CHAPTER 8 Left Turn Phasing—Permitted, Protected, or Both

Purpose

The safe separation of conflicting traffic movements was first discussed in Chapter 3. In Chapter 8, you will learn about the various ways in which left turns are served and some of the ways in which conflicts with the opposing traffic can be eliminated or reduced. Drivers can safely complete a left turn movement without waiting when a green arrow display is shown. Or, when a green ball or flashing yellow arrow is displayed, there is another level of instruction to the driver: you may proceed, but first you must judge that it is safe to do so, with a large enough gap in the opposing traffic that allows you to safely complete your left turn maneuver. You will complete a set of activities that describes the most commonly used methods of serving left turn movements, particularly the determination of whether a left turn should be protected (served by a green arrow) or permitted (served by a flashing yellow arrow or a green ball).

Learning Objectives

When you have completed the activities in this chapter, you will be able to

- Describe the methods of left turn phasing
- Describe the basic concepts of left turn phasing
- Determine the efficiency of permitted left turn operations under various opposing through traffic volumes
- Show that protected left turn phasing is more efficient than permitted left turn phasing under some conditions
- Describe the trade-offs and relative efficiencies between protected/permitted and protected left turn phasing
- Select optimal left turn phasing treatment based on analysis of performance data and observation of simulation conditions

Chapter Overview

This chapter begins with a *Reading* (Activity #45) on left turn phasing. The chapter also includes five activities, including an assessment of your understanding of left turn phasing (Activity #46) and three activities (Activities #47, #48, and #49) in which you observe the operation and performance of various left turn phasing options. In a design activity (Activity #50) you will test various left turn options for your intersection and select the best option for the conditions that you have observed. The chapter concludes with an *In Practice* activity (Activity #51) in which you will compare your left turn phasing plan with information used in practice from the *Traffic Signal Timing Manual*.

Activity List

Number and Title	Type
45 Left Turn Phasing	*Reading*
46 What Do You Know About Left Turn Phasing?	*Assessment*

Number and Title	Type
47 Permitted Left Turn Operations	*Discovery*
48 Comparing Permitted and Protected Left Turn Phasing	*Discovery*
49 Comparing Protected/Permitted and Protected Left Turn Phasing	*Discovery*
50 Analysis and Design of Left Turn Treatment	*Design*
51 Left Turn Phasing Options	*In Practice*

ACTIVITY

45 Left Turn Phasing

READING

Purpose

The purpose of this activity is to give you the chance to learn more about left turn phasing and the various options for serving left turn movements.

Learning Objective

- Describe the methods of left turn phasing

Deliverables

- Define the terms and variables in the Glossary
- Prepare a document that includes answers to the Critical Thinking Questions

Glossary

Provide a definition for each of the following terms or variables. Paraphrasing a formal definition (as provided by your text, instructor, or another resource) demonstrates that you understand the meaning of the term or phrase.

lagging left turns	
leading left turns	
left turn phasing	
permitted left turns	
protected left turns	

Critical Thinking Questions

When you have completed the reading, prepare answers to the following questions.

1. What performance measures can you extract from the graphical representations of the three queuing models presented in the reading?

2. Why should permitted left turn phasing always be considered as a phasing plan option?

3. When should protected left turn phasing be considered?

Information

The ring barrier diagram establishes the sequence of phases to be served at an actuated signalized intersection. For a standard intersection with four approaches, the movements and the numbering scheme used to identify the movements are shown in Figure 150. For leading protected left turns, the eight phases (their sequencing and the movements that they control) are represented in the ring barrier diagram shown in Figure 151.

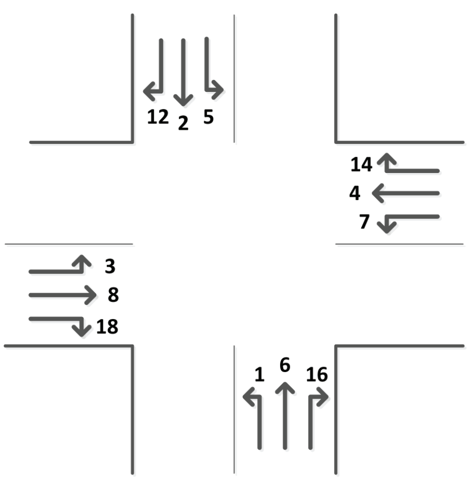

Figure 150. Movement numbers

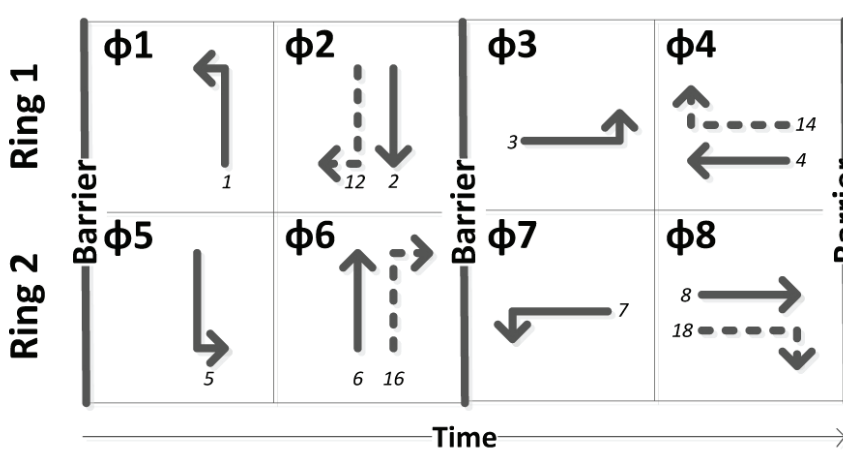

Figure 151. Ring barrier diagram for leading protected left turns

In ring 1, phase 1 (which controls the northbound left turn movement) must occur before phase 2 (which controls the opposing southbound through movement) since the left turn movement is protected: it does not have any opposing movement to contend with while phase 1 is timing. This complete time separation between the opposing left turn and through movements provides a high level of safety, especially when volumes are high.

