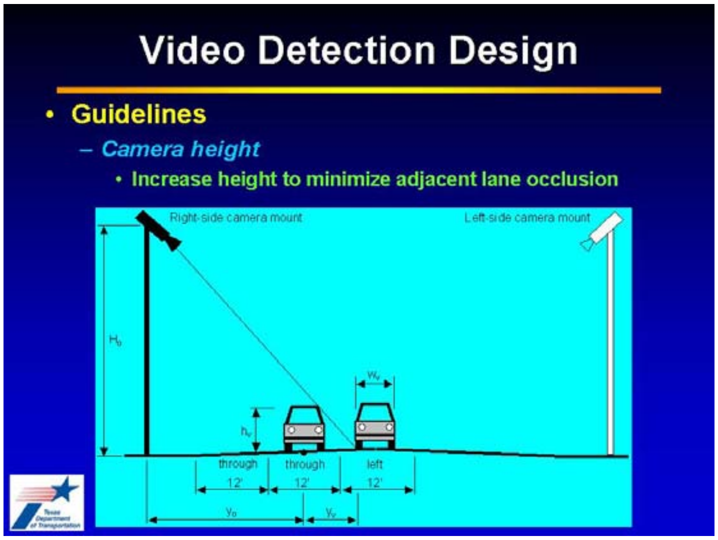
Interactivity:
Tell: Video detection cameras may be placed on solid supports like signal poles, luminaire poles, or mast arms. They cannot be placed on span wire.

Tell: If the signal heads are placed on mast arms, place the cameras at location A or B. These locations eliminate lane occlusion by allowing the cameras to face directly at the approach being monitored.

Tell: If the signal heads are supported by span wire, place the cameras at location C or D. These locations may result in unneeded calls caused by lane occlusion, but they are the only options for solid support if span wire is used.

Tell: Occlusion occurs when tall vehicles are present and the camera views the approach from an angle. With this geometry, a tall vehicle may appear to occupy multiple lanes or different lanes, which can result in unneeded calls. For example, a camera at location D may generate a false call for the eastbound left-turn phase if a large truck stops in the through lane, as the truck may appear to be in the left-turn lane from that angle.

Slide 235



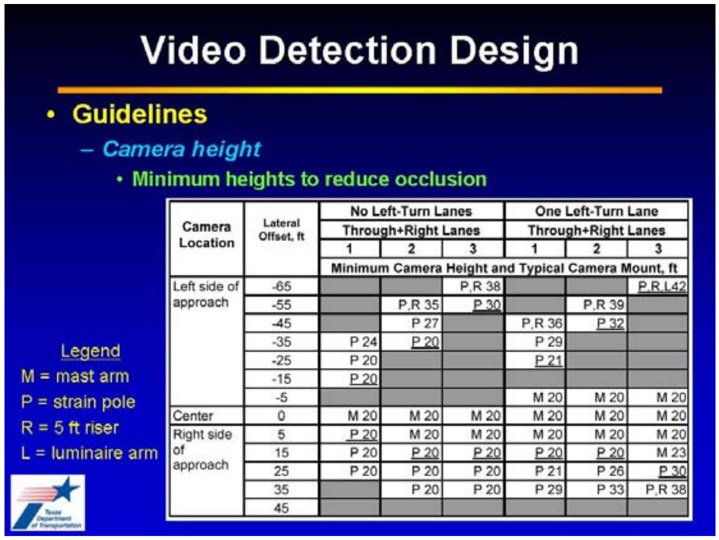
Key Message:
Lane occlusion can be minimized by mounting the camera at higher locations.

Interactivity:
Tell: In this example, we want to use the right-side camera mount (the black camera in the diagram) to provide detection for both the through and adjacent left-turn movements. We must avoid or minimize the occurrence of occlusion, when a through vehicle may appear to be in the left-turn lane.

Tell: The required mounting height is influenced by the camera offset (horizontal distance from the location of the left-turning vehicle to the camera) and the height of the vehicle in the adjacent through lane.

Tell: A similar problem can occur if the left-side camera mount (the white camera in the diagram) is used. In that case, a left-turning vehicle may appear to be in the adjacent through lane. This situation can cause an unneeded call to the through phase.

Slide 236



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

Key Message:
Table C-4 of the *Handbook* summarizes the guidelines for camera height and offset.

Interactivity:
Tell: The first column of Table C-4 the three camera location categories are specified. The camera can be placed to the left of the monitored approach, centered on the lane line that separates the through and left-turn movements, or to the right of the monitored approach.

Tell: The lateral offset is provided in the second column of Table C-4. For the analyst, the offset is dictated by the intersection width and the location of the signal mounting hardware (mast arm and/or pole).

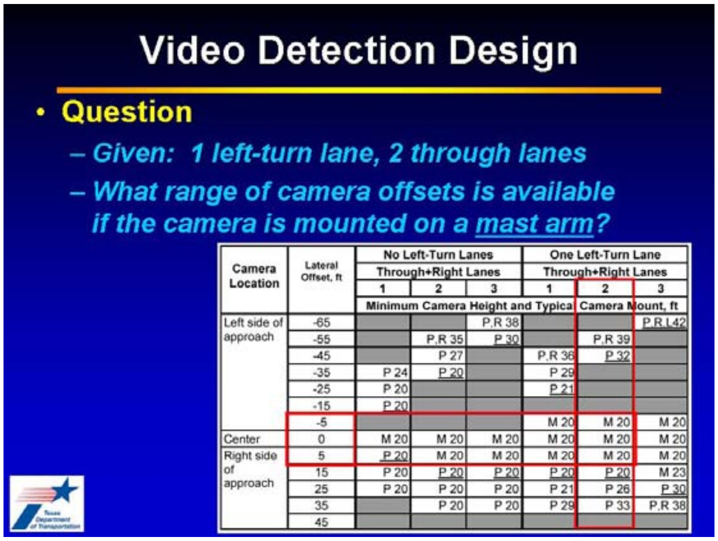
Tell: Table C-4 contains two sets of three columns, each set corresponding to presence or absence of left-turn lanes. The three columns in each set correspond to the number of through and right-turn lanes present on the monitored approach.

Tell: The letters in Table C-4 refer to the type of camera support used—mast arm, strain pole, five-foot riser, or luminaire arm.

Tell: The numbers in Table C-4 provide the minimum mounting height needed to reduce the occurrence of occlusion. Underlined values represent typical lateral offsets when the camera is mounted within 10 feet of the edge of the traveled way.

Tell: A minimum height of 20 feet is recommended to keep the camera lens clean of the dirt, spray, and mist that are generated in roadway environments.

Slide 237



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

Key Message:
Table C-4 of the *Handbook* can be used to identify a range of acceptable camera offsets for a given mounting location and intersection geometry.

Interactivity:
Tell: We have an intersection approach with one left-turn lane and two through lanes. We want to mount a video detection camera on the mast arm.

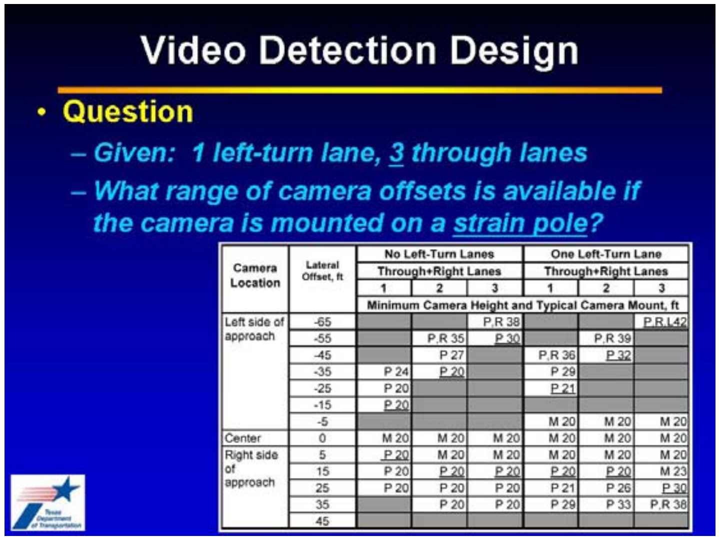
Ask: What range of camera offsets is available?

Click: Start by choosing the appropriate column in the table. We have one left-turn lane and two through lanes.

Click: Three of the rows in this column describe mast arm mounting, as denoted by the letter "M".

Click: These rows correspond to camera offsets within five feet of either side of the lane line that separates the through lanes and the left-turn lane.

Slide 238



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

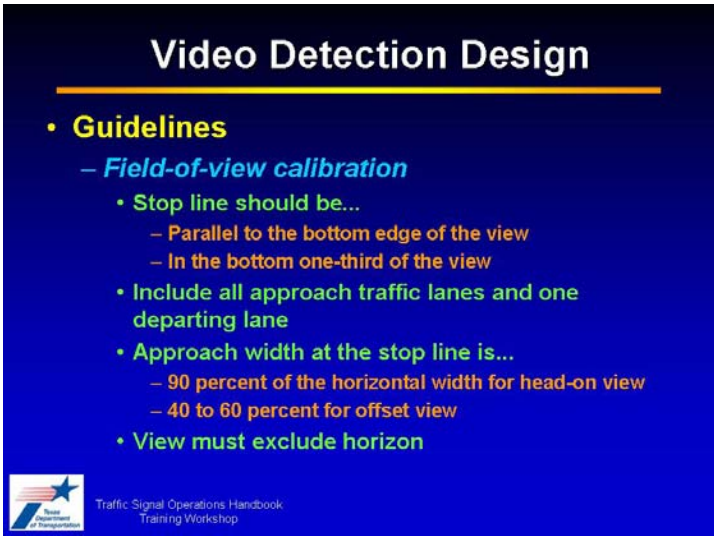
Key Message:
Table C-4 of the *Handbook* can be used to identify a range of acceptable camera offsets for a given mounting location and intersection geometry.

Interactivity:
Tell: We now have an intersection approach with one left-turn lane and *three* through lanes. We want to mount a video detection camera on a strain pole.

Ask: What range of camera offsets is available?

Tell: The camera can be offset by 65 feet if mounted on the left side, or 25-35 feet if mounted on the right side.

Slide 239



Key Message:
Field-of-view calibration involves adjusting the pitch angle and lens focal length to obtain the optimal view. The objective is to obtain a view of all movements requiring detection while avoiding glare from the sun or other lighting sources.

Interactivity:
Tell: The objective of field-of-view calibration is to obtain a view of all movements requiring detection while avoiding glare from the sun or other lighting sources. This is accomplished by adjusting the pitch angle and the lens focal length.

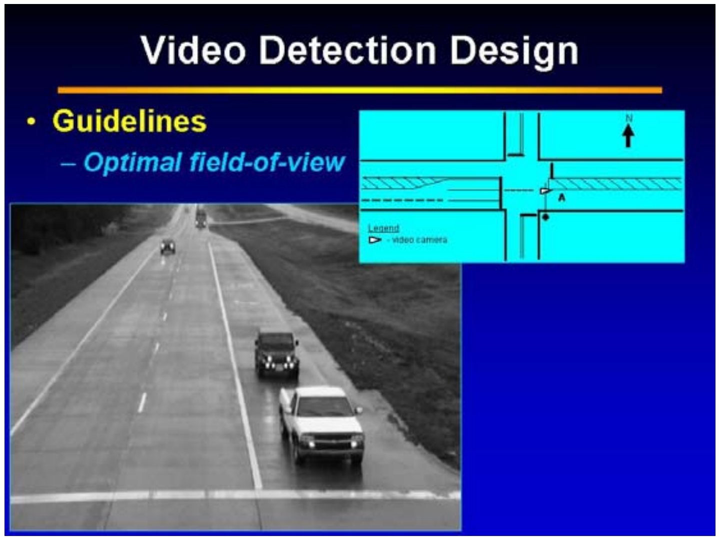
Tell: The stop line on the approach should be parallel to the bottom edge of the camera view and located in the bottom one-third of the view.

Tell: The view should include all approach lanes and one departing lane, unless there is a median that prevents the departing lane from fitting within the view.

Tell: For head-on views, the approach width at the stop line should be 90 percent of the view width. For offset views, it should be 40-60 percent of the view width.

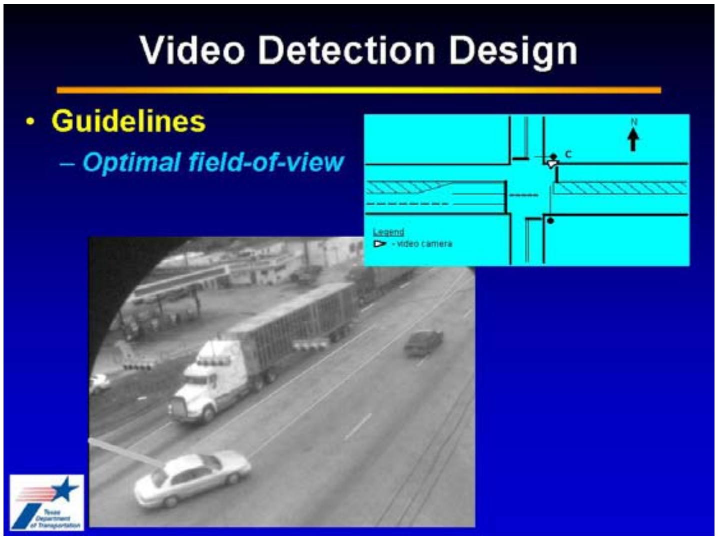
Tell: Exclude the horizon from the view. The bright sky can reduce the sensitivity of the camera by causing it to narrow its iris, and the sun can cause glare problems.

Slide 240



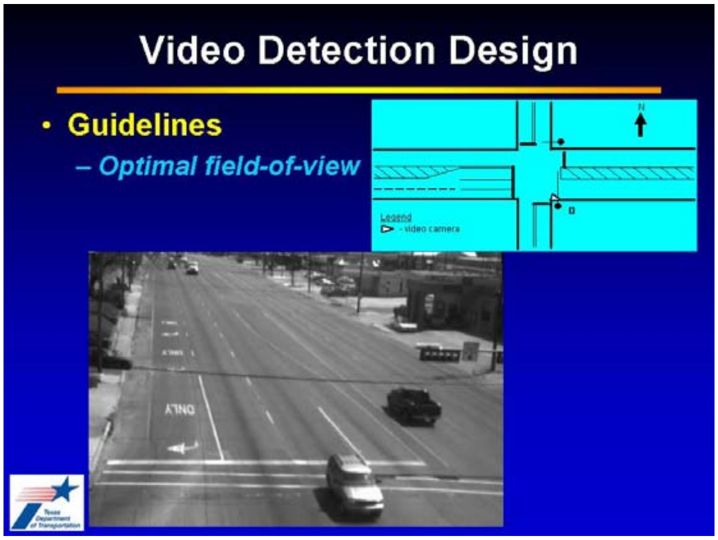
Key Message:
An optimal field of view includes all approach lanes and one departing lane (unless a median is present) and excludes the horizon. For head-on views, the approach width at the stop line should be 90 percent of the view width and the stop line should be parallel to the bottom edge of the view and located in the bottom one-third of the view.

Slide 241



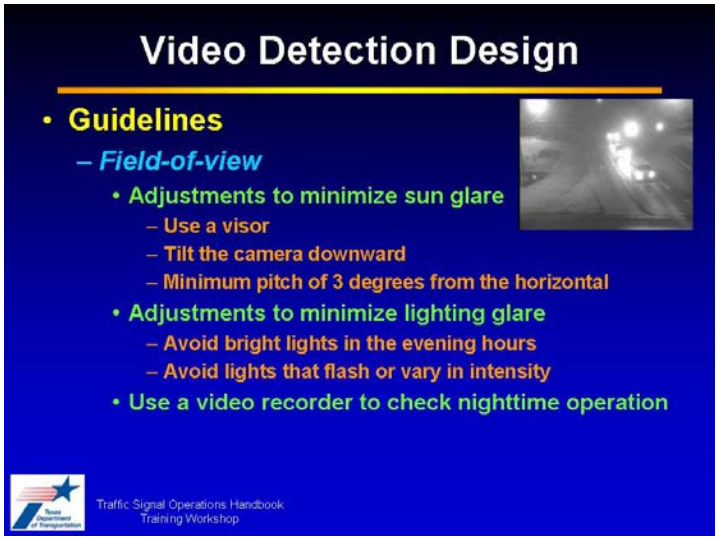
Key Message:
The optimal field of view is not achievable for most left-side camera offsets, but effort should still be made to include all approach lanes while excluding the horizon. The approach width at the stop line should be at least 40-60 percent of the view width along the same line.

Slide 242



Key Message:
The optimal field of view is achievable for many right-side camera offsets. The approach width at the stop line should be at least 40-60 percent of the view width along the same line.

Slide 243



Key Message:
The camera field of view should be adjusted to minimize glare from the sun and other lighting sources. It should also be checked under different lighting conditions to verify adequate operation.

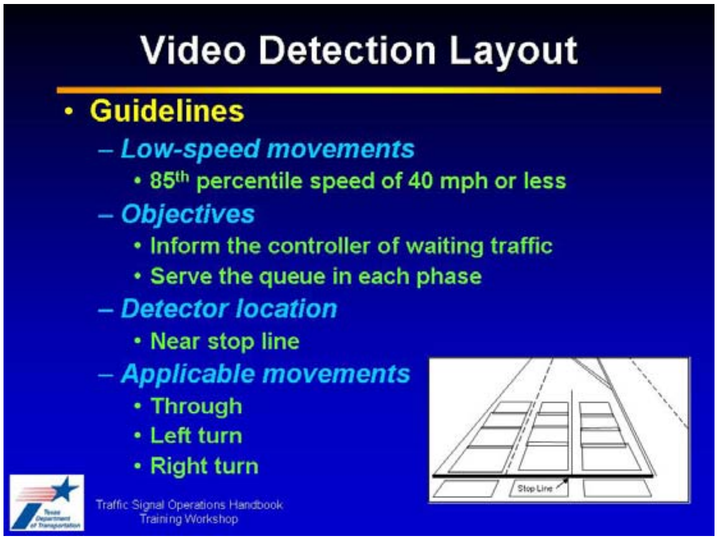
Interactivity:
Tell: Adjust the camera view to minimize sun glare. A visor can help reduce glare. It is also advisable to tilt the camera downward, at least three degrees down from the horizontal.

Tell: This picture shows glare from luminaires, which can affect detection accuracy. Adjust the camera view to minimize glare from such sources. Avoid glare from bright lights in the evening hours, especially if the light flashes or varies in intensity.

Tell: If it is not possible to avoid glare, consider alternative camera locations or place the detection zones carefully to avoid the excess light.

Tell: Verify the detection operation under different lighting conditions—morning, noon, evening, and night. A video recorder can assist with this task, especially for times when a field visit would be inconvenient.

Slide 244

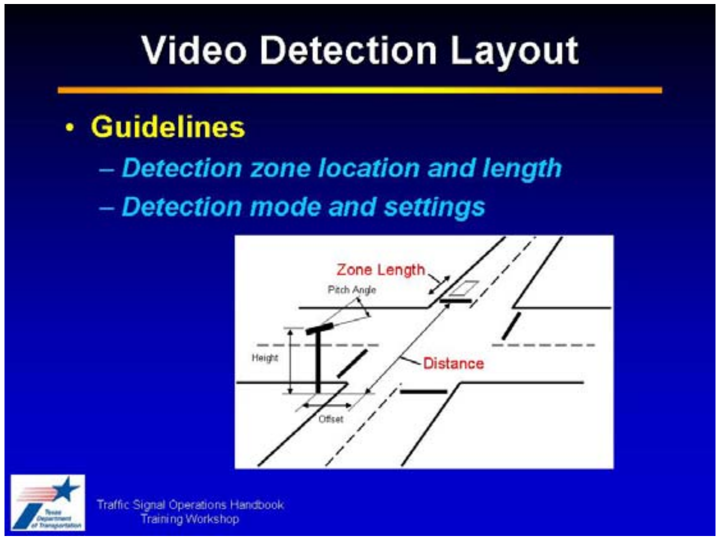


Key Message:
For low speeds (40 mph or less), video detection zones should be placed to inform the controller when waiting traffic is present and to serve queues in each phase.

Interactivity:
Tell: Speeds of 40 mph or less are considered “low” for video detection purposes. For low speeds, the objectives of video detection zone layout are to inform the signal controller when waiting vehicles are present, and to allow the queue in each phase to be served before its green indication ends.

Tell: To accomplish these objectives, place the detectors near the stop line. All movements require detection—through, left-turn, and right-turn.

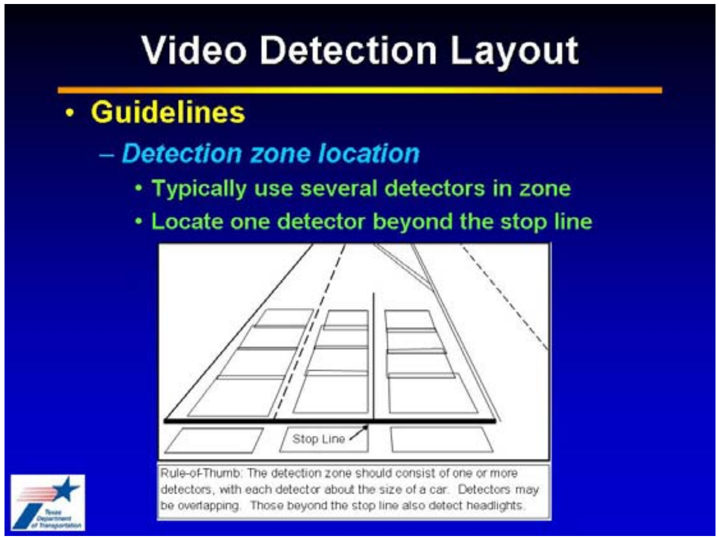
Slide 245



Key Message:
The *Handbook* guidelines for video detection layout cover detection zone location and length, mode, and settings.

Interactivity:
Tell: The *Handbook* guidelines for video detection layout refer to distance and zone length. The distance is measured between the camera and the stop line. The zone length is measured in the direction of travel along the zone. These measurements are illustrated.

Slide 246



Key Message:
A detection zone is typically drawn using several overlapping detectors, each about the size of a car.

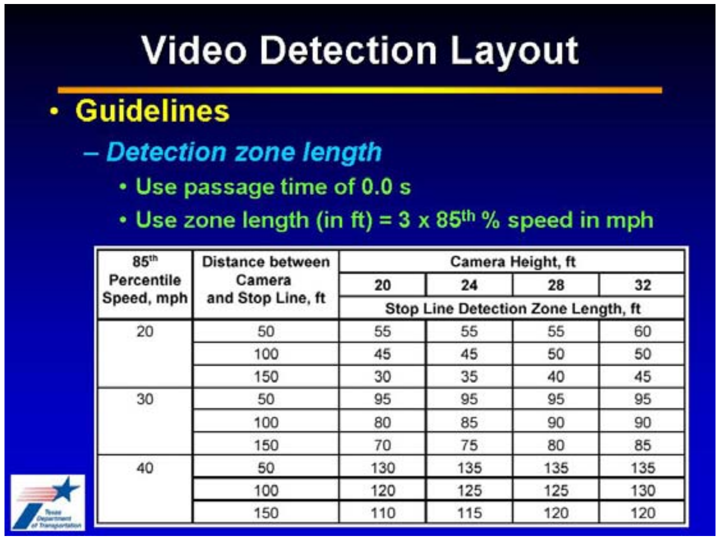
Interactivity:
Tell: A single detection zone is typically drawn using several overlapping detectors that collectively extend about 80 feet back from the stop line. This provides very reliable queue service.

Tell: Using multiple detectors instead of one long detector maximizes sensitivity because each detector will have a greater percentage of its pixels changed when a vehicle is present.

Tell: Placing detectors beyond the stop line allows vehicles to be detected if they stop beyond the stop line. It also increases detection sensitivity at night because vehicles' headlights shine on the pavement beyond the stop line.

Tell: Do not allow detectors to straddle pavement markings. Camera motion can cause pavement markings to move within a detector, possibly causing false calls. Notice that the detectors in this drawing are placed to avoid the lane lines and the stop line.

Slide 247



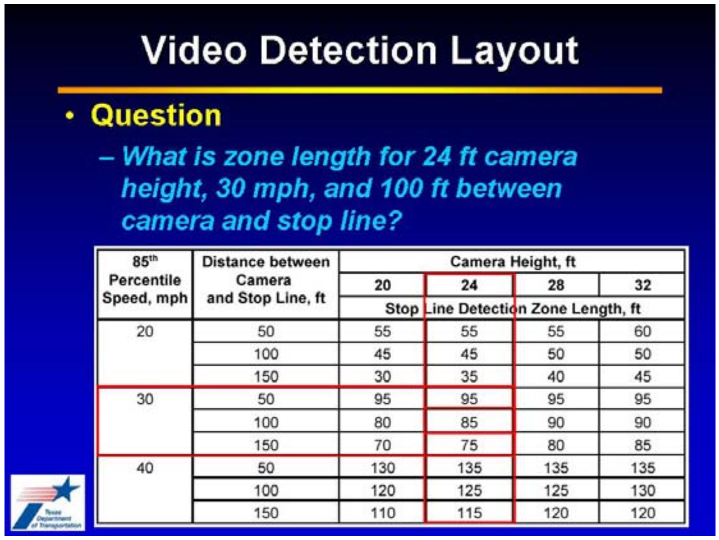
85th Percentile Speed, mph	Distance between Camera and Stop Line, ft	Camera Height, ft			
		20	24	28	32
		Stop Line Detection Zone Length, ft			
20	50	55	55	55	60
	100	45	45	50	50
	150	30	35	40	45
30	50	95	95	95	95
	100	80	85	90	90
	150	70	75	80	85
40	50	130	135	135	135
	100	120	125	125	130
	150	110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

Key Message:
Use a passage time of 0 s with video detection. As a rule of thumb, the length of the detection zones should equal three times the 85th-percentile speed in mph.

Interactivity:
Tell: Use a passage time of 0 s with video detection. Passage time is not needed because we can provide long enough detection zones to detect queues without incurring the maintenance costs associated with long loop detectors.

Tell: Detection zone length is influenced by speed and the distance between the camera and the stop line. A rule of thumb is to set the detection zone length equal to about three times the 85th-percentile speed in mph.

Slide 248



Key Message:
Video detection zone length is influenced by camera height, distance, and traffic speed. The *Handbook* guidelines for detection zone length are found in Table C-6.

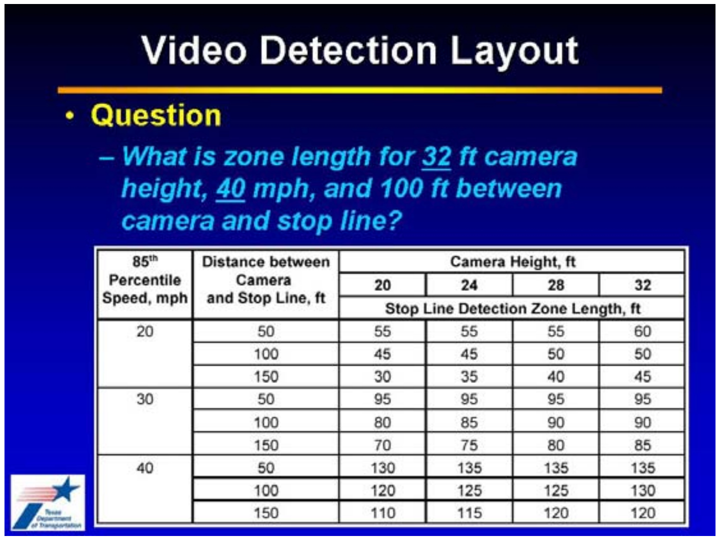
Interactivity:
Ask: What is the video detection zone length for a 24-foot camera height, an 85th-percentile speed of 30 mph, and a distance of 100 feet between the camera and the stop line?

Click: The four rightmost columns in Table C-6 correspond to different camera heights. Our camera height is 24 feet.

Click: Table C-6 provides three different options for detection zone length for a speed of 30 mph, depending on the distance between the camera and the stop line.

Click: For a distance of 100 feet, the recommended detection zone length is 85 feet.

Slide 249

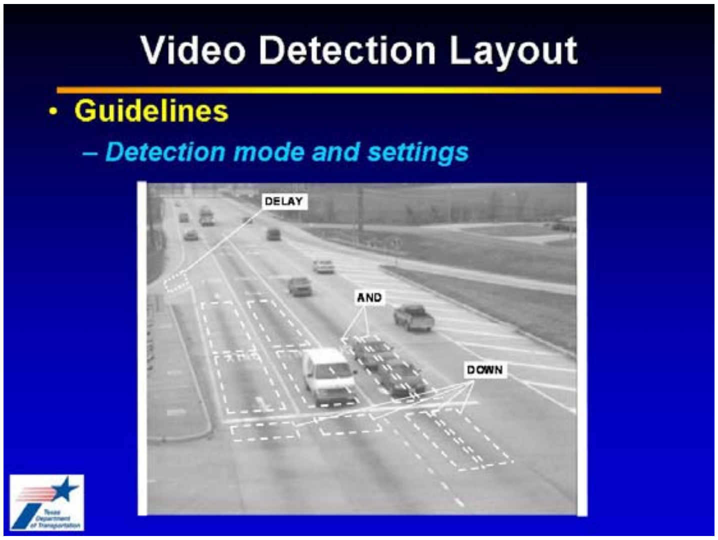


Key Message:
Video detection zone length is influenced by camera height, distance, and traffic speed. The *Handbook* guidelines for detection zone length are found in Table C-6.

Interactivity:
Ask: What is the video detection zone length for a 32-foot camera height, an 85th-percentile speed of 40 mph, and a distance of 100 feet between the camera and the stop line?

Tell: The recommended detection zone length is 130 feet.

Slide 250



Key Message:
With video detection, the detectors can be set to pulse or presence mode, and they can be linked to each other with Boolean functions.

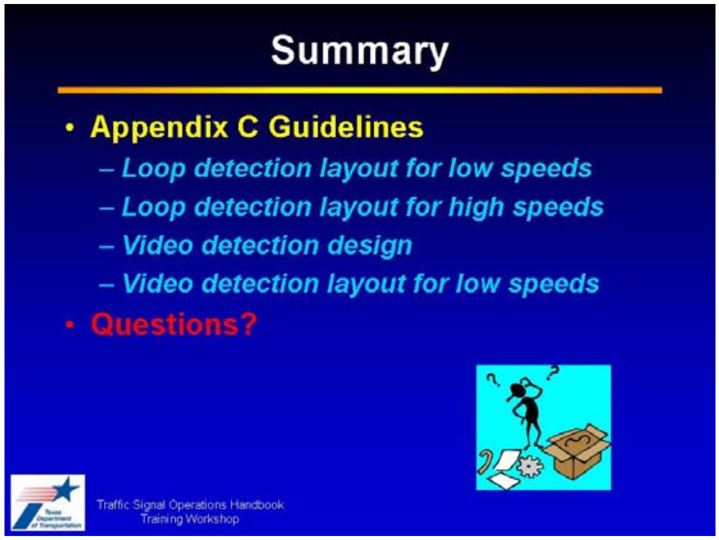
Interactivity:
Tell: As was the case with loop detectors, video detectors can be set to pulse or presence mode. Stop line detection applications require presence mode.

Tell: Boolean functions (AND, OR) can be used to link detectors. A typical detection zone is made with multiple detectors that are linked with the OR function. The AND function can be used to minimize false calls due to occlusion, as was done in the left-turn lane in this picture.

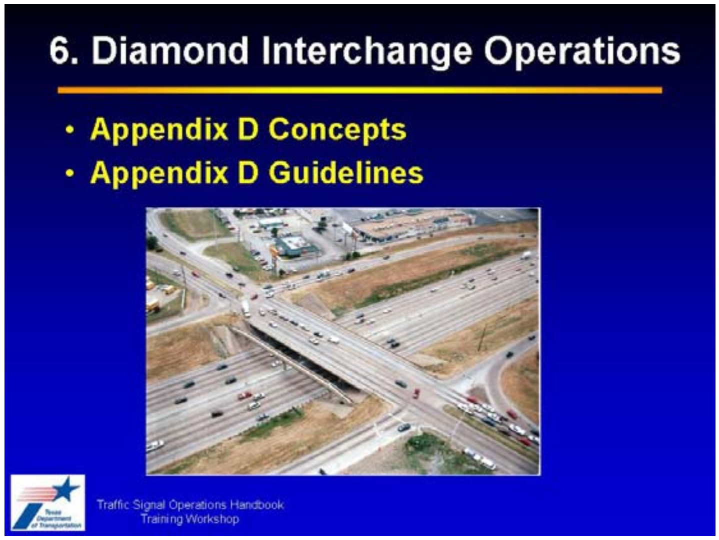
Tell: The DOWN function is used with detectors that are "directional", which means that they are only intended to detect vehicles moving in a certain direction. In this picture, the DOWN function is used with the detectors placed beyond the stop line so they will not register calls when vehicles on the cross street pass through them.

Tell: As was the case with loop detectors, video detectors can be programmed with delay or extend times. In this picture, a delay is used with the detector on the right-turn lane. This detector calls the through phase if right-turning drivers are unable to find safe gaps to turn, and they are about to spill back onto the street.