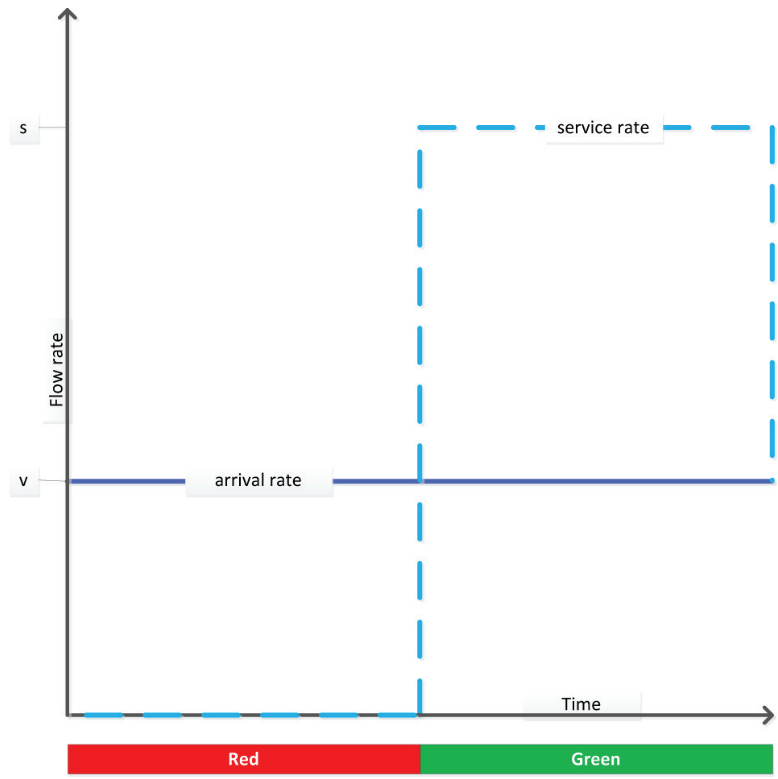

Figure 152. Flow profile diagram, protected left turn movement

The arrival and departure flow patterns for a protected left turn can be represented by a flow profile diagram, a cumulative vehicle diagram, and a queue accumulation polygon as originally discussed in Chapter 2. These three diagrams for a protected left turn movement are shown in Figure 152, Figure 153, and Figure 154. The left turn movement flows at the saturation flow rate during the green, without opposing flows, and the phase terminates when the flow has been served. Figure 153 and Figure 154 show the left turn queue building during red and clearing at the end of green.

But there are conditions, particularly when the left turn and/or opposing volumes are lower, where the driver can be given an option in which he or she can exercise safe judgment and accept or reject a gap in the opposing traffic stream. Examples of this gap acceptance behavior exist for other traffic facilities. Vehicles entering a

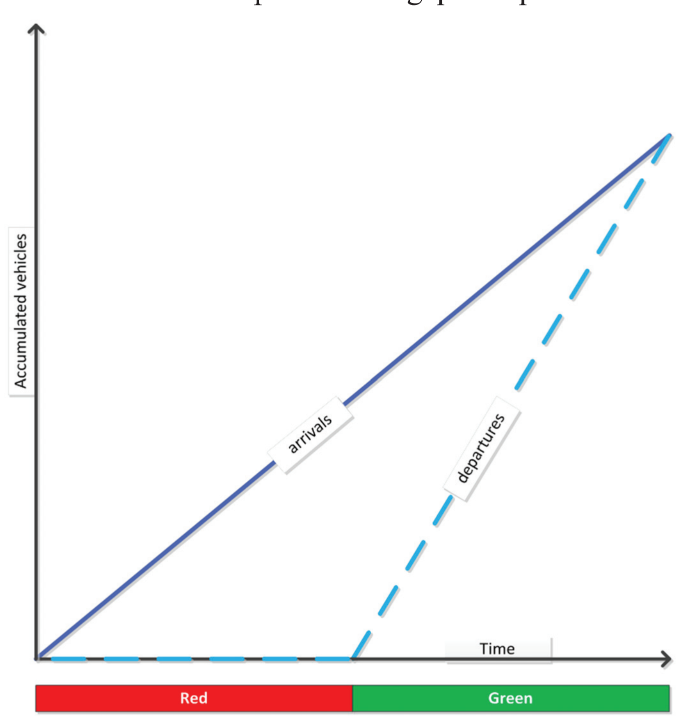

Figure 153. Cumulative vehicle diagram, protected left turn movement

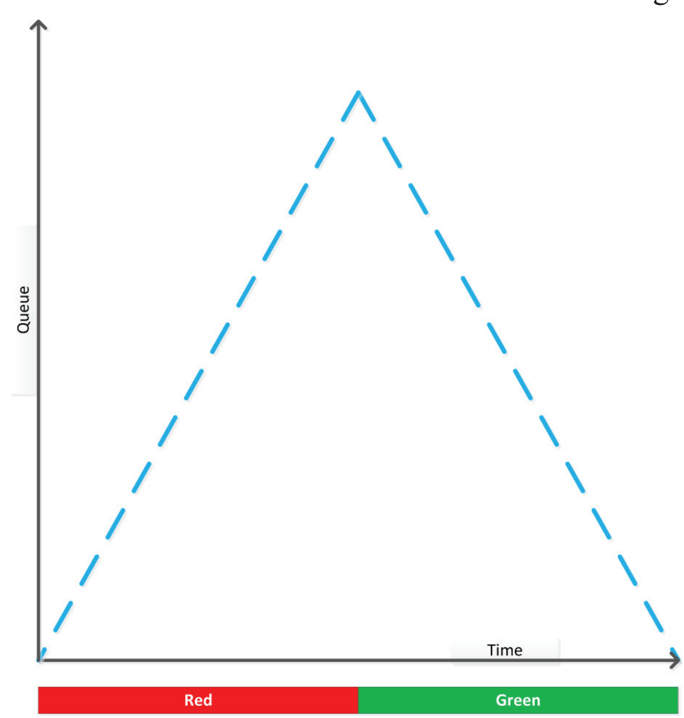

Figure 154. Queue accumulation polygon, protected left turn movement

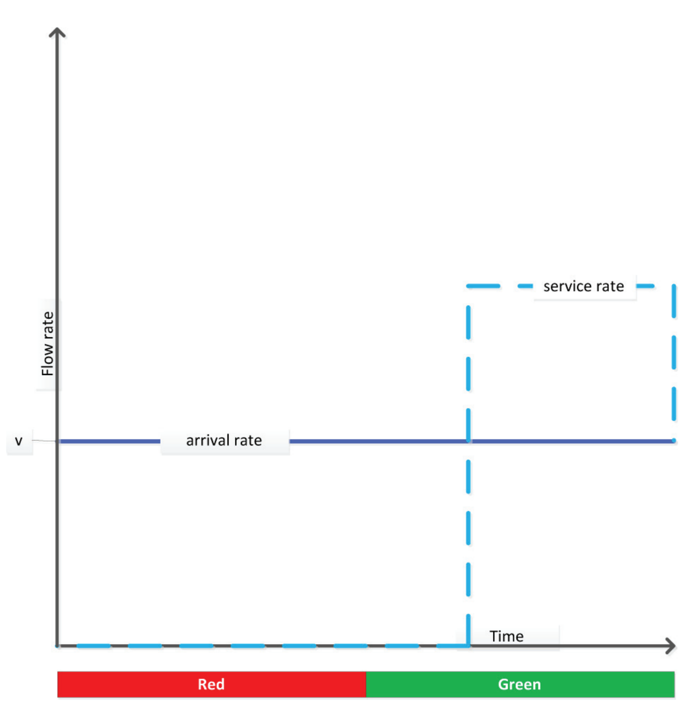

Figure 155. Flow profile diagram for permitted left turn movement

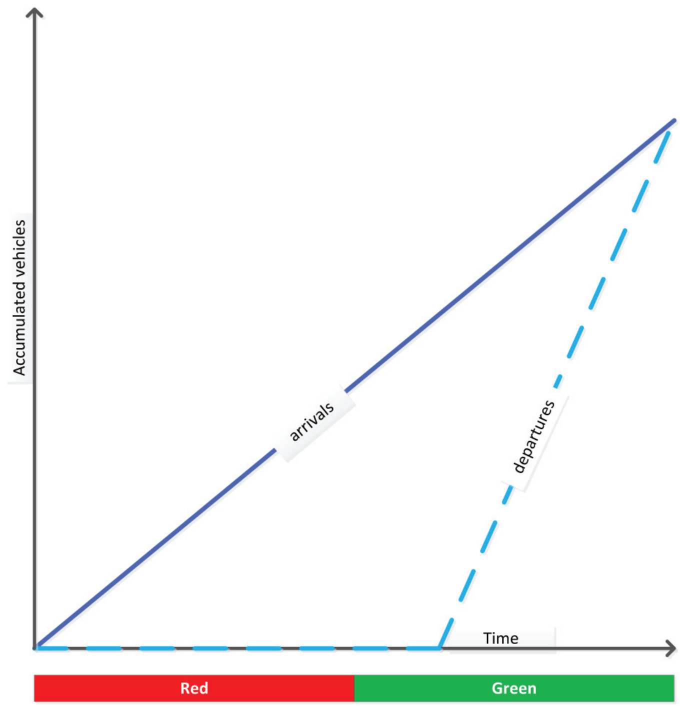

Figure 156. Cumulative vehicle diagram for permitted left turn movement

freeway have to look for a safe gap in the traffic already on the freeway before they enter the mainline. And, drivers on the minor street approach of a two-way stop-controlled intersection must find a large enough gap in the major stream before they either cross or merge into the major street. A similar option exists for permitted left turn maneuvers. The driver is shown either a solid green ball or a flashing yellow arrow, displays that indicate that a driver can proceed if, in their judgment, there is a large enough gap in the opposing traffic through which they can safely complete their turning maneuver.

Figure 155 shows the flow profile diagram for a permitted left turn movement. Here, the departure flow for the initial period of green is zero, as the opposing through movement queue is clearing. Once that opposing queue has cleared, the left turn vehicles can filter their way through the opposing gaps, when these gaps are large enough to be useful. Figure 156 and Figure 157 show the resulting cumulative vehicle diagram and queue accumulation polygon for the permitted left turn movement. As before, the total delay experienced by the left turn movement can be calculated as the area of either of these two figures.

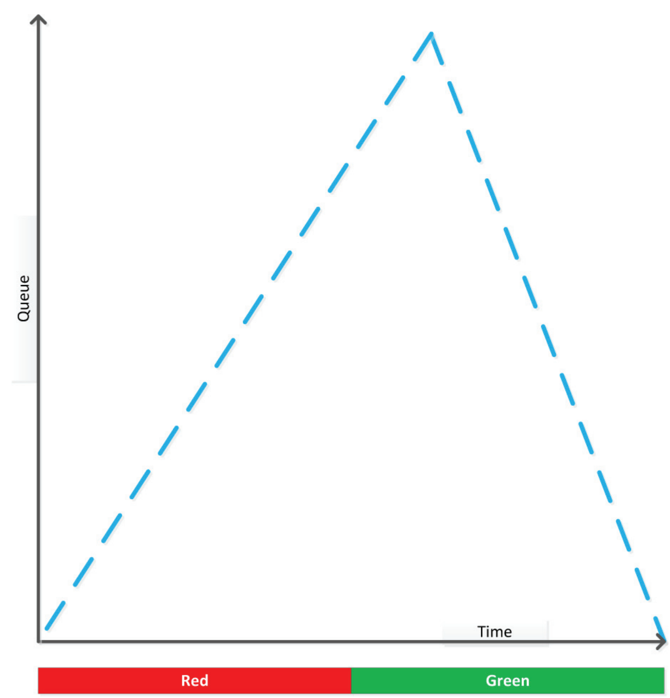

Figure 157. Queue accumulation polygon, permitted left turn movement

The ring barrier diagram for permitted left turn phasing is shown in Figure 158. Only four phases are needed, since the even numbered phases control both the left turn and through movements.

In some cases, a combination, or protected plus permitted, phasing can be used. Here at least the initial portion of the left turn queue is served with protected phasing while the remainder of the queue and any additional left turn vehicles that arrive can be served during the permitted phase. The queuing diagrams for this phasing option are shown in Figure 159, Figure 160, and Figure 161. Figure 159 shows that vehicles depart at the saturation flow rate during the protected phase. During the initial part of the permitted phase, the departing flow is zero when the opposing queue is clearing. Once the opposing queue has cleared, the departure rate is greater than zero but less than the saturation flow rate. Figure 160 and Figure 161 both show that the left turn queue is partially or completely served during the protected phase when vehicles are able to depart at the saturation flow rate (depending on the left turn flow rate and the amount of green time provided). During the permitted phase, the queue grows again when the left turn flow is zero during the period when the opposing through movement queue is clearing. Once this opposing queue has cleared, the queue of permitted left turn vehicles decreases to zero as left turn vehicles are able to filter through the opposing gaps. In this example, the queue clears at the end of green.