Slide 251

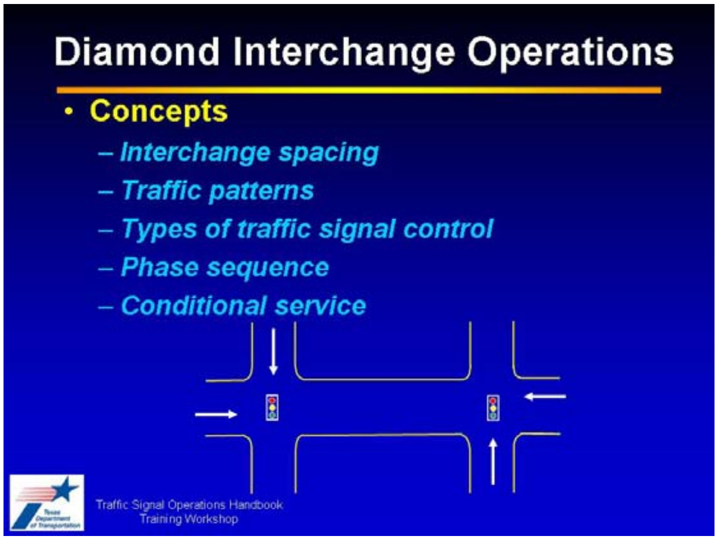

Summary
• Appendix C Guidelines
– Loop detection layout for low speeds
– Loop detection layout for high speeds
– Video detection design
– Video detection layout for low speeds
• Questions?
Traffic Signal Operations Handbook
Training Workshop

Slide 252



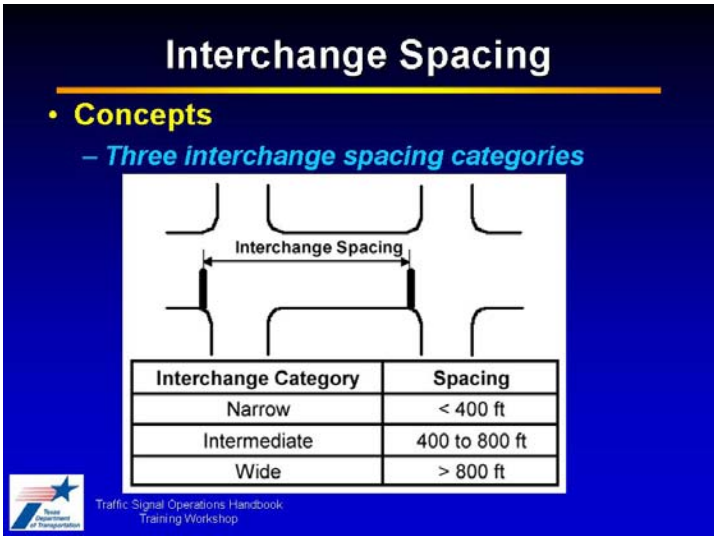
Key Message:
This lesson covers Appendix D of the *Handbook*. Appendix D focuses on signal timing for diamond interchange operations.

Slide 253



Key Message:
Diamond interchange signal timing is affected by site characteristics like interchange spacing and traffic patterns. Timing parameters to be determined include control type, phase sequence, and conditional service.

Slide 254

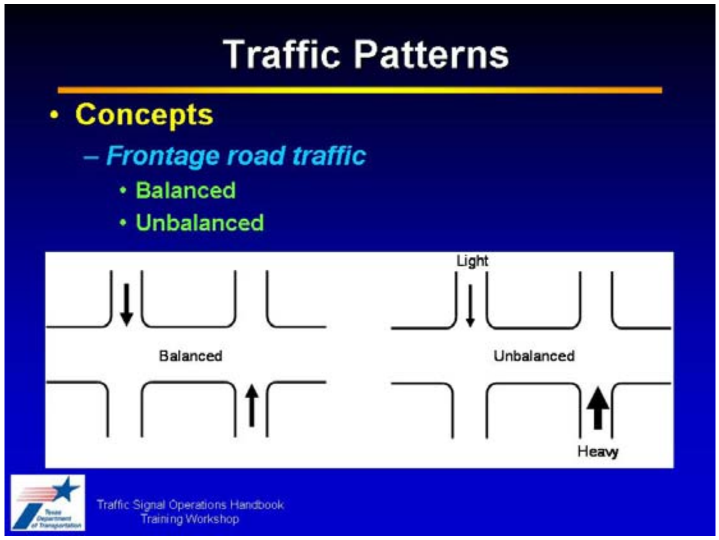


Key Message:
Diamond interchanges are categorized as narrow, intermediate, or wide, based on the distance between the two intersections.

Interactivity:
Tell: Interchange spacing is the distance between the two intersections at a diamond interchange. This distance is measured from one stop line to the next stop line in the same direction of travel.

Tell: Signals at narrow interchanges need to be timed carefully to avoid having vehicles stopped within the interchange. Wide interchanges have more space to store vehicles.

Slide 255

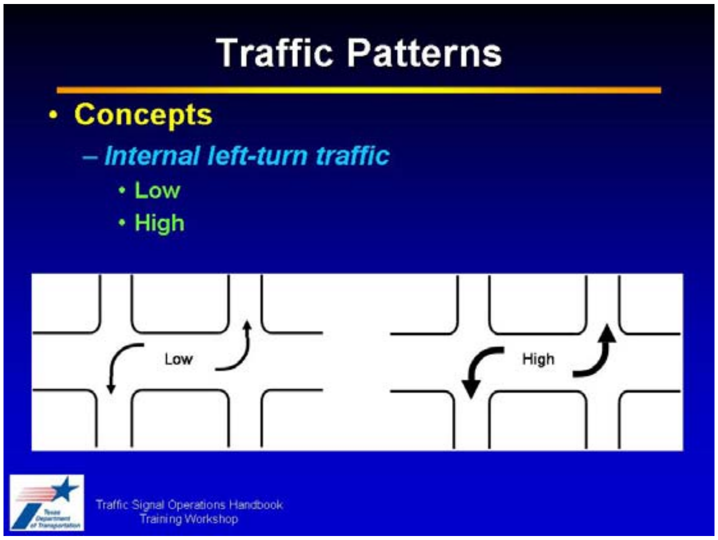


Key Message:
The frontage road traffic patterns can be described as balanced or unbalanced, based on how the volumes compare to each other.

Interactivity:
Tell: The example interchange on the left side of the diagram is considered to be “balanced” because its two frontage road approach volumes are approximately equal.

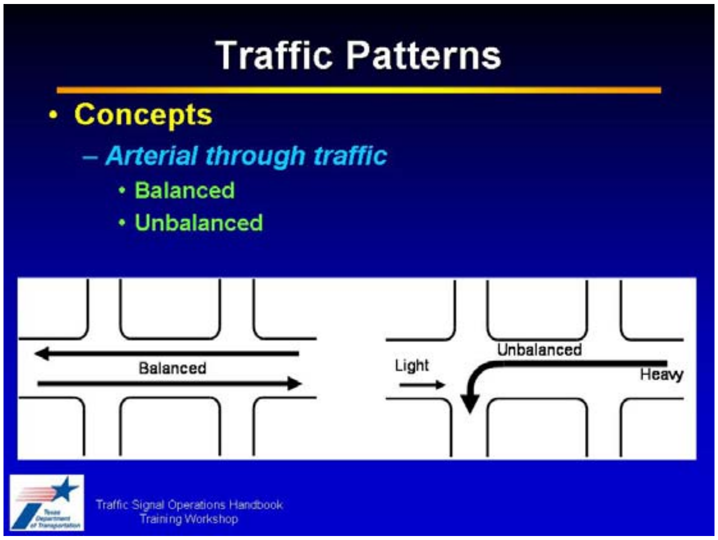
Tell: The example interchange on the right side of the diagram is considered to be “unbalanced” because its two frontage road approach volumes are different. One is notably heavier than the other.

Slide 256



Key Message:
The internal left-turn traffic can be described as low or high, depending on volume. The internal left-turn movements are illustrated.

Slide 257

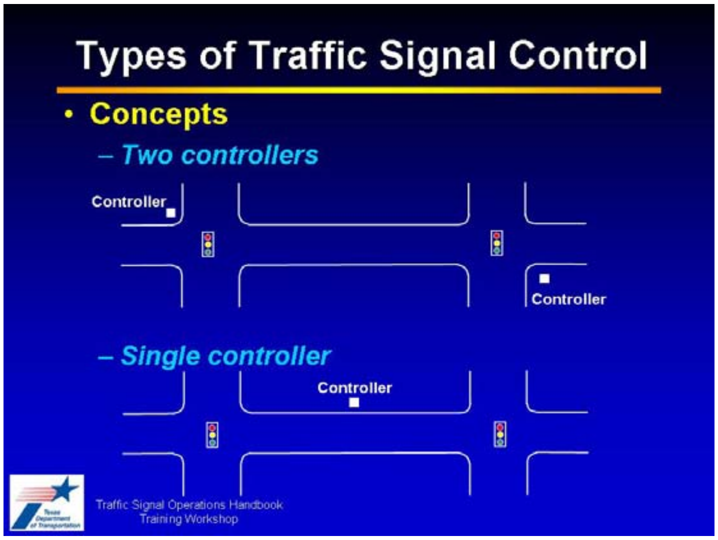


Key Message:
The arterial through traffic patterns can be described as balanced or unbalanced, depending on what proportion of the traffic is through vehicles.

Interactivity:
Tell: The example interchange on the left side of the diagram is considered to be "balanced" because most of the vehicles on the arterial street are through vehicles.

Tell: The example interchange on the right side of the diagram is considered to be "unbalanced" because most of the vehicles in one direction turn instead of proceeding through.

Slide 258



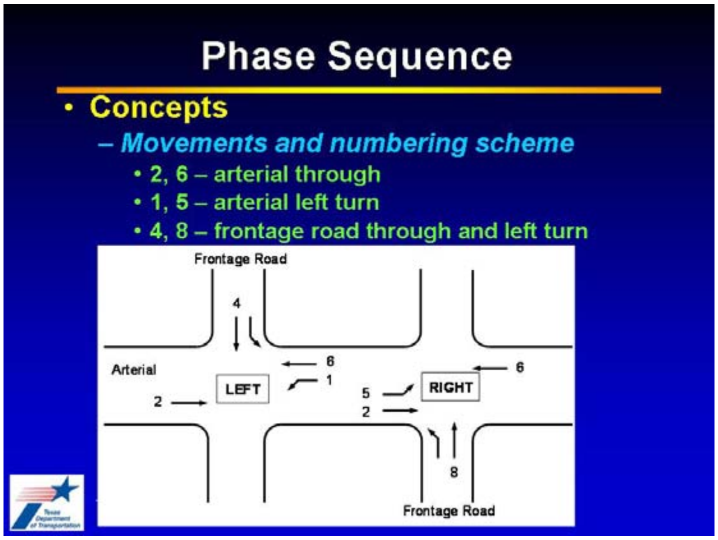
Key Message:
Diamond interchanges can be operated with one controller at each intersection, or with one controller connected to both intersections.

Interactivity:
Tell: The Texas Diamond Controller is used by TxDOT at diamond interchanges. This controller allows standard, fully-actuated operation.

Tell: A single controller is typically used to control a diamond interchange. The controller used is a dual-ring controller, with each ring assigned to one of the two intersections. This technique allows fully-actuated operation but preserves progression between the two intersections.

Tell: Using two controllers allows more variety in operational strategies, but requires knowledge of external coordination equipment and provision of more detector inputs and overlap outputs.

Slide 259



Key Message:
The movements at a signalized diamond interchange are numbered as shown in the diagram.

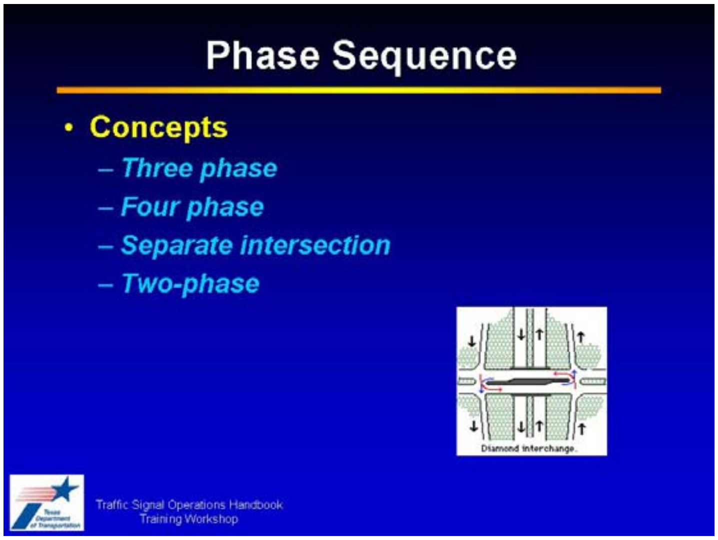
Interactivity:
Tell: Movements 2 and 6 are the arterial street through movements. This is similar to the convention of numbering the coordinated movements on an arterial street as 2 and 6.

Tell: Movements 1 and 5 are the internal left-turn movements. These drivers are turning onto the frontage roads. If frontage roads are not present, these drivers are entering the freeway.

Tell: Movements 4 and 8 are the frontage road through and left-turn movements. If frontage roads are not present, these drivers are exiting the freeway.

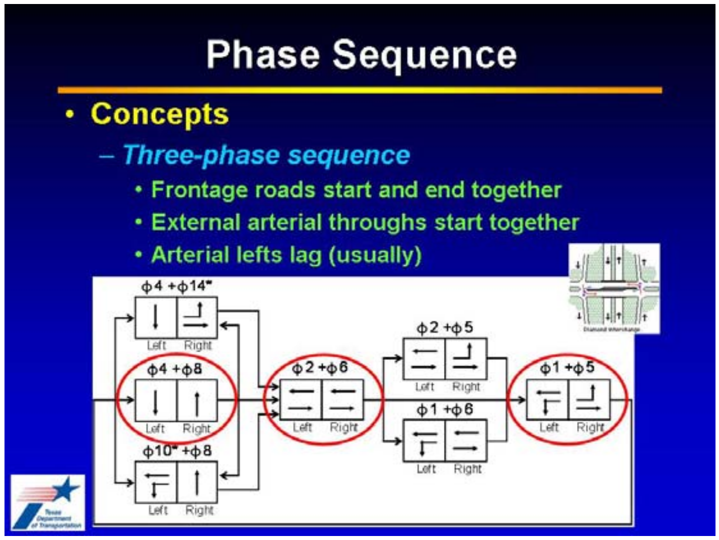
Tell: As the diagram is drawn, the two intersections are labeled “left” and “right”.

Slide 260



Key Message:
Four common phase sequences for signalized diamonds include three-phase, four-phase, separate intersection, and two-phase. These phase sequences are addressed in the *Handbook*.

Slide 261



Key Message:
In the three-phase sequence, the frontage road phases start and end together, the external arterial through phases start and end together, and the arterial left-turn phases usually lag the arterial through phases.

Interactivity:
Click: In this diagram, the frontage road phases are served first. They start and end together.

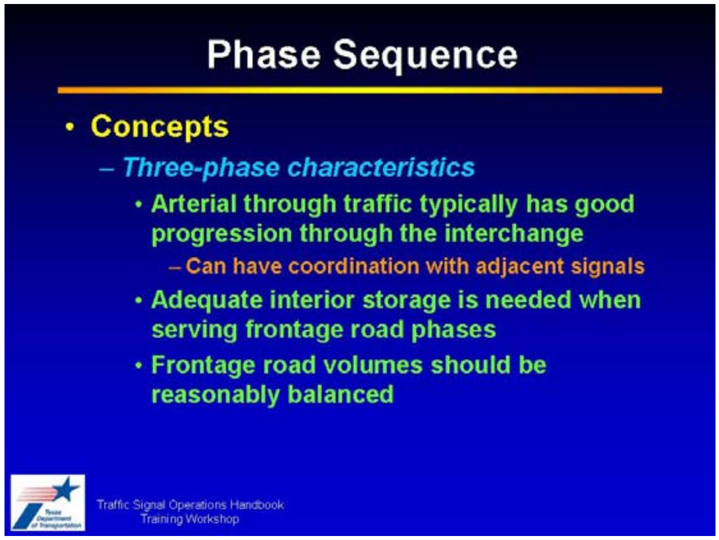
Click: The external arterial through phases are served next. They start and end together.

Click: The arterial left-turn phases are served last. They lag the arterial through phases.

Tell: As is the case with a typical intersection, phases 2 and 5 can be served together, as can phases 1 and 6. This may happen, depending on traffic volumes.

Tell: Phases 10 and 14 are added to the sequence as clearance phases. They are used to continue service to phases 1 or 5 if calls for phases 4 or 8 are not received.