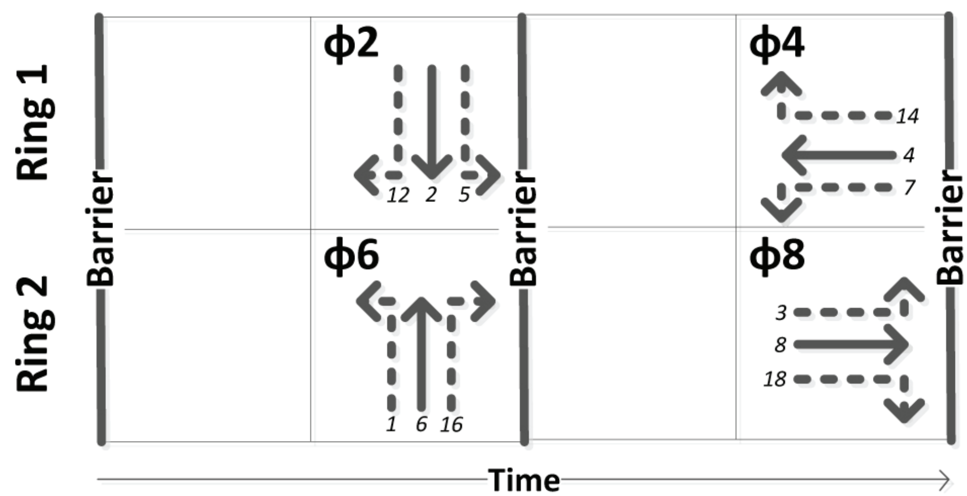

Figure 158. Ring barrier diagram, permitted left turn phasing

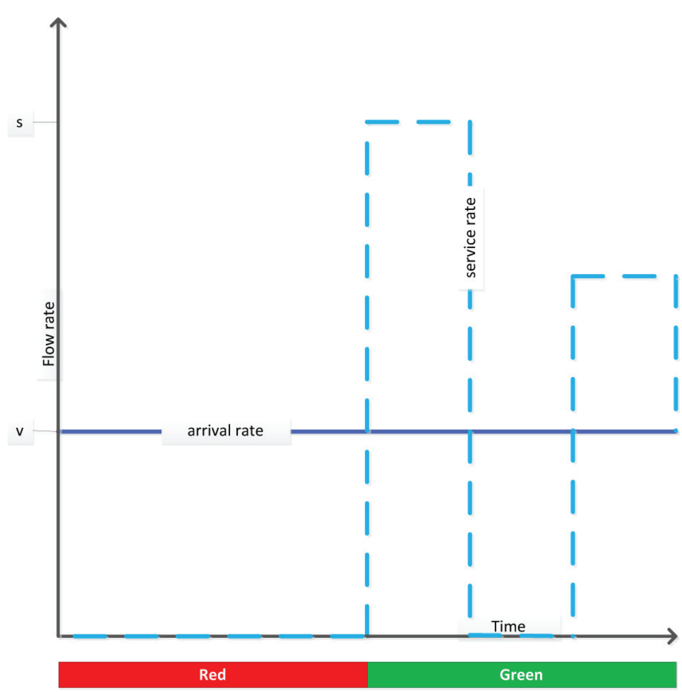

Figure 159. Flow profile diagram, protected plus permitted left turn phasing

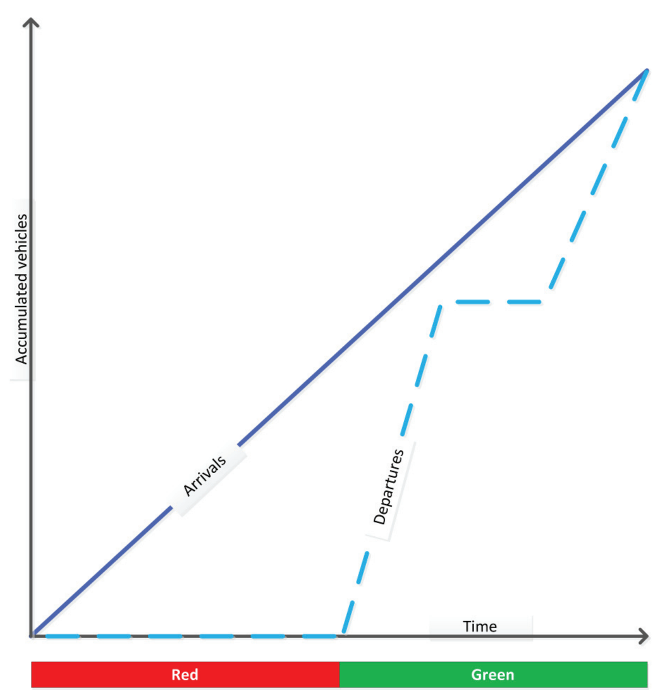

Figure 160. Cumulative vehicle diagram, protected plus permitted left turn phasing

The ring barrier diagram for protected permitted phasing is shown in Figure 162. The left turn movement is shown as a solid line during the protected phase and as a dashed line during the permitted phase.

So how do you determine which left turn phasing option is best for a particular situation? While there are a number of considerations in practice, we will consider two points that will help you in the design activity that you will complete later in this chapter. The first point is to have as few phases as possible during the cycle as this reduces the number of yellow-red clearance transitions and allows for more green time to be available to serve the traffic demand. Permitted left turn phasing means a fewer number of phases than required for protected left turn phasing. Figure 158 shows that all movements can be served with four phases requiring only two transitions per cycle. This potential efficiency means that permitted phasing should at least be considered as an option when possible.

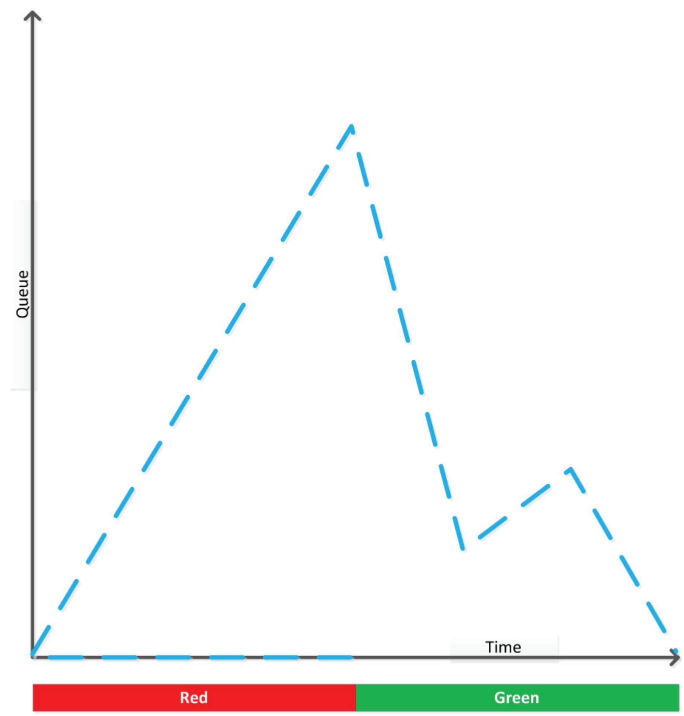

Figure 161. Queue accumulation polygon, protected plus permitted left turn phasing

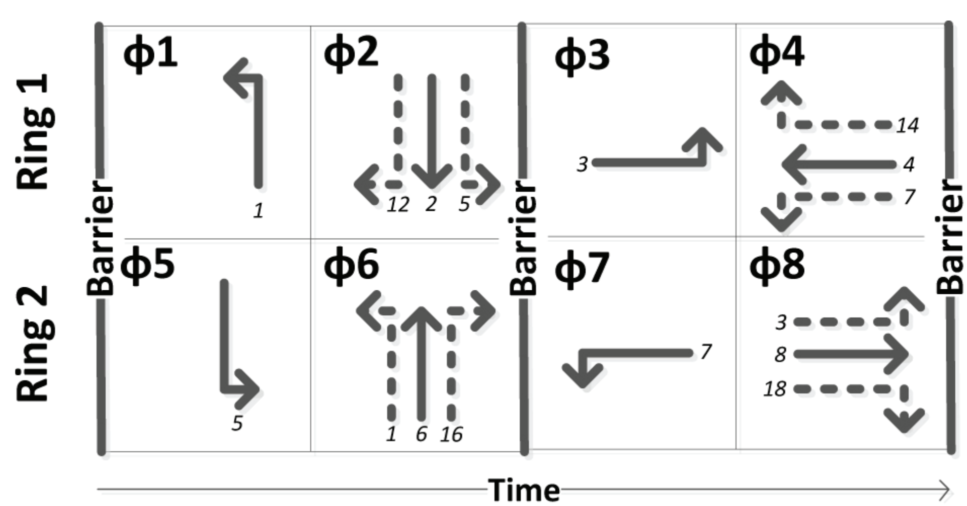

Figure 162. Ring barrier diagram, protected plus permitted left turn phasing

The second point is to make sure that there is sufficient capacity for the left turn movements. This means that if the combination of the left turn flow rate and the opposing through flow rate is high enough, there will only be sufficient left turn capacity if the phase serving the left turn movement is protected.

As you complete the activities to follow, you will see specific examples of both points when you observe the interaction of the left turn and opposing through traffic movements.

Student Notes:

ACTIVITY

46 What Do You Know About Left Turn Phasing?

ASSESSMENT

Purpose

The purpose of this activity is to give you the chance to assess your understanding of left turn phasing options.

Learning Objective

- Describe the basic concepts of left turn phasing

Deliverable

- Prepare a document with your answers to the Critical Thinking Questions

Critical Thinking Questions

1. What experiment could you construct to determine the capacity limit of the left turn and opposing through volumes for a given intersection? Describe your experiment.

2. What calculation could you make to determine the reduction in capacity that would occur in the through movements if the phasing plan was changed from permitted left turn phasing to protected left turn phasing? Describe your calculation.

Student Notes:

ACTIVITY

47 Permitted Left Turn Operations

DISCOVERY

Purpose

The purpose of this activity is to give you the opportunity to increase your understanding of permitted left turn phasing.

Learning Objective

- Determine the efficiency of permitted left turn operations under various opposing through traffic volumes

Required Resource

- Movie file: A47.wmv

Deliverable

- Prepare a document that includes your answers to the Critical Thinking Questions

Critical Thinking Questions

As you begin this activity, consider the following questions. You will come back to these questions at the end of the activity.

1. How does the opposing volume affect the quality of the left turn permitted operation for each of the two cases?

2. What change to the phasing plan would you consider, if any, to improve the quality of the operation for case 2?

3. Do the two cases that you observed conform to the queuing model diagrams described in the reading (Activity #45)? Explain your answer.

4. Prepare a brief summary of the performance of the left turn movements for each case. Consider the relative size of the queues that form and the relative delay experienced by the left turn movements.

Information

In this activity you will observe the operation of State Highway 8 and Line Street, focusing on the left turn operations on State Highway 8. An aerial view of the intersection is shown in Figure 163. State Highway 8 has two through lanes in each direction, while Line Street has one through lane in each direction.

The left turn phasing that you will observe is called "permitted," since the left turn traffic is allowed or permitted to complete their turning maneuver only if there is a safe or acceptable gap in the opposing through traffic. If an inadequate number of gaps in the opposing through traffic present themselves, the quality of the left turn operations will deteriorate.

Two cases will be considered here, each with different opposing through volumes. In the first case, the opposing through movement is 800 vehicles per hour. In the second case, the opposing through movement is 1450 vehicles per hour. In both cases, the left turn movements are 100 vehicles per hour. The minor street movements (northbound and southbound through movements) have the same volume, 600 vehicles per hour.

Figure 163. Aerial photograph, State Highway 8 and Line Street

Figure 164 shows the ring diagram for both cases. The permitted left turn movements are indicated with dashed lines.

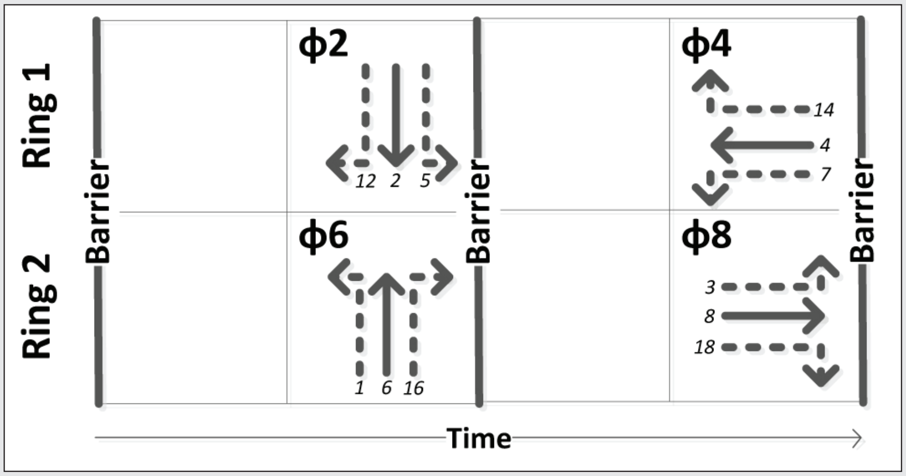

Figure 164. Ring diagram showing permitted left turn phasing

Task 1

Open the file: "A47.wmv."