Slide 262



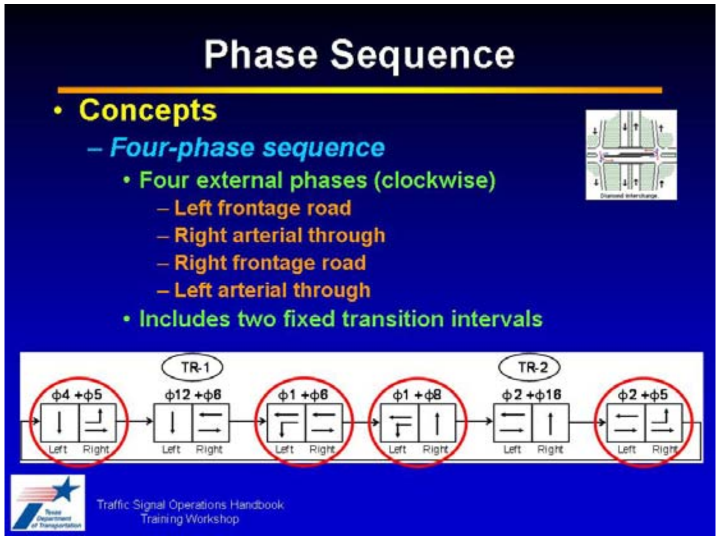
Key Message:
The three-phase sequence can preserve arterial coordination through the interchange. It works well if the interchange has adequate internal storage and the frontage road volumes are balanced.

Interactivity:
Tell: One of the benefits of the three-phase sequence is that it allows good progression on the arterial street. The intersections can even be coordinated with adjacent signals on the arterial if desired.

Tell: When the frontage road phases are served, left-turning vehicles will accumulate on the internal links. It is important for adequate storage to be available, as the frontage road left-turning vehicles can eventually fill the internal link and cause spillback. If this happens in both directions at the same time, the interchange can become gridlocked. Hence, the three-phase sequence is best suited for wide interchanges.

Tell: Three-phase operation is best suited for balanced frontage road volumes.

Slide 263



Key Message:
In the four-phase sequence, the four external entering movements are served sequentially in a clockwise pattern. There are also two fixed transition periods where arterial traffic has entered one side of the interchange but not yet reached the other intersection.

Interactivity:
Tell: The four-phase sequence is described in terms of the external movements being served. That is, the sequence is described based on which vehicles are entering the link between the two intersections. These movements are served in a clockwise pattern.

Click: The first external phase to be served is the left frontage road phase. In this example, these are the southbound through and left-turning vehicles at the left intersection.

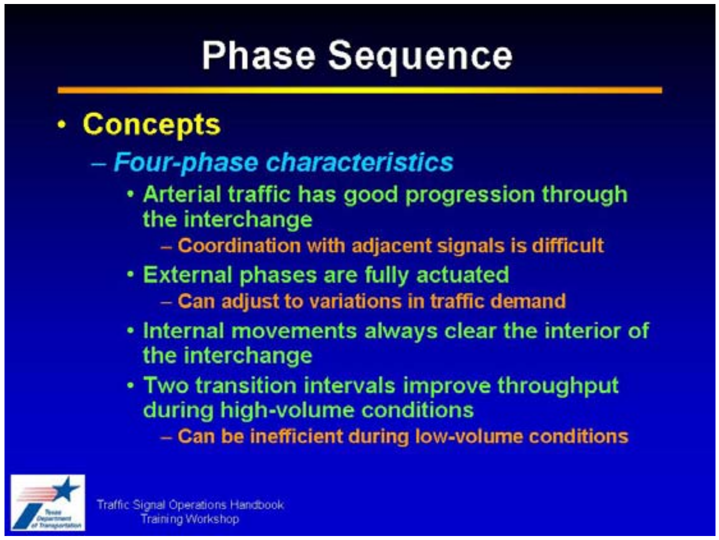
Click: The arterial through phase at the right intersection is served next. These vehicles are traveling westbound.

Click: The right frontage road phase is served next. These are the northbound through and left-turning vehicles at the right intersection.

Click: Finally, the arterial through phase at the left intersection is served. These vehicles are traveling eastbound.

Tell: The phase sequence includes two transition periods that are labeled as TR-1 and TR-2. During these two periods, one of the external arterial through movements has been allowed to enter the interchange, but the green indication to allow them to exit the other side of the interchange has not yet started. These intervals must be set to a fixed length based on the travel time between the two intersections.

Slide 264



Key Message:
The four-phase sequence can be coordinated well for movements through the interchange, but not with adjacent signals. The external phases are typically actuated. The timing allows internal movements to clear the interchange, which is important for narrow interchanges.

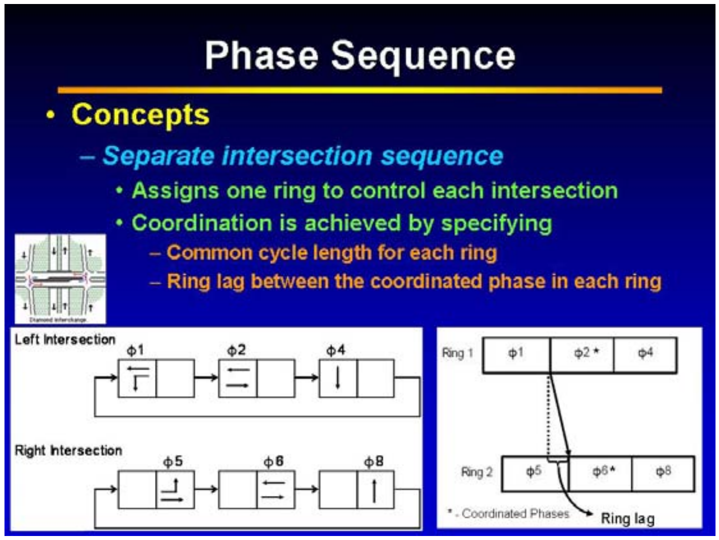
Interactivity:
Tell: The four-phase sequence is well-suited for providing progression through the interchange, but it is difficult to coordinate a four-phase diamond interchange with adjacent signals.

Tell: With the four-phase sequence, the external phases are fully actuated, which allows the controller to adjust to variations in traffic demand.

Tell: The four-phase sequence is designed such that internal movements can always clear the interchange. This characteristic is important for narrow interchanges that lack space to store large queues.

Tell: The use of the two transition intervals improves throughput during high-volume conditions. However, these intervals can reduce efficiency during low-volume conditions.

Slide 265

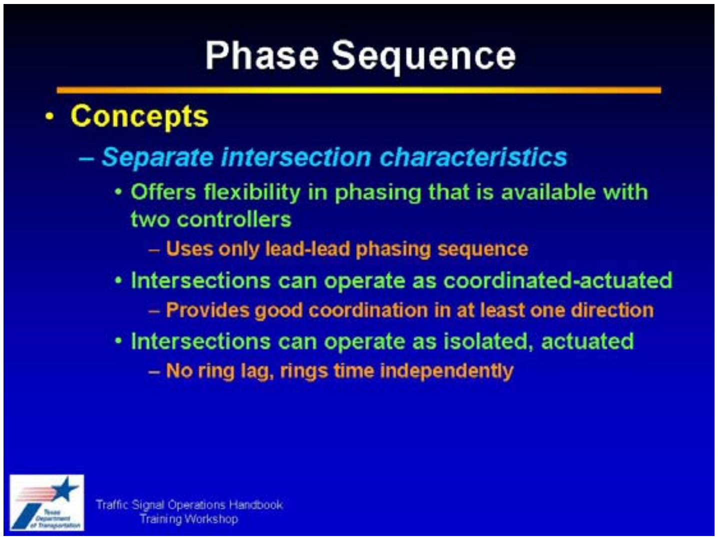


Key Message:
In the separate intersection sequence, one ring is assigned to each intersection. The two intersections are coordinated by using a common cycle length and specifying a fixed offset called a ring lag.

Interactivity:
Tell: The separate intersection sequence is implemented with one controller, using one ring to control each intersection. The two intersections each have three phases.

Tell: The intersections are coordinated with each other through the use of a common cycle length and a fixed offset called a ring lag.

Slide 266



Key Message:
The separate intersection sequence offers the flexibility that is available when using two controllers.

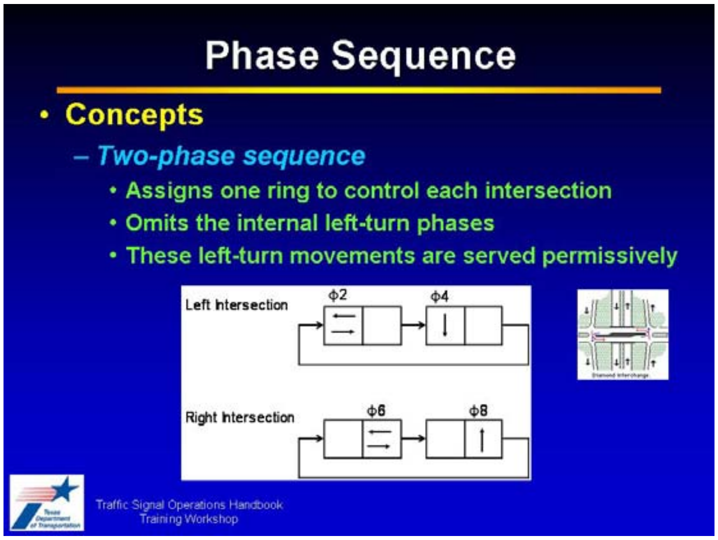
Interactivity:
Tell: Though it is implemented with one controller, the separate intersection sequence can offer most of the flexibility that is available with two controllers. One exception is that only lead-lead sequence can be used for the arterial left-turn movements.

Tell: The intersections can be operated as coordinated-actuated, in which case good progression can be achieved in one direction.

Tell: The intersections can be operated as isolated, fully actuated, in which case there is no ring lag and each ring can time independently.

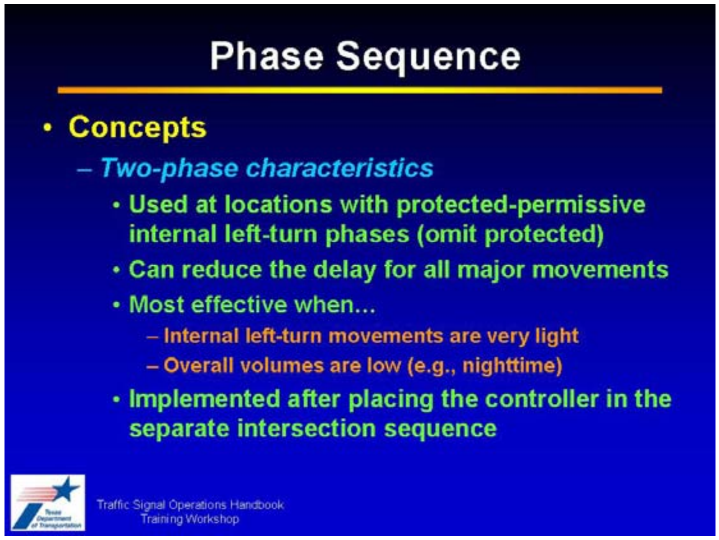
Tell: Overall, the separate intersection sequence is most effective at wide interchanges with unbalanced movements.

Slide 267



Key Message:
In the two-phase sequence, one ring is assigned to each intersection. The internal left-turn phases are omitted and their movements are served permissively.

Slide 268



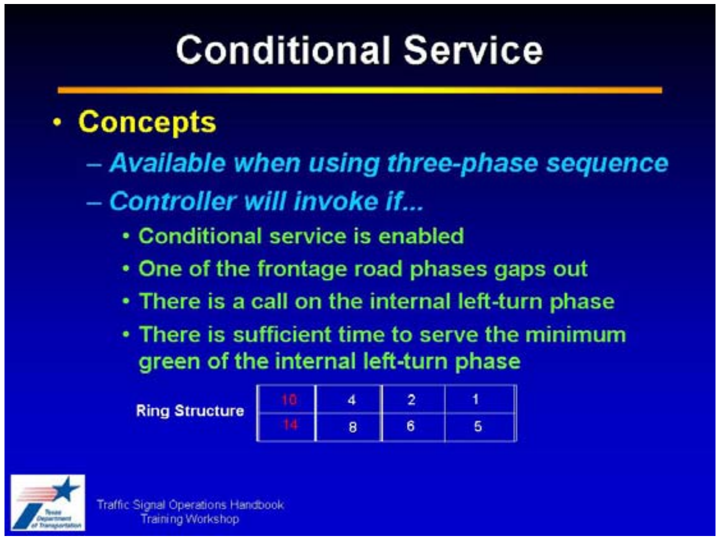
Key Message:
The two-phase sequence can be used at locations with protected-permissive left-turn phases. It can reduce delay by omitting the protected left-turn phases during low-volume periods or periods when the internal left-turn volumes are low.

Interactivity:
Tell: The two-phase sequence can be used at locations where protected-permissive mode is used for the left-turn phases. Two-phase operation is achieved by omitting the protected left-turn phases.

Tell: The two-phase sequence can reduce delay for all major movements. It is most effective when the internal left-turn volumes are low or when all volumes are low (e.g., night time).

Tell: The two-phase sequence is implemented after placing the controller in the separate intersection sequence. It represents a special case of the separate intersection sequence where protected left-turn phases are omitted.

Slide 269



Key Message:
Conditional service can be used with the three-phase sequence. One of the internal left-turn phases can be served twice if the frontage road phase at that intersection gaps out, a call is received on the left-turn phase, and sufficient time remains to serve the left-turn phase.

Interactivity:
Tell: Conditional service can be used with the three-phase sequence to provide additional green time for the internal left-turn phases (1 and 5).

Tell: Conditional service to one of the internal left-turn phases can be provided if the frontage road phase at that intersection gaps out, a call is received on the internal left-turn phase, and there is sufficient time to serve the minimum green of the internal left-turn phase before the maximum green on the other frontage road phase is reached.

Tell: Phases 10 and 14 are used to serve phases 1 and 5 conditionally.

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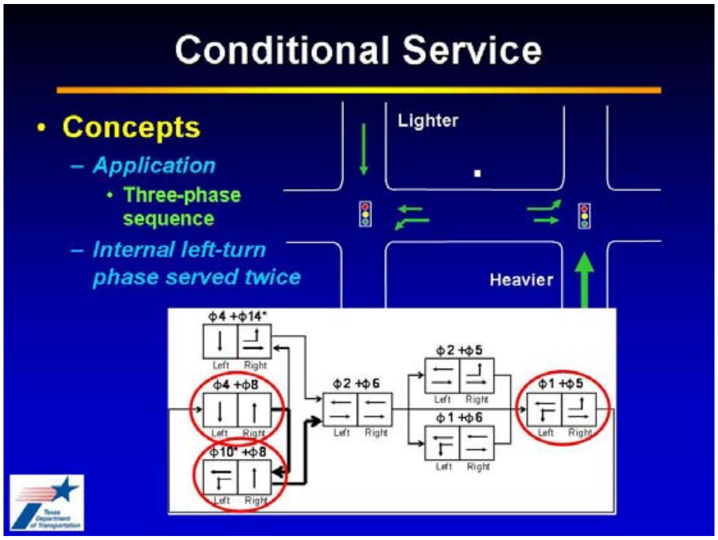


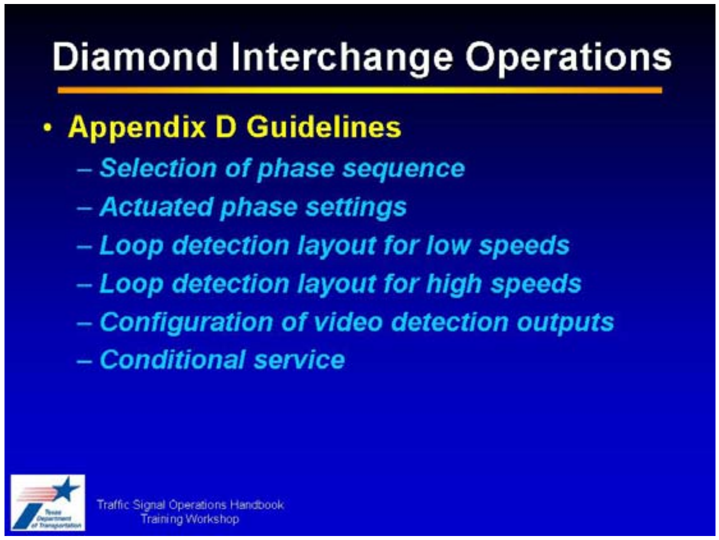
Key Message:
Conditional service can be used with the three-phase sequence.

Interactivity:
Click: In this example, the internal left-turn phases, 1 and 5, are being served.

Click: Both of the internal left-turn phases end, and service to the frontage road phases, 4, and 8, begins. The volumes on these phases are unbalanced, such that phase 8 is notably busier than phase 4.

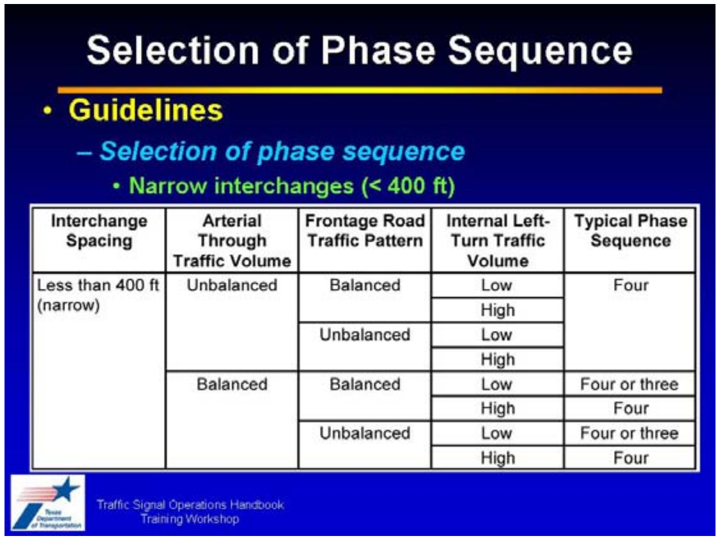
Click: If conditional service is enabled and a call is received for phase 1, phase 10 can be used to serve phase 1's movement when the frontage road phase (4) gaps out. This can only occur if the amount of green time remaining for the other frontage road phase (8) is enough to accommodate the minimum green for phase 1.