Task 2

Observe the operation of the two cases. (See Figure 165.)

- Observe the relative size of the gaps in the through traffic on State Highway 8
- Observe the eastbound left turn and westbound left turn vehicles as they first wait, and then accept gaps in the opposing through traffic. Note the relative size of the queues that form in both cases.

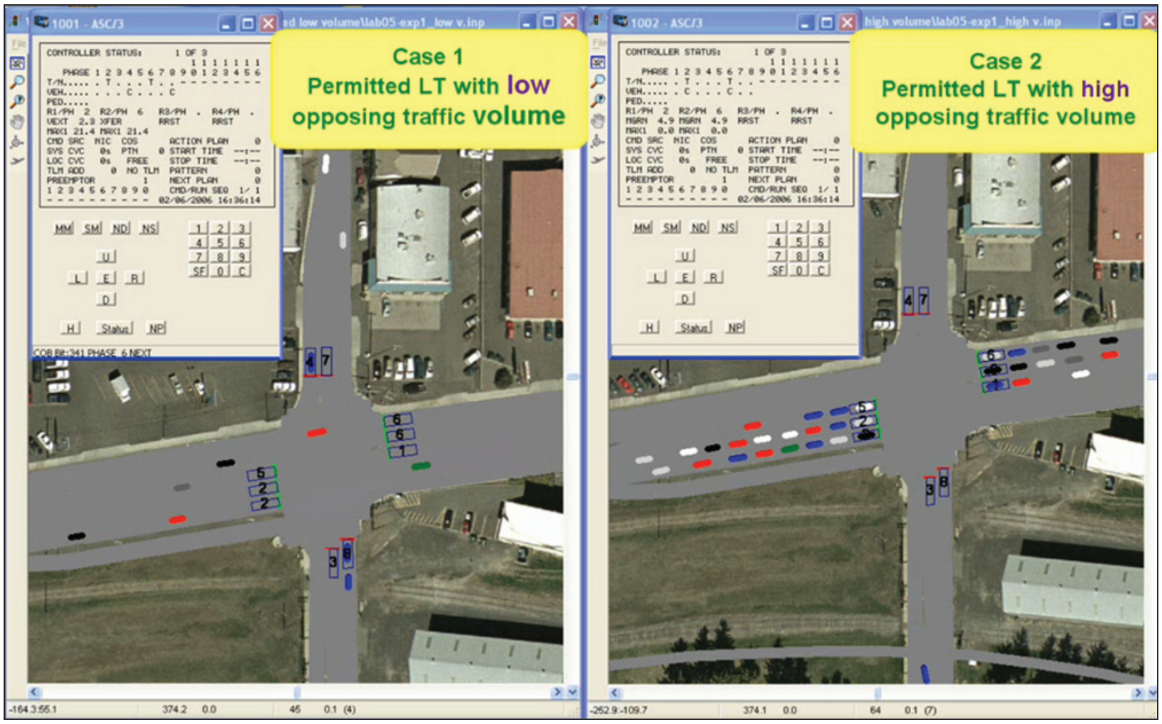

Figure 165. Animation comparing two permitted left turn phasing cases

Student Notes:

ACTIVITY

48 Comparing Permitted and Protected Left Turn Phasing

DISCOVERY

Purpose

The purpose of this activity is to give you the opportunity to compare permitted and protected left turn phasing.

Learning Objective

- Show that protected left turn phasing is more efficient than permitted left turn phasing under some conditions

Required Resource

- Movie file: A48.wmv

Deliverable

- Prepare a document that includes your answer to the Critical Thinking Question

Critical Thinking Question

As you begin this activity, consider the following question. You will come back to this question when you have completed your observations.

1. How does changing from permitted to protected left turn phasing affect the left turn operation and the operation of the entire intersection?

Information

In the previous activity, you considered the efficiency of permitted left turn operations. You saw that high opposing through volumes could seriously degrade the quality of permitted left turn operations. One option to improve the left turn operation is to change the phasing from "permitted" to "protected." Figure 166 illustrates the ring barrier diagram for full left turn protection.

In this activity you will again observe the left turn operation on State Highway 8. Both cases that you will observe have through volumes of 1450 vehicles per hour per lane and left turn volumes of 100 vehicles per hour. The only difference is in the left turn phasing. Case 1 is permitted left turn phasing (similar to case 2 in the previous activity) while case 2 is protected left turn phasing.

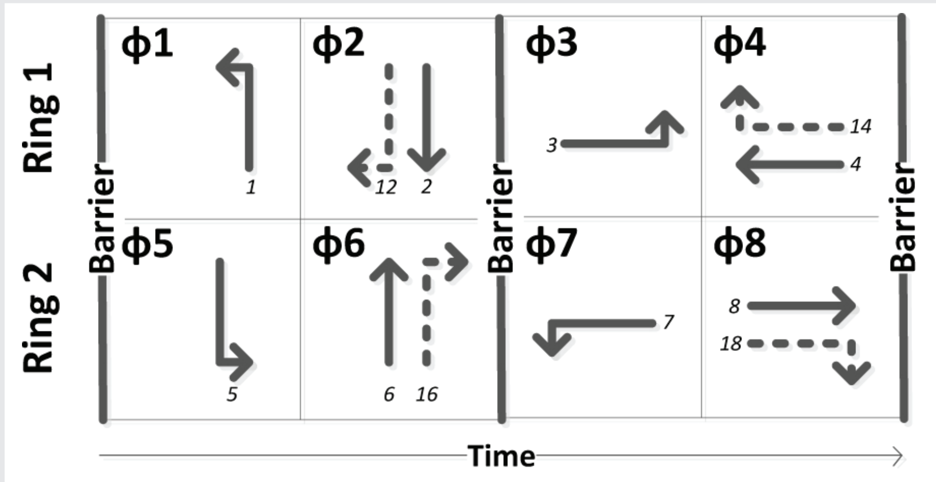

Figure 166. Ring barrier diagram for protected left turn phasing

Task 1

Open the file: "A48.wmv"

Task 2

Observe the operation of the two cases.

- Observe the left turn vehicles on the eastbound and westbound approaches for case 1 (permitted left turn) and case 2 (protected left turn). Observe the queue length for the eastbound left turn and westbound left turn movements for case 1 and the waiting time for those vehicles. Observe the same vehicles in case 2 and notice how all vehicles are served during the protected left turn. (See Figure 167.)
- Summarize your observations

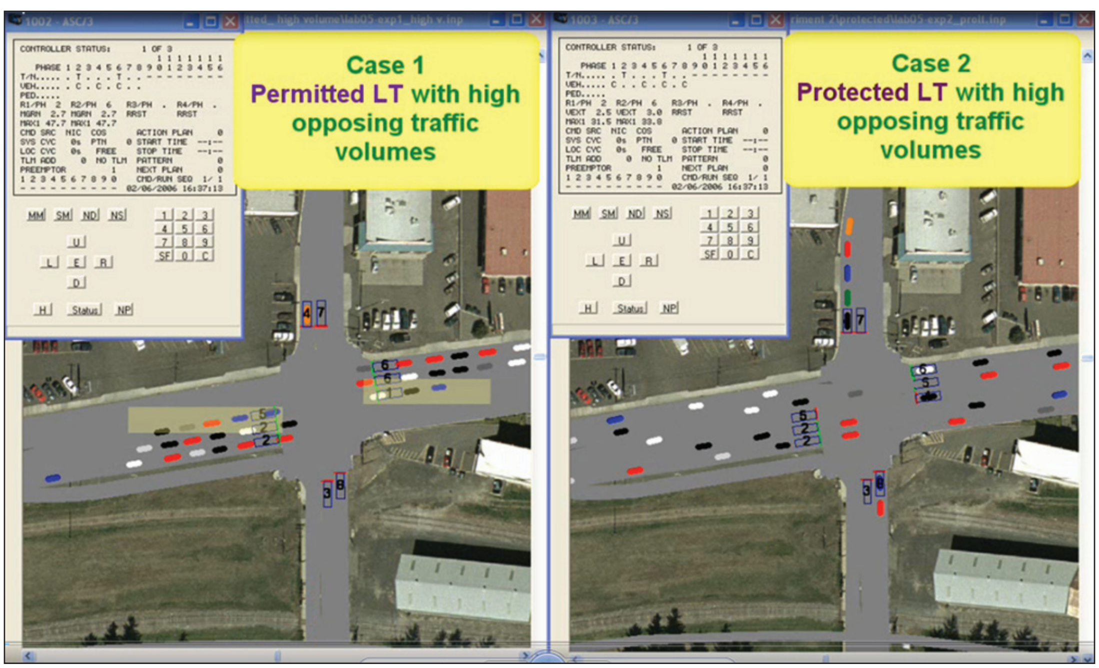

Figure 167. Animation comparing permitted and protected left turn phasing

ACTIVITY
49 Comparing Protected/Permitted and Protected Left Turn Phasing

DISCOVERY

Purpose

The purpose of this activity is to give you the opportunity to learn about protected plus permitted left turn phasing.

Learning Objective

- Describe the trade-offs and relative efficiencies between protected plus permitted and protected left turn phasing

Required Resource

- Movie file: A49.wmv

Deliverable

- Prepare a document that includes your answer to the Critical Thinking Question

Critical Thinking Question

As you begin this activity, consider the following question. You will come back to this question when you have completed the experiment.

1. Why do the eastbound left turn and westbound left turn movements have lower delay when they are operating as protected/permitted phasing as compared to the protected left turn case?

Information

In the previous activity, you considered permitted and protected left turn phasing. Protected left turn phasing offers some benefits over permitted left turn operations, such as reduced left turn delay when opposing through volumes are high, but at the expense of increasing delay for other movements. In this activity you will consider another type of left turn treatment, protected plus permitted phasing. In this type of treatment, left turn movements have two separate green intervals, protected operations followed by permitted operations.

Protected plus permitted phasing is shown in the ring barrier diagram in Figure 168.

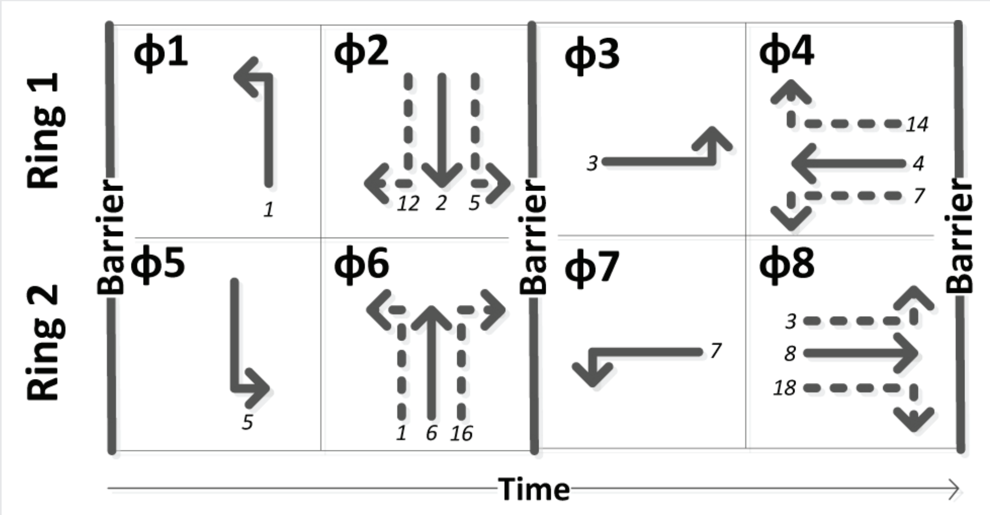

Figure 168. Ring barrier diagram for protected plus permitted left turn phasing

In this activity, you will perform tasks similar to what you did in Activity #48. You will observe the same intersection, State Highway 8 and Line Street, this time with protected and protected plus permitted left turn phasing.

Traffic volumes for all movements are the same as for the previous experiment except for eastbound left turn and westbound left turn.

- Eastbound through and westbound through: 1450 vph
- Eastbound left turn and westbound left turn: 200 vph

TASK 1

Open the file: "A49.wmv."

TASK 2

Observe the operation of both simulations.