Slide 271



Key Message:
The *Handbook* provides guidelines for a variety of issues related to diamond interchange operations, including selecting phase sequence, determining actuated phase settings, configuring detection, and providing conditional service.

Slide 272



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

Key Message:
The selection of phase sequence is influenced by interchange spacing and traffic patterns for the arterial through, frontage road, and internal left-turn movements. Narrow interchanges are most often operated with a four-phase sequence, but the three-phase sequence can be used in certain circumstances.

Interactivity:
Tell: This table represents the portion of Table D-2 in the *Handbook* that addresses narrow interchanges.

Tell: The three middle columns are used to categorize the interchange's traffic patterns. The patterns for the arterial through and frontage road movements can be described as balanced or unbalanced. The internal left-turn volumes can be described as high or low.

Tell: According to the rightmost column, the four-phase sequence is the most common option for narrow interchanges. The three-phase sequence can also be used in certain circumstances.

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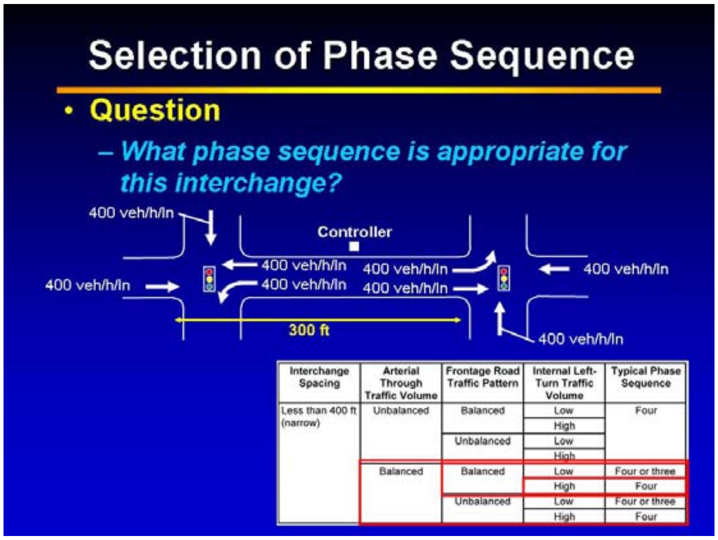

Interchange Spacing	Arterial Through Traffic Volume	Frontage Road Traffic Pattern	Internal Left-Turn Traffic Volume	Typical Phase Sequence
Less than 400 ft (narrow)	Unbalanced	Balanced	Low	Four
			High	
		Unbalanced	Low	
			High	
	Balanced	Balanced	Low	Four or three
			High	Four
		Unbalanced	Low	Four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

Key Message:
The *Handbook* guidelines can be used to select a phase sequence for this example interchange. Knowledge of interchange spacing and traffic volumes is required.

Interactivity:
Tell: This example interchange is considered narrow. Its spacing is less than 400 feet, as measured from one stop line to the next. Our goal is to choose a phase sequence for the interchange.

Ask: Is the arterial through traffic balanced or unbalanced?

Click: The arterial through traffic is balanced. A total of 400 veh/h/ln are passing through the interchange in both directions.

Ask: Is the frontage road traffic balanced or unbalanced?

Click: The frontage road traffic is balanced. Both movements have volumes of 400 veh/h/ln.

Ask: Are the internal left turn volumes high or low?

Click: The internal left-turn volumes are also 400 veh/h/ln, which is high.

Ask: What phase sequence is recommended for this interchange?

Tell: A four-phase sequence is recommended for this interchange.

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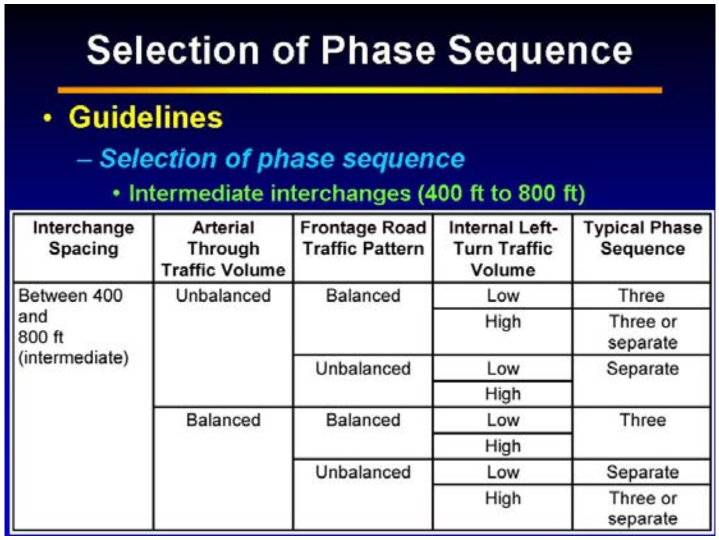

Interchange Spacing	Arterial Through Traffic Volume	Frontage Road Traffic Pattern	Internal Left-Turn Traffic Volume	Typical Phase Sequence
Between 400 and 800 ft (intermediate)	Unbalanced	Balanced	Low	Three
			High	Three or separate
		Unbalanced	Low	Separate
			High	
	Balanced	Balanced	Low	Three
			High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

Key Message:
Intermediate interchanges can be operated with the three-phase or separate intersection sequences.

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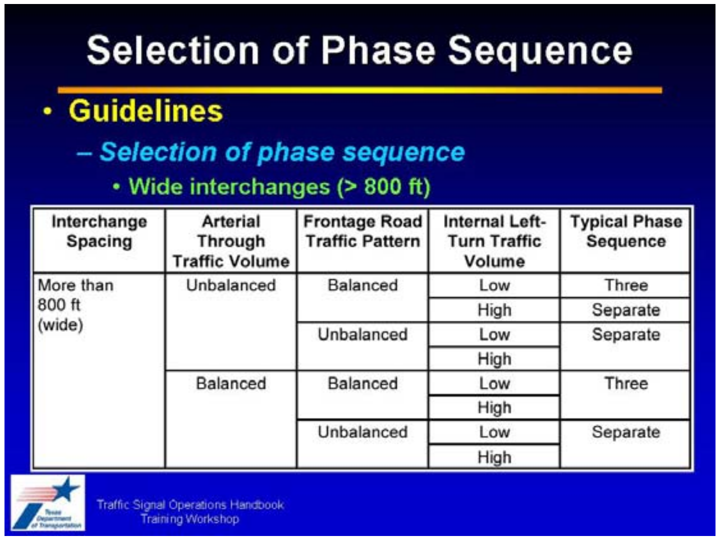

Key Message:
Wide interchanges can be operated with the three-phase or separate intersection sequences. The separate intersection sequence is more often recommended for wide interchanges than for intermediate interchanges.

Slide 276

Key Message:
The *Handbook* provides guidelines for minimum and maximum green intervals for diamond interchanges.

Slide 277

Key Message:
For most phases at a diamond interchange, use the minimum green guidelines in Chapter 2 that address driver expectancy and pedestrian crossing time needs. Additional considerations must be taken for the arterial through phases with a three-phase sequence or all through phases with a four-phase sequence.

Interactivity:
Tell: Recall that in Chapter 2, guidelines were provided for setting minimum green based on driver expectation, queue clearance, and pedestrian crossing time. These same guidelines apply for most phases at a diamond interchange, though queue clearance does not need to be considered because stop line detection is typically provided for all phases at a diamond interchange.

Tell: For a diamond interchange, there are two exceptions to the Chapter 2 guidelines for setting minimum green. The first exception is the arterial through phases with a three-phase sequence. The second exception is all through phases with a four-phase sequence.

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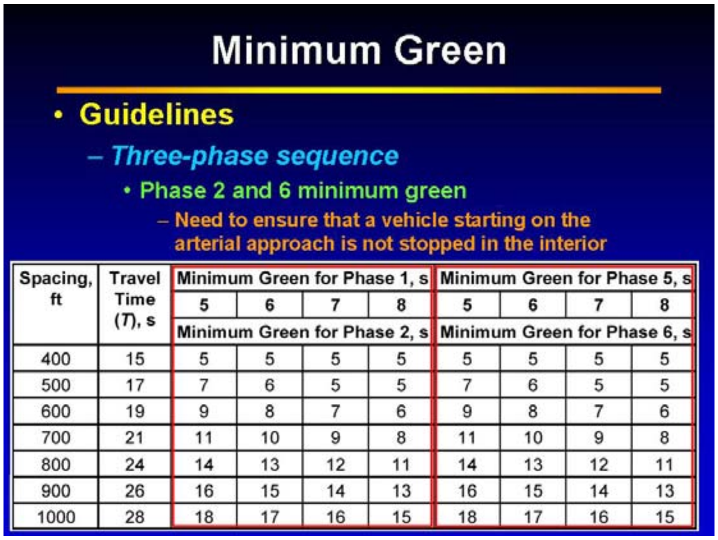

Key Message:
When the three-phase sequence is used, the minimum green intervals for phases 2 and 6 should be set long enough to ensure that vehicles originating from the arterial are not stopped in the interior of the interchange.

Interactivity:
Tell: When the three-phase sequence is used, the signals should be timed such that vehicles originating from the arterial are not stopped when they arrive at the second intersection.

Tell: This minimum green interval is influenced by the travel time between the two intersections, which in turn is influenced by the interchange spacing. Guidelines for determining the minimum green interval are provided in Table D-3 of the *Handbook*.

Click: The left portion of the table provides guidelines for setting the minimum green for phase 2, based on interchange spacing and the minimum green interval for phase 1.

Click: The right portion of the table provides guidelines for setting the minimum green for phase 6, based on interchange spacing and the minimum green interval for phase 5.

Tell: Note that for a given spacing, the minimum green for the through phase needs to be shorter if the minimum green for the left-turn phase is longer.

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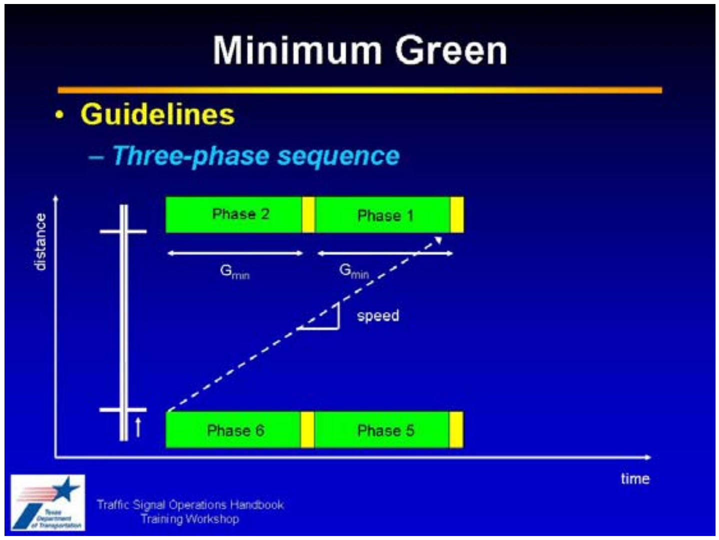

Key Message:
When the three-phase sequence is used, the minimum green intervals for phases 2 and 6 should be set long enough to ensure that vehicles originating from the arterial are not stopped in the interior of the interchange.

Interactivity:
Tell: Consider a vehicle entering the interchange from the arterial through movement served by phase 6. This vehicle should be able to continue through the interchange without getting stopped at the second intersection.

Tell: At the second intersection, the vehicle served by phase 6 will receive a green indication if phases 1 or 2 are being served. This green indication will be either the phase 1 protected left-turn green arrow or the overlap green ball on the through movement adjacent to phase 1.

Tell: The trajectory of the example vehicle is shown as a dotted line. This vehicle arrived at the beginning of phase 6 and received a green indication at the second intersection. However, a vehicle arriving slightly later into phase 6 would arrive at the second intersection after the end of phase 1 and be stopped.

Tell: Increasing the minimum green interval for phase 2 would cause the phase 1 split to be shifted to the right in this diagram, such that vehicles served by phase 6 would not be stopped in the interior of the interchange.

Tell: Likewise, increasing the minimum green interval for phase 6 would cause the phase 5 split to be shifted to the right in this diagram, such that vehicles served by phase 2 would not be stopped in the interior of the interchange.

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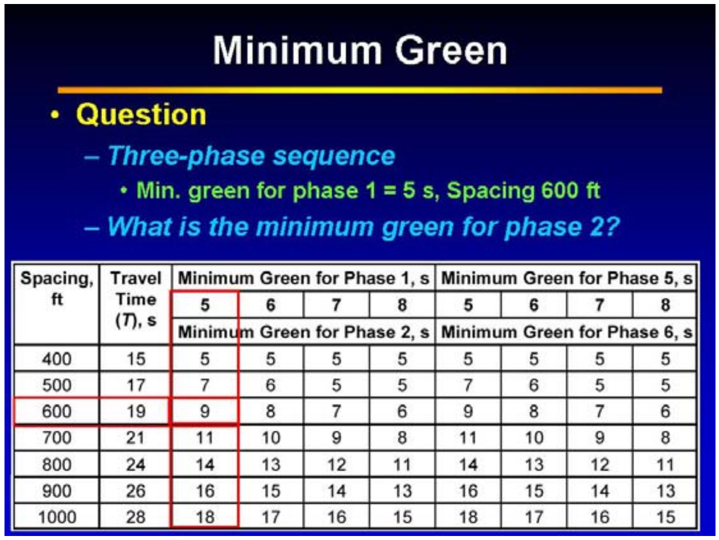

Key Message:
The *Handbook* guidelines can be used to obtain the recommended minimum green interval for a given through phase.

Interactivity:
Tell: Consider a diamond interchange being operated with the three-phase sequence. The minimum green interval for phase 1 is 5 s and the interchange spacing is 600 feet.

Ask: What is the recommended minimum green interval for phase 2?

Click: The minimum green interval for phase 1 is 5 s.

Click: The interchange spacing is 600 feet.

Click: The recommended minimum green interval for phase 2 is 9 s.

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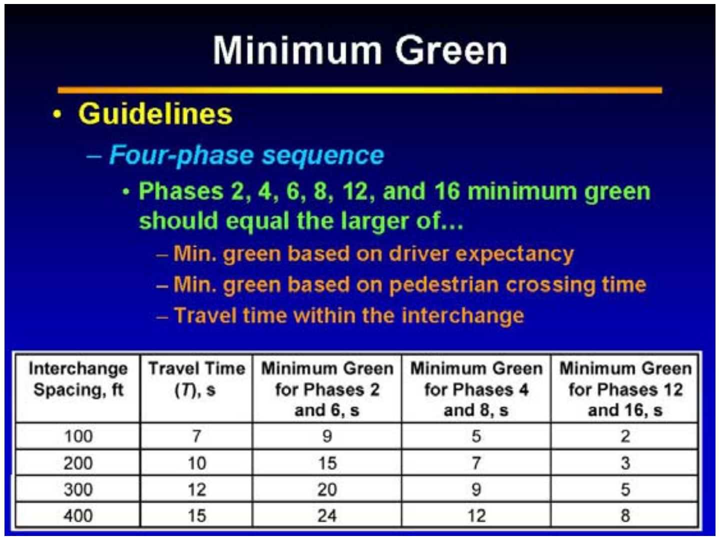

Key Message:
When the four-phase sequence is used, travel time within the interchange needs to be considered in the setting of the minimum green intervals for all phases but the internal left-turn phases.

Interactivity:
Tell: As was the case with the three-phase sequence, the goal is to avoid stopping vehicles in the interior of the interchange when running the four-phase sequence.

Tell: To avoid stopping vehicles in the interior of the interchange, the travel time within the interchange must be considered in the setting of the minimum green intervals. These travel times are different for each phase.

Tell: Table D-4 of the *Handbook* contains guidance on setting minimum green intervals for the four-phase sequence.

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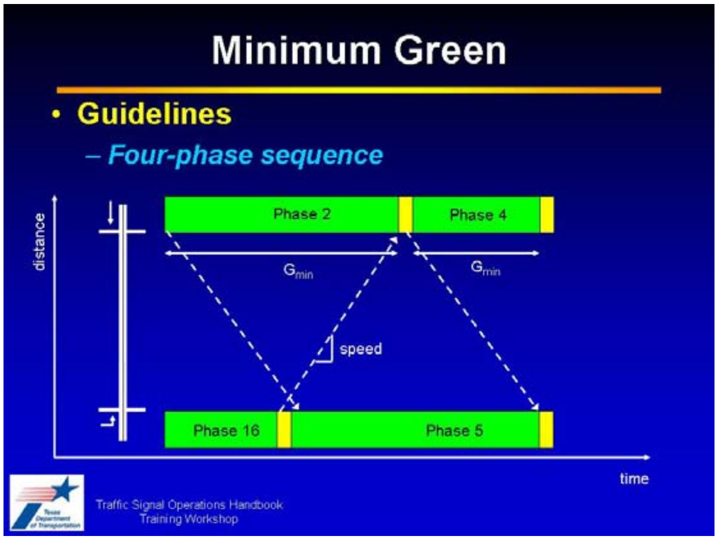
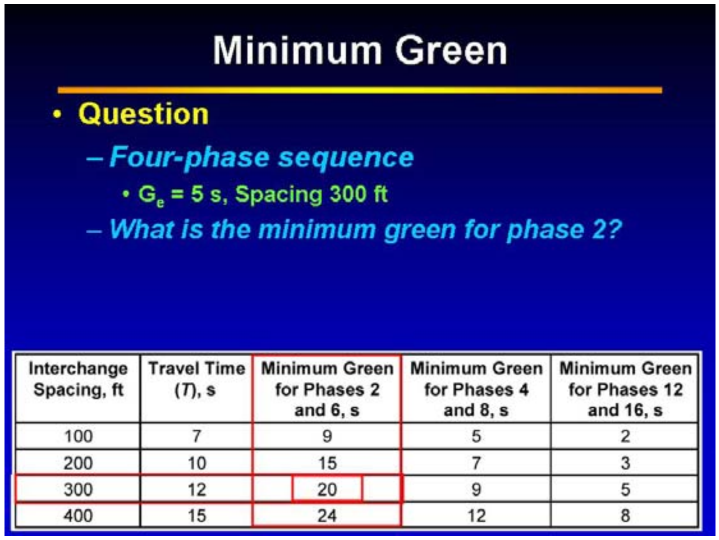


Key Message:
When the four-phase sequence is used, travel time within the interchange needs to be considered in the setting of the minimum green intervals for all phases but the internal left-turn phases.

Interactivity:
Tell: In this diagram, the two downward-pointing dotted arrows represent the trajectories of vehicles entering the interchange at the beginning and the end of phase 2. Both of these vehicles arrive at the second intersection during green.

Tell: The upward-pointing dotted arrow represents the trajectory of a vehicle entering the interchange at the end of phase 16. This vehicle arrives at the second intersection at the end of phase 2.

Slide 283



Key Message:
The *Handbook* guidelines can be used to obtain the recommended minimum green interval for a given phase.

Interactivity:
Tell: Consider a diamond interchange being operated with the four-phase sequence. The minimum green interval to satisfy driver expectation is 5 s and the interchange spacing is 300 feet.

Ask: What is the recommended minimum green interval for phase 2?

Click: Use the third column in the table for phases 2 and 6.

Click: The interchange spacing is 300 feet.

Click: The recommended minimum green interval for phase 2 is 20 s.

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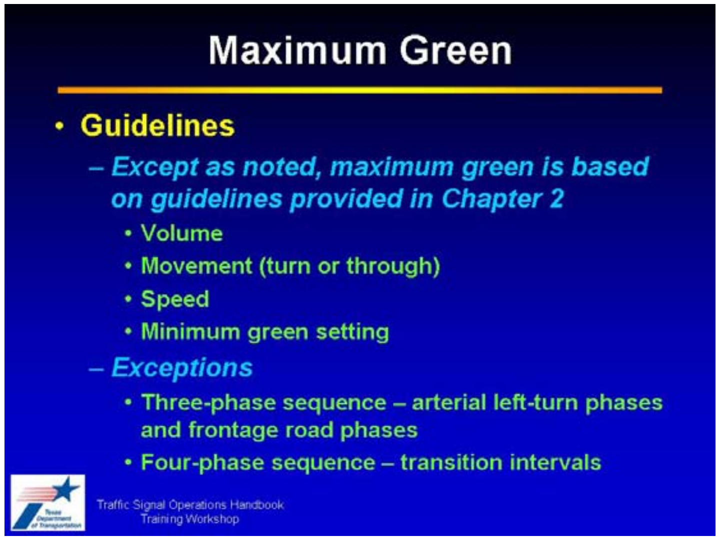

Key Message:
For most phases at a diamond interchange, use the maximum green guidelines in Chapter 2 that reflect considerations of volume, movement type, speed, and the minimum green interval. Additional considerations must be taken for the arterial through phases and frontage road phases with a three-phase sequence or the transition intervals with a four-phase sequence.

Interactivity:
Tell: Recall that in Chapter 2, guidelines were provided for setting maximum green based on volume, movement type, speed, and the minimum green interval. These same guidelines apply for most phases at a diamond interchange.

Tell: For a diamond interchange, there are two exceptions to the Chapter 2 guidelines for setting maximum green. The first exception is arterial through phases and frontage road phases with a three-phase sequence. The second exception is transition intervals with a four-phase sequence.

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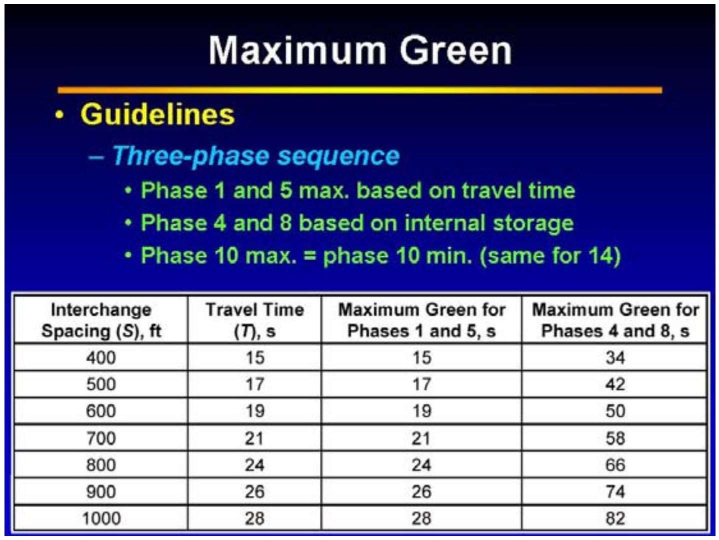

Interchange Spacing (*S*), ft	Travel Time (*T*), s	Maximum Green for Phases 1 and 5, s	Maximum Green for Phases 4 and 8, s
400	15	15	34
500	17	17	42
600	19	19	50
700	21	21	58
800	24	24	66
900	26	26	74
1000	28	28	82

Key Message:
When the three-phase sequence is used, travel time and internal storage capacity must be considered in the setting of the maximum green intervals for the internal left-turn and frontage road phases. The clearance phases (10 and 14) must also be set to fixed intervals.

Interactivity:
Tell: The maximum green for the internal left-turn phases (1 and 5) is set equal to the travel time between the intersections. If the internal left-turn phases are held in green longer than the time needed to clear the interchange, external vehicles will be prevented from entering the interchange even though no vehicles remain to be cleared out.

Tell: The maximum green for the frontage road phases (4 and 8) is set equal to the time needed to fill the internal approaches with queued vehicles. Maximum green intervals exceeding this time can cause gridlock.

Tell: Set the maximum green equal to the minimum green for phases 10 and 14. These phases are used for clearance if calls for phases 4 or 8 are not received.

Tell: Table D-5 of the *Handbook* contains guidance on setting maximum green intervals for the three-phase sequence.

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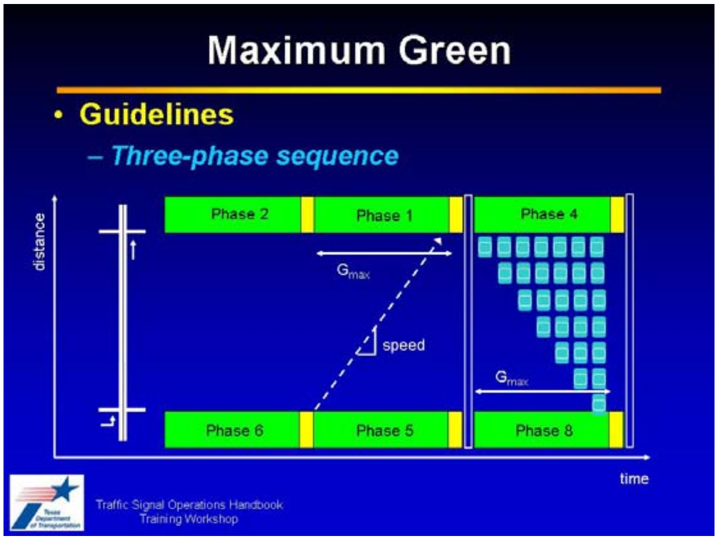

Key Message:
When the three-phase sequence is used, travel time and internal storage capacity must be considered in the setting of the maximum green intervals for the internal left-turn and frontage road phases.

Interactivity:
Tell: In the middle portion of this diagram, the dotted line represents the trajectory of the last vehicle originating from phase 6 before the phase ends. The maximum green for phase 1 is set long enough to serve this vehicle. A longer maximum green for phase 1 would block external vehicles from entering the interchange, but would not be useful because no internal vehicles remain to be served.

Tell: In the right portion of this diagram, vehicles originating from phase 8 are shown to be queuing inside the interchange before the phase 2 green begins to serve them. The maximum green for phase 8 is no longer than the time for the interior of the interchange to fill with vehicles. A longer maximum green could cause vehicles from the frontage road to spill back into the intersection. Gridlock can result if this occurs at both intersections at the same time.

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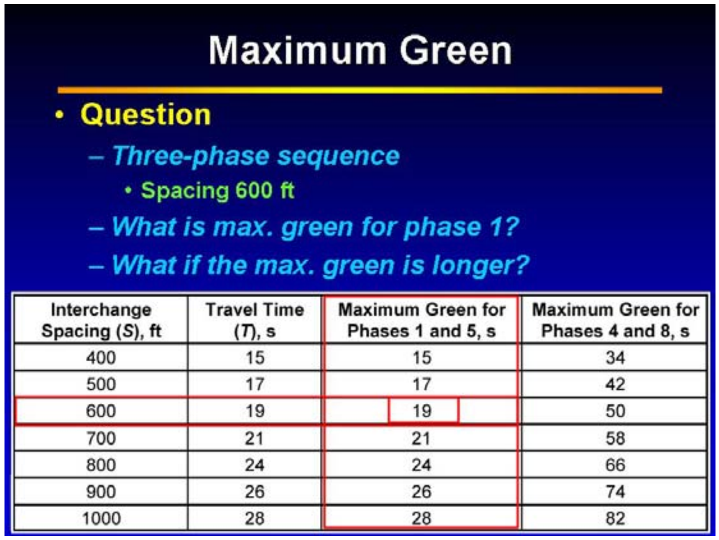

Interchange Spacing (S), ft	Travel Time (T), s	Maximum Green for Phases 1 and 5, s	Maximum Green for Phases 4 and 8, s
400	15	15	34
500	17	17	42
600	19	19	50
700	21	21	58
800	24	24	66
900	26	26	74
1000	28	28	82

Key Message:
The *Handbook* guidelines can be used to obtain the recommended maximum green interval for a given phase.

Interactivity:
Tell: Consider a diamond interchange being operated with the three-phase sequence. The interchange spacing is 600 feet.

Ask: What is the recommended maximum green interval for phase 2?

Click: The third column of the table contains the guidance for phase 1.

Click: The interchange spacing is 600 feet.

Click: The recommended maximum green interval for phase 1 is 19 s.

Ask: What happens if the maximum green is longer than 19 s?

Tell: As long as phase 1 is held in green, no external vehicles can enter the interchange from the arterial street (phase 2) or the frontage road (phase 4). Queues on these movements will continue to grow. Meanwhile, no internal vehicles remain to be served because the green interval for phase 1 has been held as long as the travel time from the other intersection, and this green interval began after the external movement green intervals at the other intersection ended.

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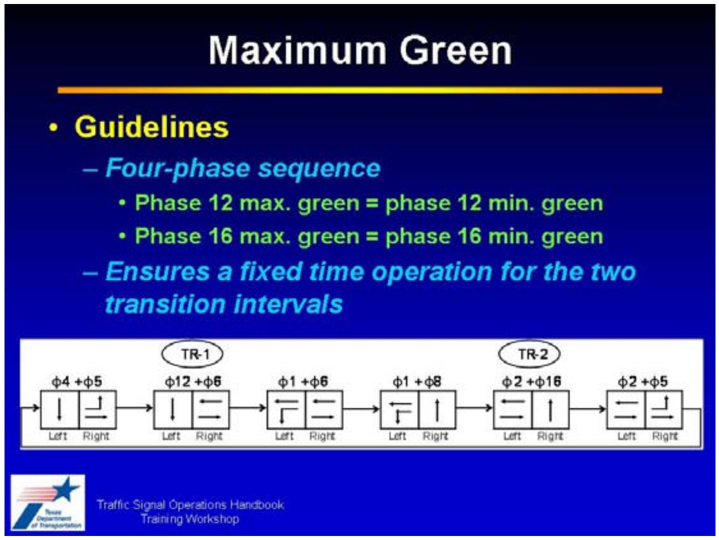
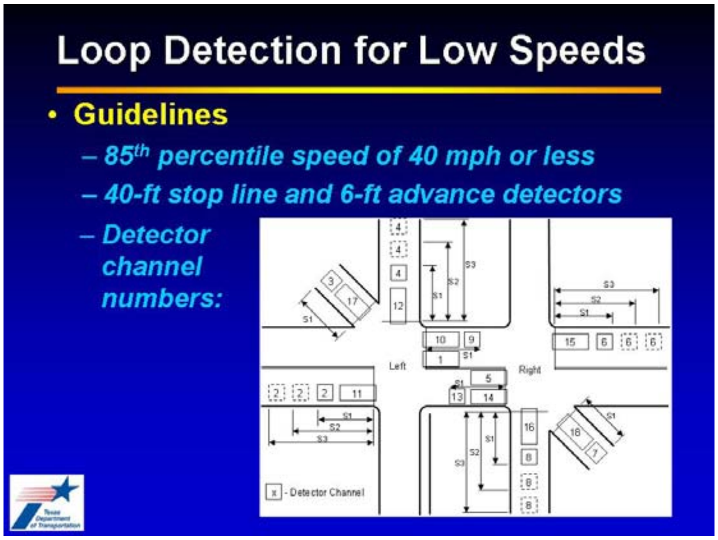


Key Message:
When the four-phase sequence is used, the transition intervals (phases 12 and 16) must be set to fixed intervals.

Interactivity:
Tell: Recall that the minimum green intervals for phases 12 and 16 were set equal to the travel time between the two intersections.

Tell: Set the maximum green for these phases equal to their minimum green intervals. This practice ensures that the transition intervals will have fixed durations. If the green intervals for phases 12 or 16 extend beyond the travel time between intersections, internal vehicles will arrive at the second intersection while the frontage road movements are still being served, possibly resulting in conflicts.

Slide 289



Key Message:
The *Handbook* provides guidelines for the design of loop detection for low-speed diamond interchanges.

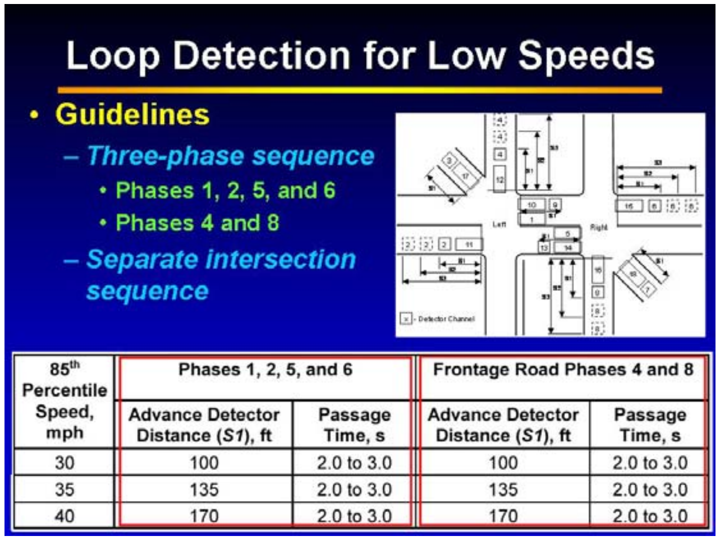
Interactivity:
Tell: The objectives of detection design at a low-speed diamond interchange are to ensure the detection of waiting traffic and the service of queues.

Tell: An interchange is considered "low-speed" if the 85th percentile speeds are 40 mph or less.

Tell: The detector channel numbers are shown in the diagram. These numbers are pre-assigned in the Texas Diamond Controller. The stop line detectors are 40 feet long and the advance detectors are six feet long.

Tell: For low-speed interchanges, only one advance detector is used on each through movement. Additional advance detectors are shown with dotted lines, but these are only used for high-speed interchanges.

Slide 290



Key Message:
The *Handbook* provides guidelines for the design of loop detection for low-speed diamond interchanges operating with the three-phase or separate intersection sequences.

Interactivity:
Tell: All of the numbers in the diagram represent the detector channel numbers. The mapping of the detector numbers to the phase numbers is provided in Table D-1 of the *Handbook*.

Tell: Table D-6 of the *Handbook* contains the guidelines for advance detector location and passage time setting for the three-phase sequence.

Click: The left portion of Table D-6 provides guidelines for phases 1, 2, 5, and 6. These are the arterial through phases and the internal left-turn phases.

Click: The right portion of Table D-6 provides guidelines for phases 4 and 8. These are the frontage road phases.

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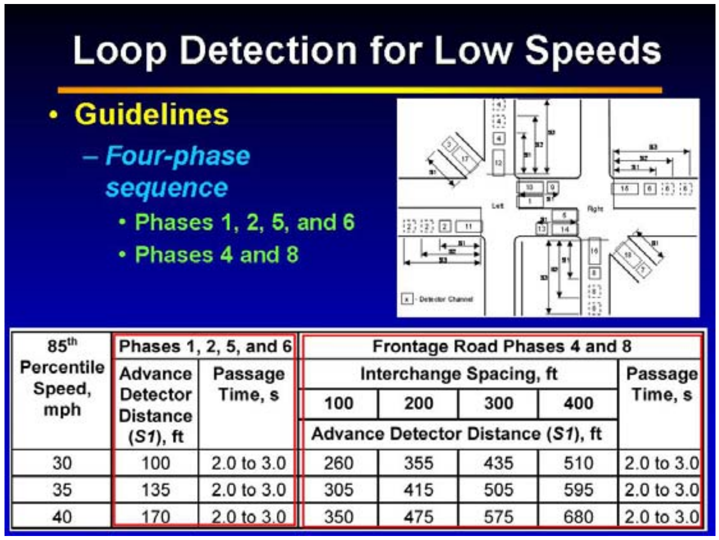


85th Percentile Speed, mph	Phases 1, 2, 5, and 6		Frontage Road Phases 4 and 8				
	Advance Detector Distance (*S1*), ft	Passage Time, s	Interchange Spacing, ft				Passage Time, s
			100	200	300	400	
			Advance Detector Distance (*S1*), ft				
30	100	2.0 to 3.0	260	355	435	510	2.0 to 3.0
35	135	2.0 to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

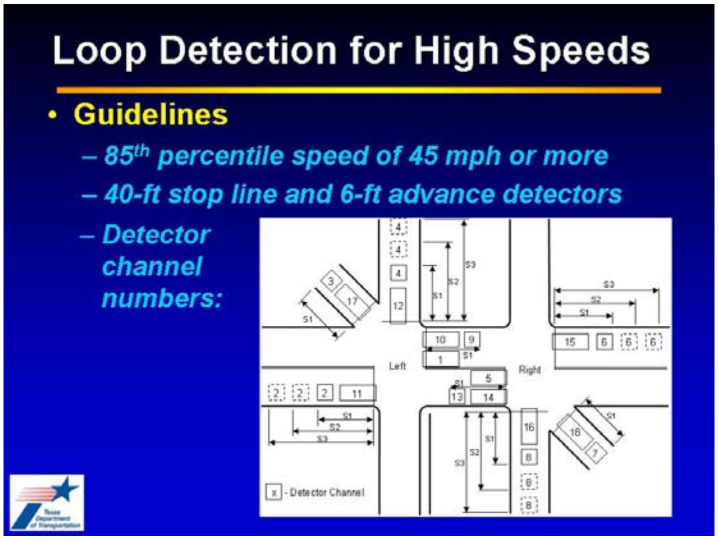
Key Message:
The *Handbook* provides guidelines for the design of loop detection for low-speed diamond interchanges operating with the four-phase sequence.

Interactivity:
Tell: Table D-7 of the *Handbook* contains the guidelines for advance detector location and passage time setting for the four-phase sequence.

Click: The left portion of Table D-7 provides guidelines for phases 1, 2, 5, and 6. These are the arterial through phases and the internal left-turn phases.

Click: The right portion of Table D-7 provides guidelines for phases 4 and 8. These are the frontage road phases.

Slide 292



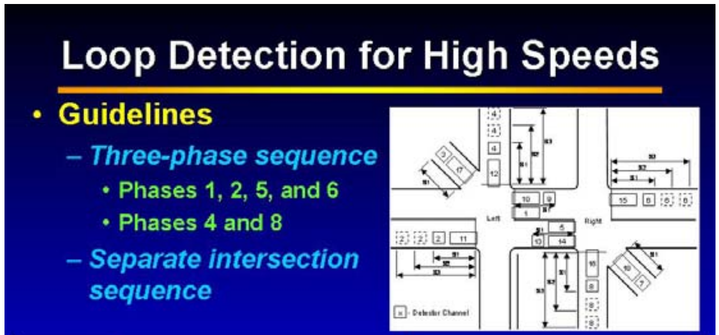
Key Message:
The *Handbook* provides guidelines for the design of loop detection for high-speed diamond interchanges.

Interactivity:
Tell: The objectives of detection design at a high-speed diamond interchange are to ensure the detection of waiting traffic and the service of queues, as well as to avoid ending green indications when vehicles are located in the indecision zone.

Tell: An interchange is considered "high-speed" if the 85^{th} percentile speeds are 45 mph or more. For these interchanges, the additional advance detectors illustrated with dotted lines are used.

Tell: The detector channel numbers are shown in the diagram. These numbers are pre-assigned in the Texas Diamond Controller. The stop line detectors are 40 feet long and the advance detectors are six feet long.

Slide 293



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

Key Message:
The *Handbook* provides guidelines for the design of loop detection for high-speed diamond interchanges operating with the three-phase or separate intersection sequences.

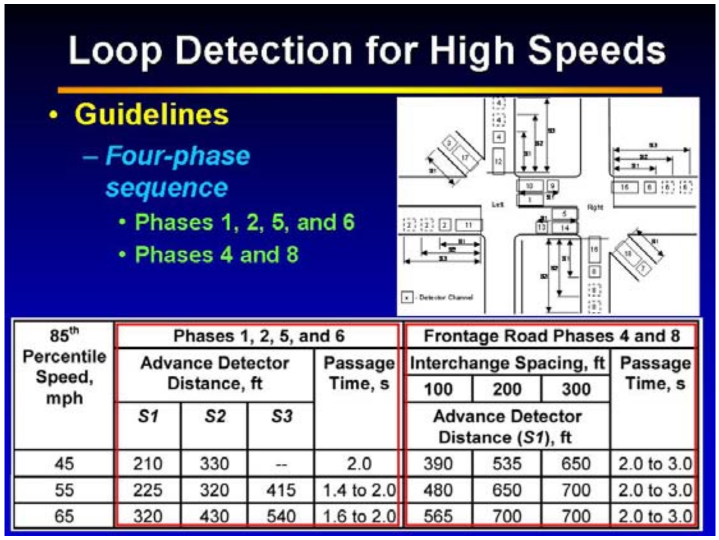
Interactivity:
Tell: All of the numbers in the diagram represent the detector channel numbers. The mapping of the detector numbers to the phase numbers is provided in Table D-1 of the *Handbook*.

Tell: Table D-8 of the *Handbook* contains the guidelines for advance detector location and passage time setting for the three-phase sequence.

Click: The left portion of Table D-8 provides guidelines for phases 1, 2, 5, and 6. These are the arterial through phases and the internal left-turn phases.

Click: The right portion of Table D-8 provides guidelines for phases 4 and 8. These are the frontage road phases.

Slide 294



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

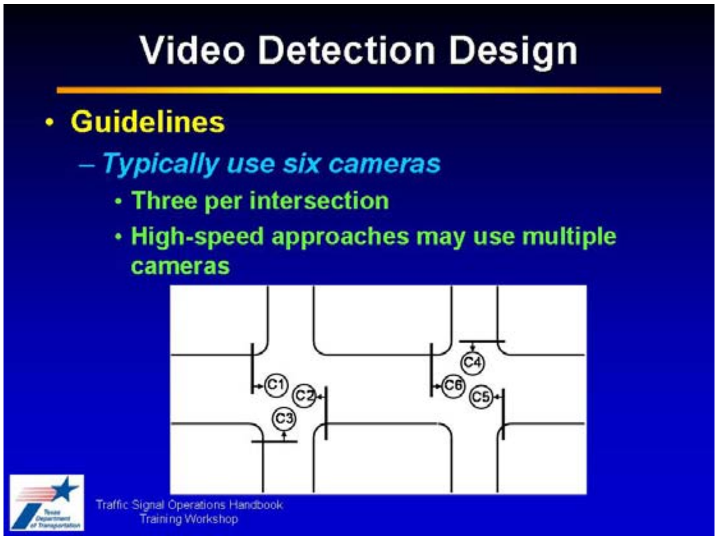
Key Message:
The *Handbook* provides guidelines for the design of loop detection for high-speed diamond interchanges operating with the four-phase sequence.

Interactivity:
Tell: Table D-9 of the *Handbook* contains the guidelines for advance detector location and passage time setting for the four-phase sequence.

Click: The left portion of Table D-9 provides guidelines for phases 1, 2, 5, and 6. These are the arterial through phases and the internal left-turn phases.

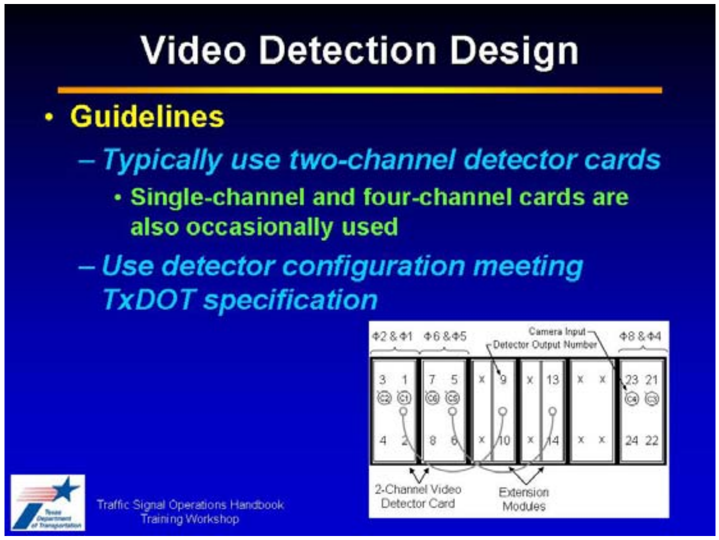
Click: The right portion of Table D-9 provides guidelines for phases 4 and 8. These are the frontage road phases.

Slide 295



Key Message:
Video detection is implemented at a low-speed diamond interchange using six cameras. Additional cameras may be used to provide adequate detection on high-speed approaches.

Slide 296



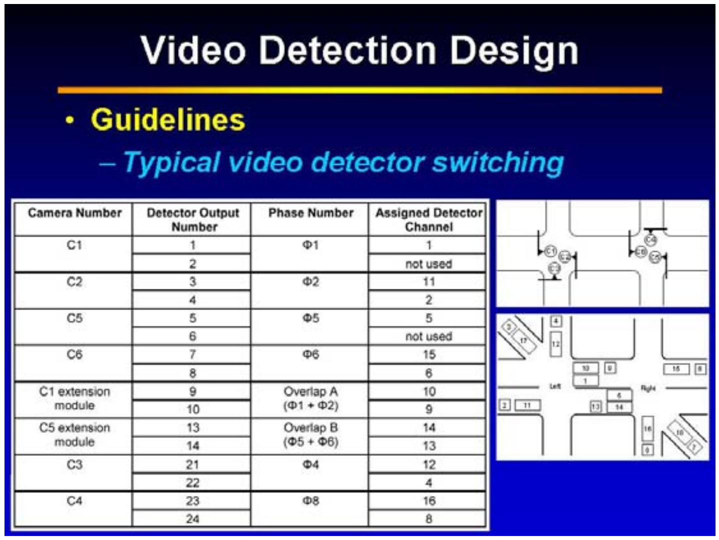
Key Message:
Rack-mounted video detection systems in Texas typically use two-channel detector cards. To implement a six-camera system, two extension modules must be used.

Interactivity:
Tell: Video detector cards are rack-mounted in the controller cabinet. Cards having two-channel detectors are typically used in Texas. These cards have two video camera inputs and four detector outputs. One-channel and four-channel cards are also available but not commonly used.

Tell: With a six-camera configuration, two extension modules need to be used to provide the needed number of detector outputs.

Tell: The detector output numbers on the cards do not match the detector channel numbers that are pre-assigned to each detection zone in the Texas Diamond Controller. Care must be taken to map the detector output numbers and the channel numbers to the correct phases in the controller.

Slide 297



Camera Number	Detector Output Number	Phase Number	Assigned Detector Channel
C1	1	Φ1	1
	2		not used
C2	3	Φ2	11
	4		2
C5	5	Φ5	5
	6		not used
C6	7	Φ6	15
	8		6
C1 extension module	9	Overlap A (Φ1 + Φ2)	10
	10		9
C5 extension module	13	Overlap B (Φ5 + Φ6)	14
	14		13
C3	21	Φ4	12
	22		4
C4	23	Φ8	16
	24		8

Key Message:
The *Handbook* guidelines specify how to configure video detection settings for a diamond interchange.

Interactivity:
Tell: Table D-10 of the *Handbook* contains guidelines for mapping the detector output numbers and the channel numbers to the correct phases. These settings are made in the controller.

Tell: The camera numbers are provided in the first column of Table D-10 and illustrated in the top diagram, which is Figure D-11 in the *Handbook*.

Tell: The detector output numbers are provided in the second column of Table D-10. These numbers and their positions on the detector cards are also illustrated in Figure D-12 of the *Handbook*.

Tell: The phase numbers assigned to each detector output number are provided in the third column of Table D-10.

Tell: The assigned detector channels for each phase are provided in the fourth column of Table D-10. They are also illustrated in the bottom diagram, which is Figure D-8 of the *Handbook*. These numbers are pre-assigned in the Texas Diamond Controller.

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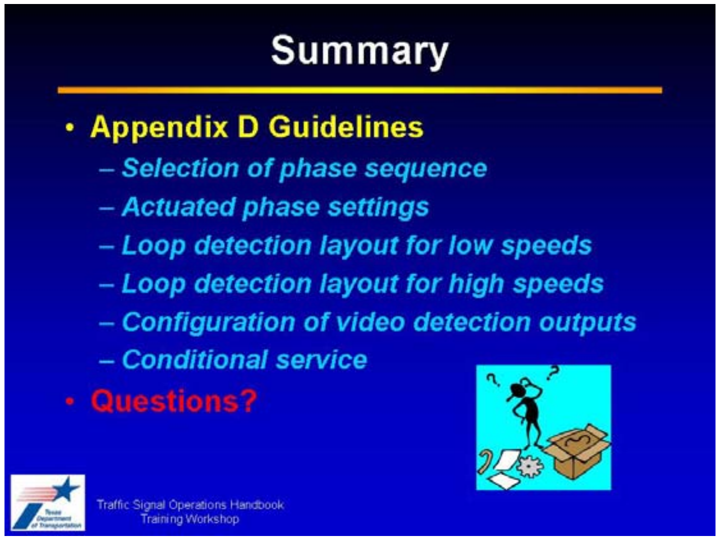
Key Message:
Conditional service can be used when the minimum green for the conditionally served phases is short and the frontage road volumes are very unbalanced.

Interactivity:
Tell: Conditional service is available for the internal left-turn phases when three-phase operation is used.

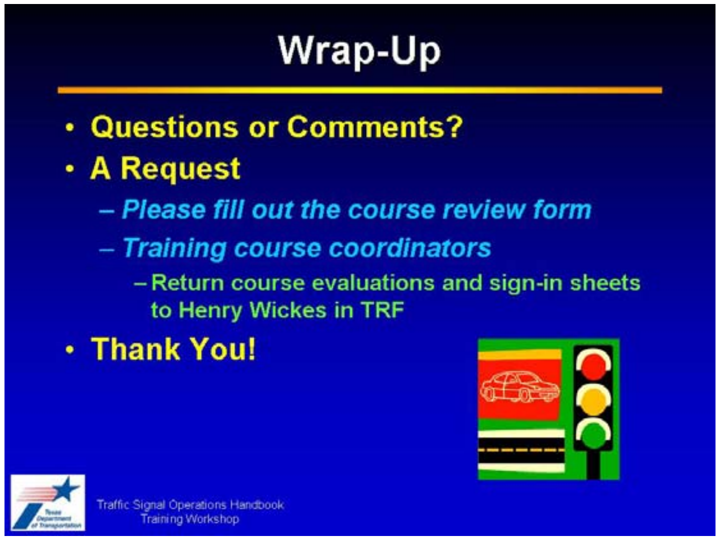
Tell: Conditional service can be used when the difference between the average green intervals of the two frontage road phases exceeds 10-12 s and the minimum green for the conditionally-served left-turn phases is no more than 8 s.

Tell: The decision to use conditional service should be based on consideration of the frontage road volumes, not the left-turn volumes. The frontage road volumes must be very unbalanced (as suggested by an average difference in green times that exceeds 10-12 s). Otherwise, the conditional service can cause the frontage road phases to extend needlessly and increase delay to the arterial through movements.

Slide 299


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?
Traffic Signal Operations Handbook
Training Workshop

Slide 300



Key Message:
None.

Interactivity:
Ask: Request that the participants fill out the course evaluation forms and return them to the instructor of their training course coordinators.

Tell: Training course coordinators need to send the evaluation forms to Henry Wickes in the Traffic Operations Division.

SOLUTIONS TO EXAMPLE PROBLEMS

1: MAXIMUM GREEN
2: MAXIMUM GREEN
3: TIMING PLAN DESIGN
4: TIMING PLAN DESIGN
5: PHASE SPLITS
6: PHASE SPLITS
7: LEFT-TURN MODE
8: LEFT-TURN MODE
9: RAIL PREEMPTION
10: RAIL PREEMPTION
11: ADVANCE DETECTION EVALUATION
12: ADVANCE DETECTION EVALUATION

EXAMPLE 1: MAXIMUM GREEN

Location: Through phase for a signalized intersection

INPUT DATA

General Information

Through plus right volume in peak hour: 430 veh/h westbound

Approach Configuration Data

Lanes: 2 (one through, one through plus right-turn)

Signal Timing Data

Minimum green interval: 10 s

CALCULATIONS

What is the critical peak-period volume per lane (veh/h/ln)? ………………… $\boxed{215}$

The maximum green interval is the larger of:

1) 30 s

2) Minimum green interval + 10 s = $\boxed{10}$ s + 10 s = $\boxed{20}$ s

3) $^{1}/_{10}$ of the volume per lane = $^{1}/_{10}$ x $\boxed{215}$ = $\boxed{22}$ s

OUTPUT SUMMARY

What is the maximum green interval (s)? ……………………………………………… $\boxed{30}$

EXAMPLE 2: MAXIMUM GREEN

Location: Evening peak hour at 4-leg signalized intersection

INPUT DATA

General Information

Phase 2 direction: Eastbound

Roadway	Major	Minor
Direction	East/West	North/South
Functional classification	Arterial	Arterial
Average annual daily traffic (AADT), veh/d	15,500	7,500

Lane Geometry Input Data

Analysis period: evening peak hour

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Lanes	1	2	1	2	0	2	0	2

Signal Timing Data

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

CALCULATIONS

Movement phase	Peak-period volume, veh/h	Peak-period lane volume, veh/h/ln	Minimum green interval, s	Maximum green interval, s, based on. . .		
				Shortest	Min green	Volume
Westbound through+right	*673*	*337*	12	30	*22*	*34*
Southbound through+right	*306*	*153*	14	20	*24*	*15*
Westbound left-turn			6	15	*16*	*17*

OUTPUT SUMMARY

What is the maximum green interval (s)? Westbound through….................	*34*
What is the maximum green interval (s)? Southbound through…..................	*24*
What is the maximum green interval (s)? Westbound left-turn…..................	*17*

EXAMPLE 3: TIMING PLAN DESIGN

Location: Existing street with four signalized intersections

INPUT DATA

General Information

Cycle length range: 60 to 80 s

Phase 2 direction: Eastbound

Signal Timing Data

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

Segment Data

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

OUTPUT SUMMARY

Question		Answer
What is the optimal cycle length (s)?		*70*
What are the optimal offsets (s)?	Intersection 1:	*0*
	Intersection 3:	*55*
	Intersection 5:	*12*
	Intersection 9:	*69*
What is the progression bandwidth associated with this timing plan? …...		*27*

EXAMPLE 4: TIMING PLAN DESIGN

Location: Proposed 4-leg signalized intersection (coded as Intersection 7)

INPUT DATA

General Information

Cycle length: 70 s

Phase 2 direction: Eastbound

Signal Timing Data

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

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

Segment Data

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

OUTPUT SUMMARY

What is the optimal offset for the proposed signal (s)?	Alternative 1:	*35*
	Alternative 2:	*35*
What is the bandwidth (s)?	Alternative 1:	*13.6*
	Alternative 2:	*27*
Which alternative is better?		*2*

EXAMPLE 5: PHASE SPLITS

Location: Evening peak hour at 4-leg signalized intersection

INPUT DATA

General Information

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

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

Volume and Lane Geometry Input Data

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

Change Period and Minimum Green Data

Yellow + red clearance: 5 s (all phases)

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

OUTPUT SUMMARY

What phase splits should be used?

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Phase split, s	*11*	*50*	*11*	*50*		*19*		*19*
Phase split, percent of cycle	*14*	*63*	*14*	*63*		*24*		*24*

EXAMPLE 6: PHASE SPLITS

Location: Evening peak hour at 4-leg signalized intersection

INPUT DATA

General Information

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

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

Volume and Lane Geometry Input Data

Analysis period: evening peak hour

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

Change Period and Minimum Green Data

Yellow + red clearance: 5 s (all phases)

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

OUTPUT SUMMARY

What phase splits should be used?

Approach	Eastbound		Westbound		Northbound		Southbound	
Movement	Left	Thru	Left	Thru	Left	Thru	Left	Thru
Phase split, s	*11*	*29*	*11*	*29*	*11*	*19*	*11*	*19*
Phase split, percent of cycle	*16*	*41*	*16*	*41*	*16*	*27*	*16*	*27*

EXAMPLE 7: LEFT-TURN MODE

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 100 s
Phase 2 direction: Eastbound

Volume and Lane Geometry Input Data

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

Crash History Data

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

Time period for crashes: 2 years

Speed and Sight Distance Data

Major-road approach speed: 45 mph (eastbound and westbound)
Minor-road approach speed: 35 mph (northbound and southbound)
Sight distance: Adequate for all left-turn movements

OUTPUT SUMMARY

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

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

EXAMPLE 8: LEFT-TURN MODE

Location: 4-leg signalized intersection

INPUT DATA

General Information

Cycle length: 100 s
Phase 2 direction: Eastbound

Volume and Lane Geometry Input Data

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

Crash History Data

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

Time period for crashes: 2 years

Speed and Sight Distance Data

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

OUTPUT SUMMARY

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

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

EXAMPLE 9: RAIL PREEMPTION

Location: Highway-rail grade crossing near a signalized intersection

INPUT DATA

Section 1: Right-of-Way Transfer Time Calculation

Preempt Verification and Response Time

Controller response time to preempt: 0.2 s

Worst-Case Conflicting Vehicle Time

Minimum green: 2.0 s
Yellow change time: 4.0 s
Red clearance time: 1.0 s

Worst-Case Pedestrian Time

Minimum WALK time: 2.0 s
Pedestrian clearance time: 10.0 s
Vehicle yellow change time: 4.0 s
Vehicle red clearance time: 1.0 s

Section 2: Queue Clearance Time Calculation

Design vehicle: Large school bus
Approach grade: Level
Warning time variability: Low
Clear storage distance (CSD): 60 ft
Minimum track clearance distance (MTCD): 25 ft

Section 3: Maximum Preemption Time Calculation

Desired minimum separation time: 4.0 s

Section 4: Sufficient Warning Time Check

Advance preemption time (APT): 0.0 s

OUTPUT SUMMARY

Basic Computations

What is the right-of-way transfer time (s)? ………….…………...…......…	*17*
What is the queue clearance time (s)? ……………………………………...	*13.3*
What is the maximum preemption time (s)? ………………………………	*34.5*

The maximum preemption time (MPT) represents the time needed to clear the design vehicle off the tracks. If the MPT is more than the 20.0 s that the railroad is required to provide, APT may be needed.

How much APT is needed to clear the tracks before the train arrives (s)? …. (Enter this APT into TSCO and answer the next four questions)	*15.0*
What track clearance green interval is needed (s) ? ……………...…......…...	*34*

Does the green extend beyond the "gate down" time?..................................	*Yes*
Is there a preempt trap caused by this design?...	*No*
Is there a likely vehicle-gate interaction?...	*Yes*
How much APT is needed to avoid this interaction and clear the tracks (s)?	*22*

EXAMPLE 10: RAIL PREEMPTION

Location: Highway-rail grade crossing near a signalized intersection

INPUT DATA

Section 1: Right-of-Way Transfer Time Calculation

Preempt Verification and Response Time

Controller response time to preempt: 0.2 s

Worst-Case Conflicting Vehicle Time

Minimum green: 2.0 s
Yellow change time: 4.0 s
Red clearance time: 0.5 s

Worst-Case Pedestrian Time

Minimum WALK time: 2.0 s
Pedestrian clearance time: 10.0 s
Vehicle yellow change time: 4.0 s
Vehicle red clearance time: 0.5 s

Section 2: Queue Clearance Time Calculation

Design vehicle: Single-unit truck
Approach grade: 3% uphill
Warning time variability: Low
Clear storage distance (CSD): 40 ft
Minimum track clearance distance (MTCD): 25 ft

Section 3: Maximum Preemption Time Calculation

Desired minimum separation time: 4.0 s

Section 4: Sufficient Warning Time Check

Advance preemption time (APT): 0.0 s

OUTPUT SUMMARY

Basic Computations

What is the right-of-way transfer time (s)? …………………………………	*17*
What is the queue clearance time (s)? ………………………………………...	*10.8*
What is the maximum preemption time (s)? ……………………………….	*31.5*

The maximum preemption time (MPT) represents the time needed to clear the design vehicle off the tracks. If the MPT is more than the 20.0 s of warning time that the railroad is required to provide, APT may be needed.

How much APT is needed to clear the tracks before the train arrives (s)? ... (Enter this APT into TSCO and answer the next four questions.)	*12*
What track clearance green interval is needed (s)? ………………………….	*30*

Does the green extend beyond the “gate down” time? ……………………..	*Yes*
Is there a preempt trap caused by this design? ……………………………..	*No*
Is there a likely vehicle-gate interaction? …………………………………..	*Yes*
How much APT is needed to avoid this interaction and clear the tracks (s) ?	*19*

EXAMPLE 11: ADVANCE DETECTION EVALUATION

Objective: Evaluate effectiveness of the "Option 2" advance detection design
Instructions:
1. Open the "option2.wmv" file. Click the Pause/Play button to hold the playback until ready.

2. Press the Pause/Play button to start. Pause the file at the start of **green** for the eastbound and westbound through movements. Record the time (in minutes and seconds) for each movement in the table below. Hint: A quick, double click on the Pause/Play button will advance the video in about 0.25-s increments.

Obs. Number	Eastbound		Westbound		Eastbound		Eastbound	
	Start of Green		Start of Green		Start of Red		Start of Red	
	min	sec	min	sec	min	sec	min	sec
1	*1*	*2*	*1*	*2*	*1*	*27*	*1*	*27*
2	*1*	*47*	*1*	*47*	*2*	*18*	*2*	*18*
3	*2*	*44*	*2*	*44*	*3*	*16*	*3*	*16*
4	*3*	*36*	*3*	*36*	*4*	*11*	*4*	*11*
5	*4*	*35*	*4*	*35*	*5*	*1*	*5*	*1*
6								
	Indecision Zone Count at Start of Yellow		Indecision Zone Count at Start of Yellow		Queue Count at Start of Red		Queue Count at Start of Red	
1	*0*		*1*		*0*		*1*	
2	*0*		*1*		*0*		*0*	
3	*0*		*0*		*0*		*0*	
4	*0*		*0*		*0*		*0*	
5	*0*		*0*		*0*		*0*	
6								

3. Press the Pause/Play button to advance the video to the start of the **yellow** for the eastbound and westbound through movements. Record the number of vehicles in the indecision zone. A vehicle is in this zone if it is fully past the first advance detector and fully before the start of the left-turn bay taper.

4. Press the Pause/Play button to advance the video to the start of the **red** for the eastbound and westbound through movements. Record the time for each movement in the table. Hint: The start of red is exactly 4.0 s after the start of yellow.

Record the count of "queued" vehicles at the start of red. This count begins at the stop line. A vehicle at the stop line is queued if it is stopped. Any subsequent vehicle is queued if it is (1) stopped or (2) about to stop and within one car length of a queued vehicle ahead.

EXAMPLE 11: ADVANCE DETECTION EVALUATION (continued)

OUTPUT SUMMARY

Enter the data from the table into the spreadsheet provided (AdvDet.xls). Record the results from the spreadsheet in the places provided below:

Average green duration (s)?	Eastbound:	*25.8*
	Westbound:	*25.8*
	North/South:	*17.5*
No. of vehicles in the indecision zone (veh/cycle)?	Eastbound:	*0.00*
	Westbound:	*0.40*
Queue count at start of red (veh/cycle)?	Eastbound:	*0.00*
	Westbound:	*0.20*
Average delay (s/veh)?	Eastbound:	*12.7*
	Westbound:	*12.7*
	North/South:	*16.0*

Observations:
This option occasionally leaves queued vehicles unserved on the westbound approach. That is, cycle failures sometimes occur. Otherwise, its performance is reasonable.

EXAMPLE 12: ADVANCE DETECTION EVALUATION

Objective: Evaluate effectiveness of the "Option 3" advance detection design
Instructions:
1. Open the "option3.wmv" file. Click the Pause/Play button to hold the playback until ready.

2. Press the Pause/Play button to start. Pause the file at the start of **green** for the eastbound and westbound through movements. Record the time (in minutes and seconds) for each movement in the table below. Hint: A quick, double click on the Pause/Play button will advance the video in about 0.25-s increments.

Obs. Number	Eastbound		Westbound		Eastbound		Eastbound	
	Start of Green		Start of Green		Start of Red		Start of Red	
	min	sec	min	sec	min	sec	min	sec
1	*1*	*3*	*1*	*3*	*1*	*45*	*1*	*45*
2	*2*	*12*	*2*	*12*	*3*	*1*	*3*	*1*
3	*3*	*23*	*3*	*23*	*4*	*12*	*4*	*12*
4	*4*	*35*	*4*	*35*	*5*	*24*	*5*	*24*
5								
6								
	Indecision Zone Count at Start of Yellow		Indecision Zone Count at Start of Yellow		Queue Count at Start of Red		Queue Count at Start of Red	
1	*0*		*0*		*0*		*0*	
2	*1*		*0*		*0*		*0*	
3	*0*		*1*		*0*		*0*	
4	*0*		*3*		*1*		*1*	
5								
6								

3. Press the Pause/Play button to advance the video to the start of the **yellow** for the eastbound and westbound through movements. Record the number of vehicles in the indecision zone. A vehicle is in this zone if it is fully past the first advance detector and fully before the start of the left-turn bay taper.

4. Press the Pause/Play button to advance the video to the start of the **red** for the eastbound and westbound through movements. Record the time for each movement in the table. Hint: The start of red is exactly 4.0 s after the start of yellow.

Record the count of "queued" vehicles at the start of red. This count begins at the stop line. A vehicle at the stop line is queued if it is stopped. Any subsequent vehicle is queued if it is (1) stopped or (2) about to stop and within one car length of a queued vehicle ahead.

EXAMPLE 12: ADVANCE DETECTION EVALUATION (continued)

OUTPUT SUMMARY

Enter the data from the table into the spreadsheet provided (AdvDet.xls). Record the results from the spreadsheet in the places provided below:

Average green duration (s)?	Eastbound:	*43.3*
	Westbound:	*43.3*
	North/South:	*19.0*
No. of vehicles in the indecision zone (veh/cycle)?	Eastbound:	*0.25*
	Westbound:	*1.00*
Queue count at start of red (veh/cycle)?	Eastbound:	*0.25*
	Westbound:	*0.25*
Average delay (s/veh)?	Eastbound:	*9.6*
	Westbound:	*9.6*
	North/South:	*25.2*

Observations:
Compared to option 2, option 3 extends the eastbound and westbound through phases more. This increases delay to the minor movements. Option 3 also leaves queued vehicles on the eastbound and westbound approaches unserved more often.

ACRONYM AND ABBREVIATION LIST

AADT	Average annual daily traffic
APT	Advance preemption time
AREMA	American Railway Engineering and Maintenance-of-Way Association
CSD	Clear storage distance
FHWA	Federal Highway Administration
ITE	Institute of Transportation Engineers
MAH	Maximum allowable headway
MPT	Maximum preemption time
MTCD	Minimum track clearance distance
PASSER	Progression Analysis and Signal System Evaluation Routine
PCI	Pedestrian change interval
PCT	Pedestrian clearance time
ROW	Right of way
TMUTCD	*Texas Manual on Uniform Traffic Control Devices*
TSCO	*Texas Signal Coordination Optimizer* (spreadsheet program)
TxDOT	Texas Department of Transportation
VTC	Virtual teleconferencing

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