- Observe the left turn vehicles on the eastbound and westbound approaches for case 1 (protected left turn) and case 2 (protected plus permitted left turn) (See Figure 169.)
- Observe vehicles that are served during the permitted phase in case 2 but are still waiting for the protected phase in case 1
- Observe the queue length that resulted for both cases
- Summarize your observations

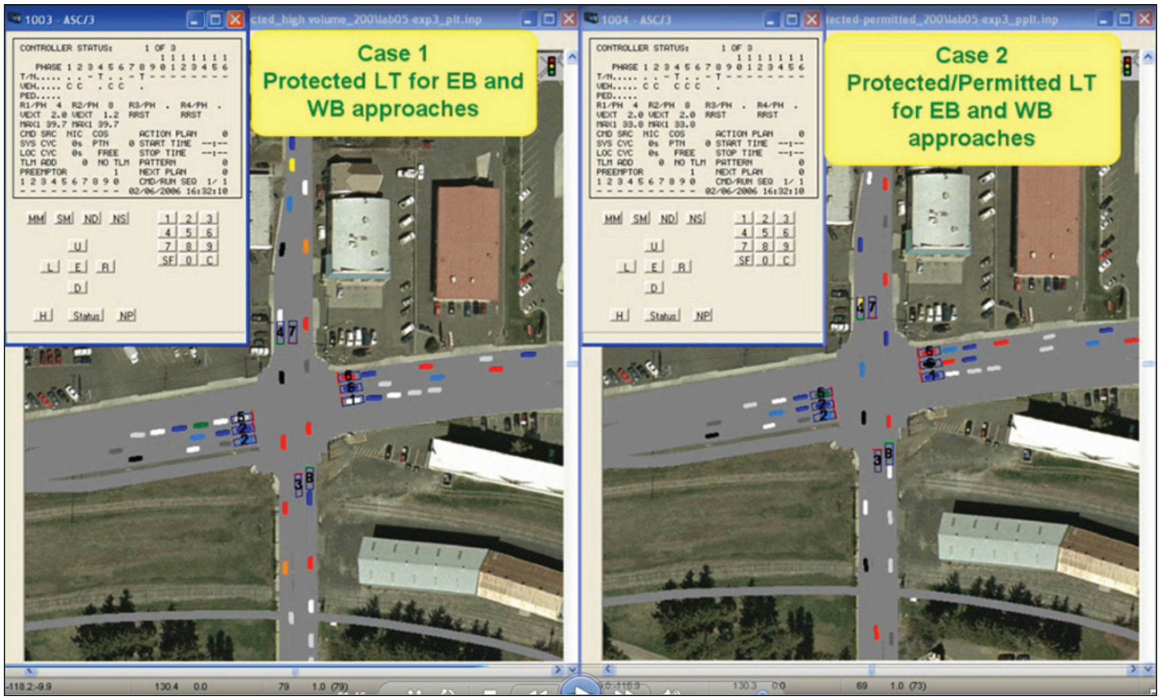

Figure 169. Animation comparing protected and protected plus permitted left turn phasing

Student Notes:

ACTIVITY

50 Analysis and Design of Left Turn Treatment

DESIGN

PURPOSE

The purpose of this activity is to give you the chance to compare protected and permitted left turn phasing treatments for your design problem and to select the most appropriate phasing treatment for the intersection.

LEARNING OBJECTIVE

- Select optimal left turn phasing treatment based on an analysis of performance data and observation of simulation conditions

REQUIRED RESOURCES

- VISSIM input file created in Activity #43

DELIVERABLES

- Prepare a spreadsheet with required data, analysis, and conclusions as per Tasks 2 through 5:

  Tab 1: Title page with activity number and title, authors, and date completed

  Tab 2: Performance data comparing both left turn treatments

  Tab 3: Ring barrier diagram for your recommended phasing plan

INFORMATION

> How will you balance the relative advantages of permitted left turn phasing compared to protected left turn phasing? Completing the following tasks will help you make this decision.

TASK 1

Make a copy of the folder that includes your VISSIM files from Activity #43. Name this new folder “a50”. Use this VISSIM file as the basis for your analysis and design of your left turn treatments.

TASK 2

Change the phasing plan to “permitted left turn” operation. See the VISSIM tutorial for help in making these changes. Collect data for delay and queue length, as in previous design activities.

TASK 3

Observe the simulation for the two left turn options. Make notes on your observations on the operation and performance of both simulations.

TASK 4

Compare the performance data and visual observation notes for both permitted and protected left turn treatment. Based on this comparison, make a determination of your recommended left turn treatment option.

TASK 5

Prepare a ring barrier diagram for the phasing plan that you recommend.

ACTIVITY
51 Left Turn Phasing Options

IN PRACTICE

Purpose

The purpose of this activity is to give you the opportunity to learn how left turn phasing decisions are made in practice.

Learning Objectives

- Describe the process for selecting left turn phasing
- Contrast the advantages and disadvantages of each left turn phasing option

Required Resource

- *Traffic Signal Timing Manual*

Deliverables

Prepare a document that includes

- Answers to the Critical Thinking Question
- Completed Concept Map

Link to Practice

Read the sections from the *Traffic Signal Timing Manual* on left turn phasing as assigned by your instructor.

Critical Thinking Questions

When you have completed the reading, prepare answers to the following questions:

1. What are the advantages and disadvantages of the common left turn phasing options?

2. Describe the process followed in practice to select an appropriate left turn phasing plan.

3. Based on your reading, would you change the left turn phasing plan that you developed in Activity #50? Explain your answer.

In My Practice...

by Tom Urbanik

Two issues have a profound effect on left turn operation and therefore phasing considerations. First is available storage which may be constrained due to closely spaced intersections. If the cycle length is long and the volume is high, consideration may need to be given to running the left turn twice per cycle. While one might think it is less efficient with two clearance intervals per cycle, a green indication with through traffic blocking the left turning traffic or left turning traffic blocking through traffic is more inefficient.

The second issue is when does left turning traffic arrive at the left turn lane. Again, with closely spaced intersections, left turning traffic may arrive too late to be served on the current cycle, causing increased delay for left turning traffic. Lagging rather than leading the left turn phase may provide reduced delay. This situation is very common at diamond interchanges where lagging the left turn to the ramp is often the preferred sequence.

CONCEPT MAP

Terms and variables that should appear in your map are listed below.

lagging left turns | left turn phasing | protected left turns
leading left turns | permitted left turns

Student Notes: