CHAPTER 8: LEFT TURN PHASING: PROTECTED, PERMITTED OR BOTH?

This chapter includes information that you will need to prepare for, conduct, and assess each of the seven activities included in Chapter 8 of the student activity book Figure 1 shows the various files that are available to support your works as you use these activities, including mini-lecture slides, solution files, and student resource files.

Chapter 8 Left Turn Phasing	Mini-lecture slides	Solution files	Student resource files
A#45 Reading			
A#46 Assessment			
A#47 Discovery			
A#48 Discovery			
A#49 Discovery			
A#50 Design			
A#51 In Practice			

Figure 1. Support files

Figure 2 shows the kind of work required for each activity, how the activities might be grouped, and the approximate amount of class time required to complete the activity. The figure also identifies whether there is homework involved, a mini-lecture could be presented, student discussion could take place, and group work to do.

Chapter 8 Left Turn Phasing	A#45 Reading	A#46 Assessment	A#47 Discovery	A#48 Discovery	A#49 Discovery	A#50 Design	A#51 In Practice
	30 min	60-90 min	60 min			120 min	30 min

Homework
Mini-lecture
Student discussion
Group work

Figure 2. Activity work

Using Activity #45: Left Turn Phasing (Reading)

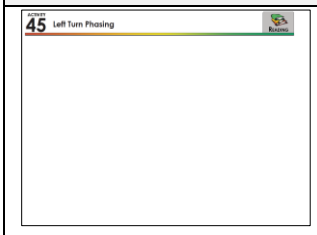
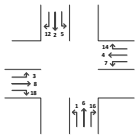
Overview
In this activity, students will learn the typical types of left turn phasing.

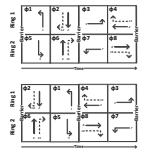
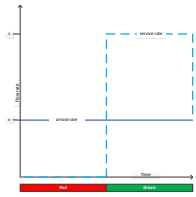
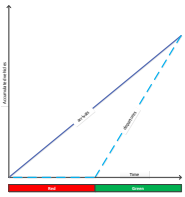
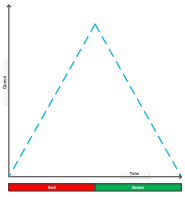
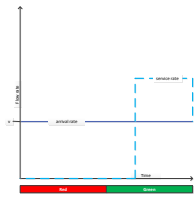
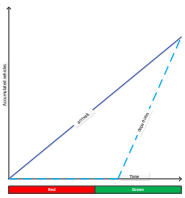
Options for Use
The reading, defining the terms in the glossary, and answering the critical thinking questions are usually done as homework, to prepare for class discussion. After the students complete this work, the instructor has several options for assessing and clarifying student understanding of the reading during class:

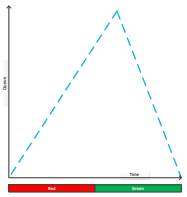
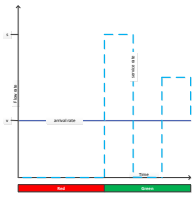
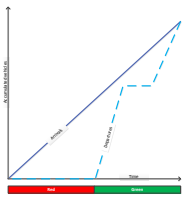
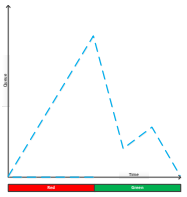
- Quiz to assess their understanding and to hold them accountable for the reading.
- Present mini-lecture summarizing key points from the reading, with active questioning of the students as the lecture material is presented.
- Discussion and synthesis of the answers to the quiz, the glossary definitions, and answers to the critical thinking questions.

Preparing for the Activity
- Decide which of the options you want to do during class.
- Prepare for class by reviewing Activity #45, including the "Information", the Glossary definitions, and the Critical Thinking Questions and answers.

Doing the Activity (Script)
[Slides: slides 45.pptx]
The following script can be used along with the PowerPoint slides for this activity. The script and slides can be modified based on your needs and what you decide to emphasize.

Slide	Notes
	One of the major purposes of a traffic signal system is to provide time separation between conflicting movements. But each time we provide this time separation, we are adding change and clearance intervals to make sure that the time separation exists. So while the protected LT movement is clearly the safest possible, it is not always the most efficient. We are going to look at cases when we don't need this level of separation, what we call permitted left turns.
	Standard movement diagram.

Slide	Notes
	RBD for protected left turns, both leading and lagging
	Flow profile diagram for protected left turns.
	Cumulative vehicle diagram for protected left turns.
	Queue accumulation polygon for protected left turns.
	RBD for permitted left turns.
	Flow profile diagram for permitted left turns.
	Cumulative vehicle diagram for permitted left turns.

Slide	Notes
	Queue accumulation polygon for permitted left turns.
	RBD for protected plus permitted left turns.
	Flow profile diagram for protected plus permitted left turns.
	Cumulative vehicle diagram for protected plus permitted left turns.
	Queue accumulation polygon for protected plus permitted left turns.

Solutions

Included here are:

- Critical thinking questions and answers
- Glossary and terms

Critical Thinking Questions and Answers

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

- Delay, queue length.

2. Why should permitted left turn phasing always be considered in a phasing plan options?

- Because it has the potential to be more efficient (fewer phase changes).

3. When should protected left turn phasing be considered?

- Why the combination of left turn volume and opposing through volume is high enough to result in significant delays or reduced safety, protected left turns should be considered.

Glossary and Terms (Answers)

Left turn phasing -	Different treatments options for left turns which include leading and lagging left turns
Permitted left turns -	Left turns are allowed while an opposing movement has right-of-way.
Protected left turns -	Left turns are allowed only
Leading left turns	- In a ring barrier diagram where the through movements are before the left turns.
Lagging left turns -	In a ring barrier diagram where the through movements are after the left turns.

Using Activity #46: What Do You Know About Left Turn Phasing (Assessment)

Overview

The purpose of this activity is for students to learn about left turn phasing options, to test their understanding of the options, and to test their understanding of when the options are appropriate to use. The phasing option that students are most commonly confused about is split phasing. One approach to help students understand split phasing is to discuss how movements in a ring barrier diagram are served. Because movements in the same ring are served sequentially, and all movements in split phasing are served in the same ring, each approach is served separately from the other approaches.

Options for Use

- Completion of tasks as homework.
- Completion of tasks during class.

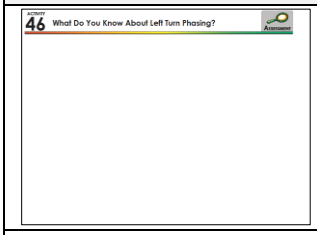
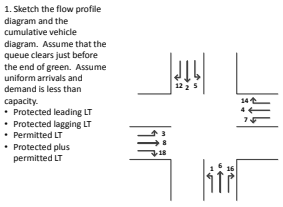
Preparing for the Activity

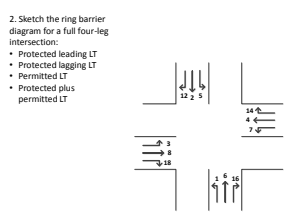
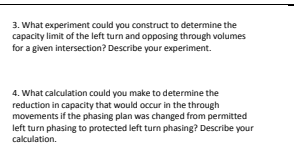
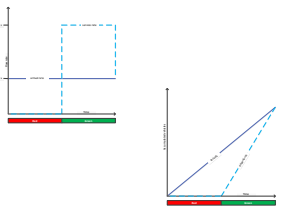
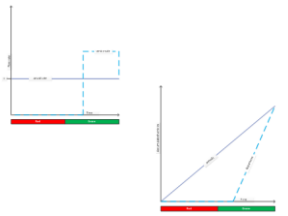
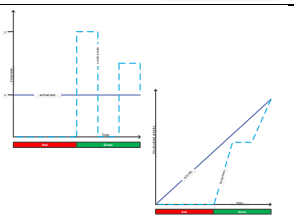
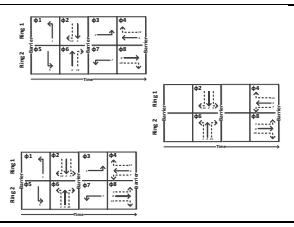
- Confirm options for class period.
- Review the critical thinking questions and answers.

Doing the Activity (Script)

[Slides: slides46.pptx]

The following script may be used to assist in the conduct of the activity.

Slide	Text
	
	We're going to start with a quiz on "left turn phasing". For the following phasing options, Sketch the flow profile diagram and the cumulative vehicle diagram. Assume that the queue clears just before the end of green. Assume uniform arrivals and demand is less than capacity. • Protected leading LT • Protected lagging LT • Permitted LT • Protected plus permitted LT

Slide	Text
	For these same phasing options, sketch the ring barrier diagram for a full four-leg intersection: • Protected leading LT • Protected lagging LT • Permitted LT • Protected plus permitted LT
	
	
	
	
	

Solutions

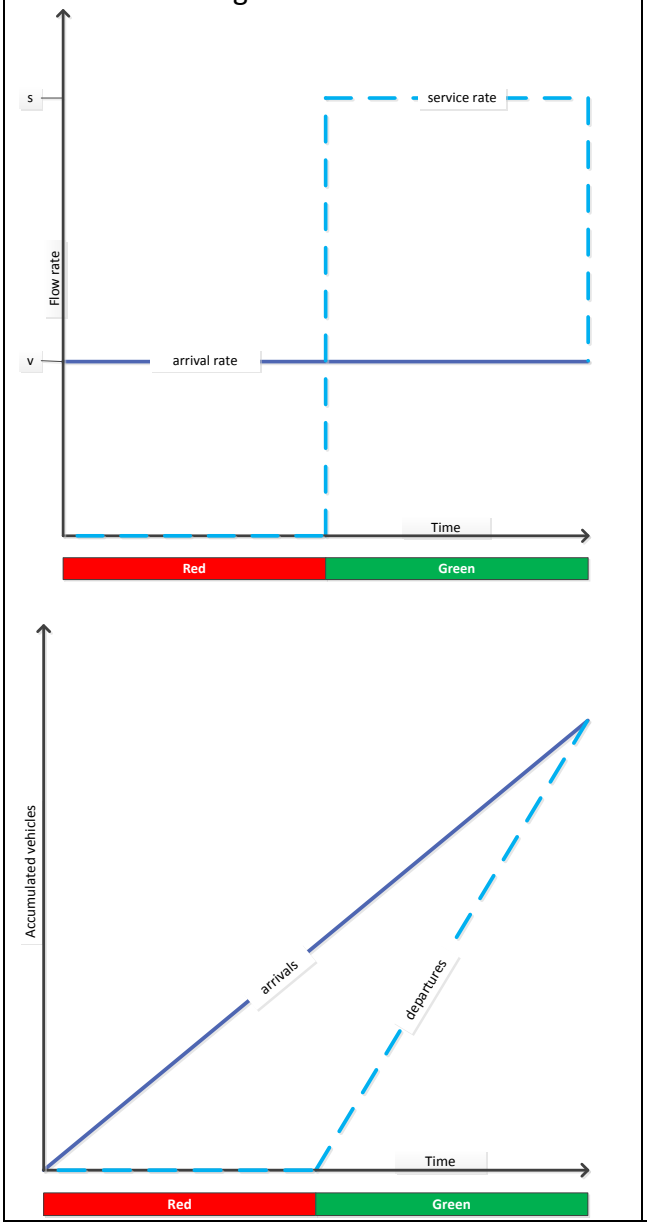
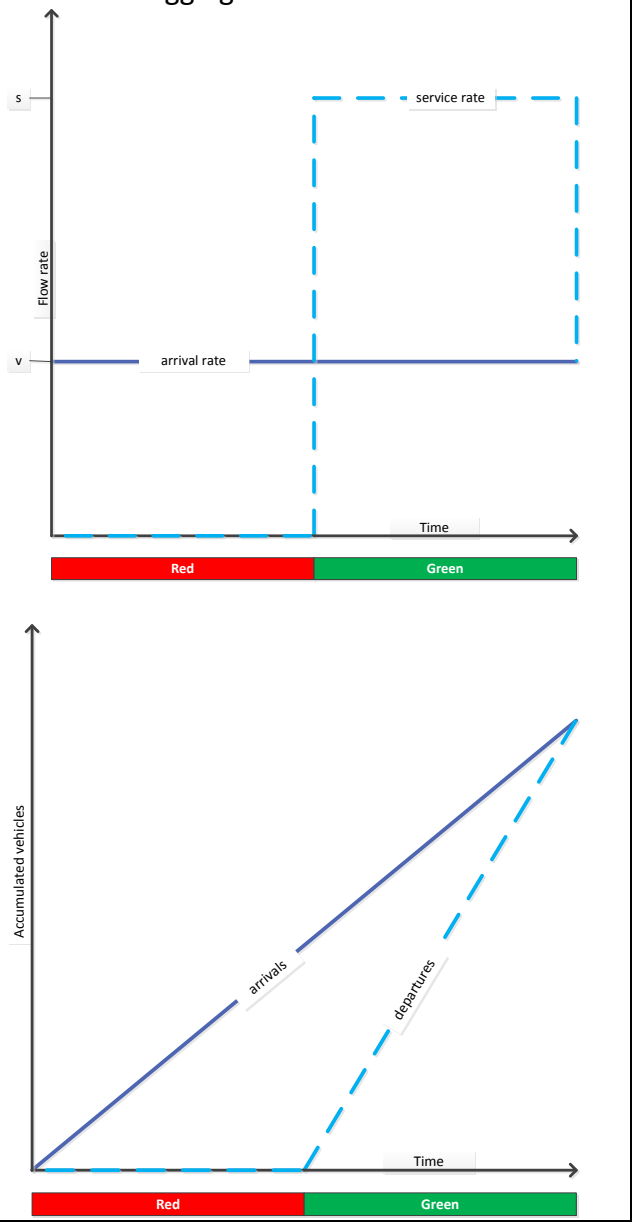
Included here are:

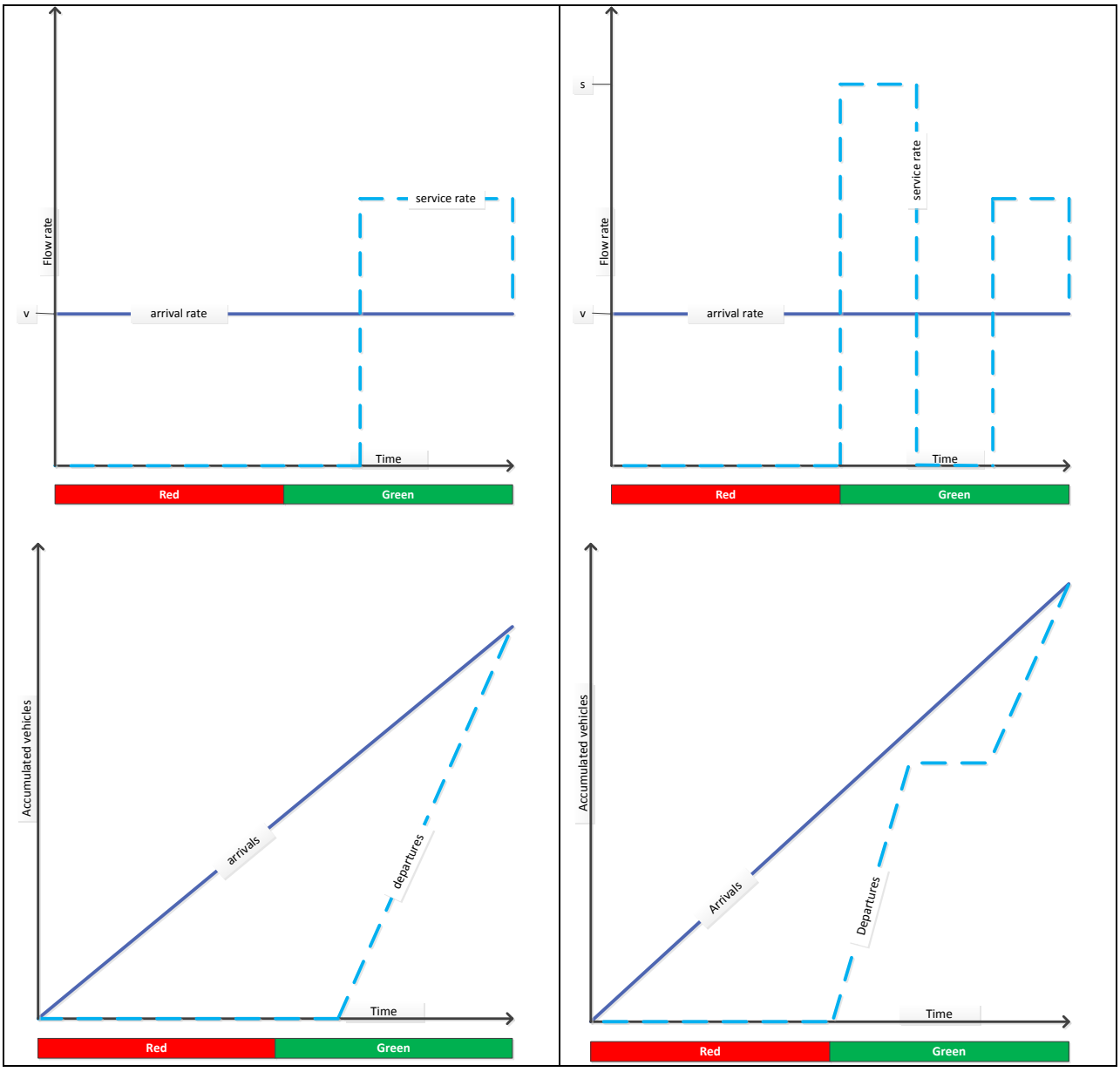
- Quiz answers
- Critical thinking questions and answers

Quiz answers

1. For the following phasing options, Sketch the flow profile diagram and the cumulative vehicle diagram. Assume that the queue clears just before the end of green. Assume uniform arrivals and demand is less than capacity.

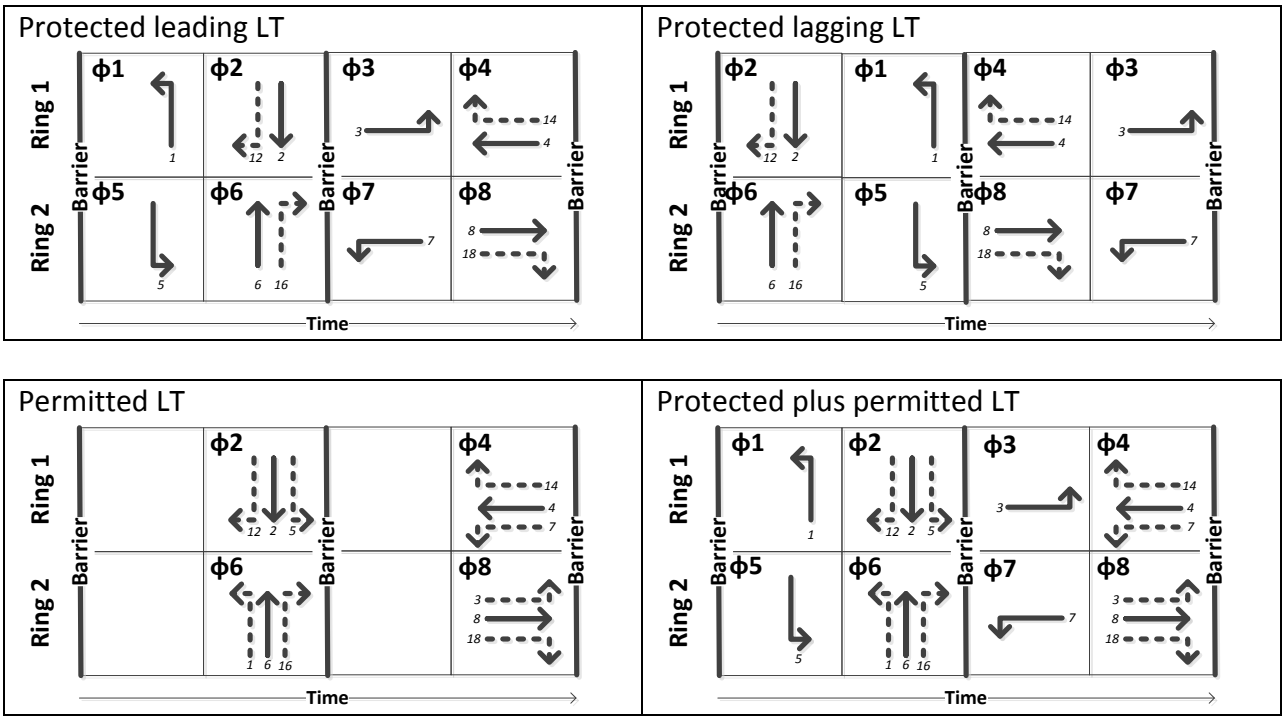
- Protected leading LT
- Protected lagging LT
- Permitted LT
- Protected plus permitted LT

Protected leading LT	Protected lagging LT
	
Permitted LT	Protected plus permitted LT



2. For these same phasing options, sketch the ring barrier diagram for a full four-leg intersection:

- Protected leading LT
- Protected lagging LT
- Permitted LT
- Protected plus permitted LT



Critical Thinking Questions and Answers

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 calculations 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 turns to protected left turn phasing? Describe your calculation.

Using Activity #47: Permitted Left Turn Operations (Discovery)

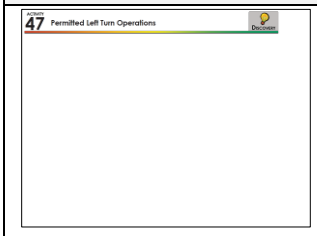
Overview
In this activity, students will learn about different turning treatments. The purpose of this activity is to allow students to understand permitted left turn phasing. Students will watch a video of the intersection of State Highway 8 and Line Street, focusing on the left turn operations. Students will be observing a permitted left hand turn under two conditions. In the first case, the opposing through movement is 800 vehicles per hour and in the second case, the through movement is 1450 vehicles per hour. In both cases the left turn movements are 100 vehicles per hour. By the end of this activity, students will be able to determine the efficiency of permitted left turn operations under various opposing through traffic volumes.

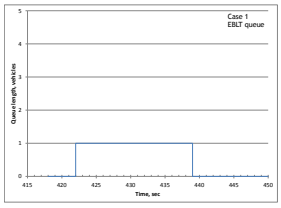
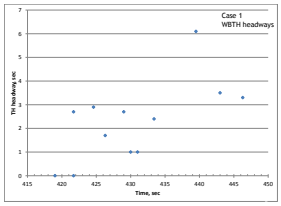
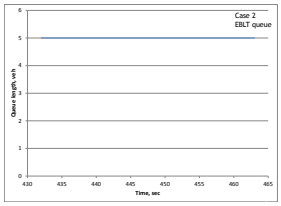
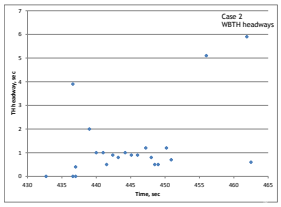
Options for Use
- Activity #47 can be conducted either during class or as homework.
- Activity #47 is often conducted together with Activities #48 and #49.

Preparing for the Activity
Watch the video to understand the key concepts shown in the video. Review the learning outcomes for this activity. Note that it is important to talk them through the activity so that they know what is important as they are watching the video; what are they supposed to observe?

This activity, as other previous activities, depends on the student viewing an video and making conclusions based on what they observed. That is, what will the student see, do, read, think about, compare? For example, when a student is viewing a video like this, there is a lot of visual information: traffic flow characteristics, signal timing status data, among others. What is important that the student will observe? How does it tie back to theory or reading that has been completed before the activity? What quantitative data can be collected that will supplement what they will see? What will the student see (details like traffic flow rates or signal timing settings) and what we are asking the student to focus on. The "questions to consider" for such an activity should really identify those points that we want them to focus on and give them the framework for this focus. So, for these activities, the instructor needs to be a journalist or a scientist and describe what I see as an introduction for an instructor, what are the "facts".

Doing the Activity (Script)
[Slides: slides47.pptx]
The following script and the accompanying slides (slides41.pptx) can be used to lead the activity.

Slide	Text
	The purpose of this class (set of three activities) is to learn more about LT options by observing three scenarios. The videos showing each scenario are between 3.5 and 4.5 minutes each. I will provide a framework from which you will view each scenario and then we will relate this work to the design activity (Activity #50) where you will compare LT options for your intersection and select what you believe to be the optimal one for the conditions at your intersection. When considering each scenario, we will have a framework with which to view the scenario, and that is our three queuing diagrams. So to start, let's take a few minutes to construct the flow profile diagram, the cumulative vehicle diagram, and the queue accumulation polygon for our three scenarios. [draw or review from quiz results] We're now going to observe the animations and you're going to use the framework of the queuing diagrams to help you observe and document the traffic flow characteristics. In addition, you are going to pay attention to the gap acceptance phenomenon that occurs for permitted LT operation. [draw on board three scenarios from these three activities, with conditions for each]
	This activity compares permitted LT operation with two different opposing TH volume levels. [Draw on board sketch of case 1 and case 2 volumes (100 permitted LT and 800-1450 for TH per lane] Learning objective: be able to determine the efficiency of permitted LT operation under various TH volume conditions. What to observe [read instructions]: EBLT traffic only • Relative size gaps in opposing TH traffic • Observe LT behavior (what size gaps do they accept and reject • Consider queues that form and delays that results in both scenarios • Connection between theory and your observations Reflections/answers to questions • How does the opposing TH volume affect the quality of permitted

Slide	Text
	LT operation for these two cases • What change to the phasing plan would you consider to improve operations and why
	
	
	
	
Question 2 • What change to the phasing plan would you consider, if any, to improve the quality of the operation for case 2?	
Running the Experiment Step 1. Open the movie file. Step2. Observe the operation of the two cases. 	**Tell:** Read through the instructions before beginning the lesson. Record your observations.
Considering the Questions • How does the opposing volume affect the quality of the left turn permitted operation for each of the two cases? • What change to the phasing plan would you consider, if any, to improve the quality of the operation for case 2?	**Tell:** You are presented again with the "questions to consider." **Tell:** Be ready to discuss your answers with the class.

Slide	Text
Question 1 • How does the opposing volume affect the quality of the left turn permitted operation for each of the two cases?	**Ask:** How does the opposing volume affect the quality of the left turn permitted operation for each of the two cases?
Question 1 • Table 1 Average delay for each movement. Movements / Average delay (sec/veh): Low opposing TH volumes (800 vph) / High opposing TH volumes (1450 vph) EBTH 9.4 12.1 WBTH 9.0 13.4 SBTH 19.4 19.1 NBTH 18.0 20.2 WBLT 19.0 72.6 EBLT 15.7 172.6 Intersection 13.3 18.0	**Answer:** There is a significant difference in the quality of the left turn operation for both cases. In case 1, you observed left turn vehicles on the EB and WB approach can easily find gaps in the opposing traffic to complete their maneuver, while in case 2, left turn vehicles had to wait for more than one cycle to find acceptable gaps to cross the intersection. The difference in the opposing through volumes is the clear reason for the differences in these observations. We can also show the difference in the performance by comparing average delay for each movement. This table shows the average delay for six movements, and for the intersection as a whole. These delay results represent averages of ten simulations, each with 900 seconds of simulation time. The following points can be noted from the table: • The left turn movements on the major street (EB and WB) experience significantly higher delays in case 2 than in case 1. The WBLT delay increases from 19.0 to 72.6 seconds per vehicle, while the EBLT delay increases from 15.7 to 172.6 seconds per vehicle. • The increase in delay for the other movements is much more modest. There is actually a small decrease for one movement (SB TH). What can we conclude from this experiment? Permitted left turn operation provides efficient operation when opposing volumes are low. However, in the case where opposing through volumes reach 1450 vehicles per hour, the delay increases significantly. Note that these two volumes are given as examples and are not intended to imply specific standards.
Question 2 • What change to the phasing plan would you consider, if any, to improve the quality of the operation for case 2?	**Ask:** What change to the phasing plan would you consider, if any, to improve the quality of the operation for case 2? **Answer:** One obvious change to the phasing plan is to eliminate the opposing through movements, so that the left turn movements can move with no delay. This type of phasing is known as protected LT phasing and will be illustrated in the next experiment. While protected LT phasing offers some obvious benefits, there is also a downside that must be considered. Providing a separate phase for the LT movement means that time is taken away from other movements,

Slide	Text
	likely increasing their delay.

Solutions

Critical Thinking Questions and Answers

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

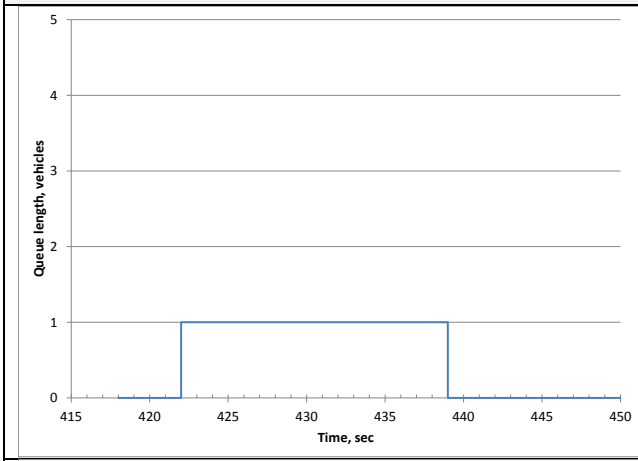
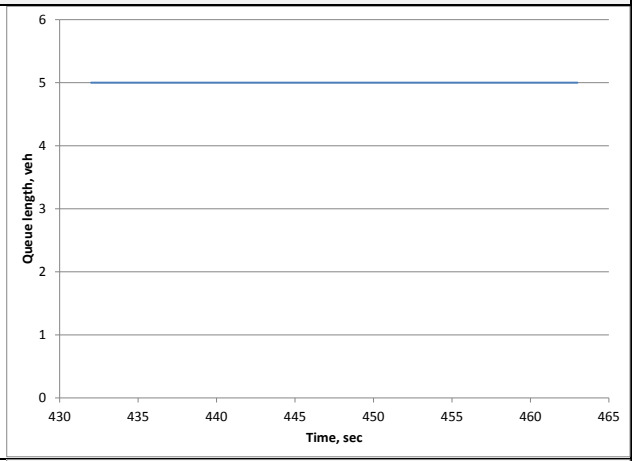
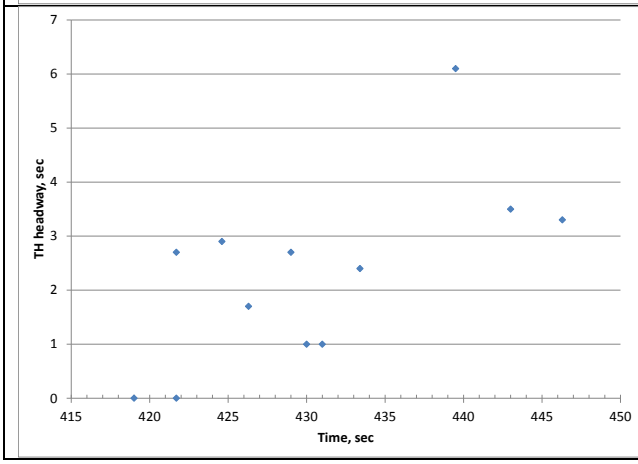
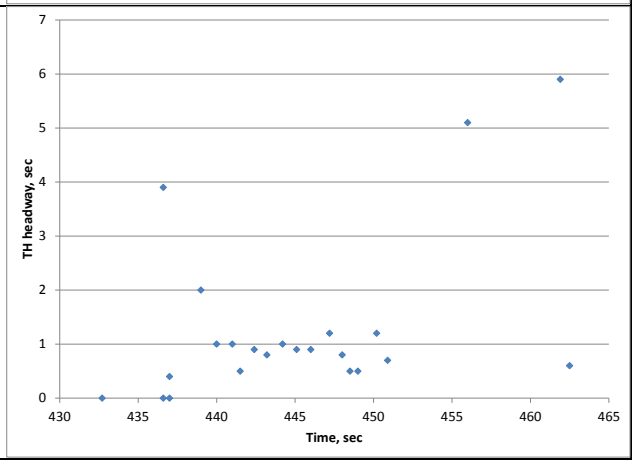
- There is a significant difference in the quality of the left turn operation for both cases. In case 1, you observed left turn vehicles on the EB and WB approach can easily find gaps in the opposing traffic to complete their maneuver, while in case 2, left turn vehicles had to wait for more than one cycle to find acceptable gaps to cross the intersection. The difference in the opposing through volumes is the clear reason for the differences in these observations.
- We can also show the difference in the performance by comparing average delay for each movement.
- The figure shows the average delay for six movements, and for the intersection as a whole. These delay results represent averages of ten simulations, each with 900 seconds of simulation time. The following points can be noted from the table:
- The left turn movements on the major street (EB and WB) experience significantly higher delays in case 2 than in case 1. The WBLT delay increases from 19.0 to 72.6 seconds per vehicle, while the EBLT delay increases from 15.7 to 172.6 seconds per vehicle.
- The increase in delay for the other movements is much more modest. There is actually a small decrease for one movement (SB TH).
- What can we conclude from this experiment? Permitted left turn operation provides efficient operation when opposing volumes are low. However, in the case where opposing through volumes reach 1450 vehicles per hour, the delay increases significantly. Note that these two volumes are given as examples and are not intended to imply specific standards.

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

- One obvious change to the phasing plan is to eliminate the opposing through movements, so that the left turn movements can move with no delay. This type of phasing is known as protected LT phasing and will be illustrated in the next experiment. While protected LT phasing offers some obvious benefits, there is also a downside that must be considered. Providing a separate phase for the LT movement means that time is taken away from other movements, likely increasing their delay.

Other Notes

These figures showing data from the video can be incorporated into the presentation notes.

Case 1	Case 2
	
	

Using Activity #48: Comparing Permitted and Protected Left Turn Phasing (Discovery)

Overview

The purpose of this activity is to allow students to gain an understanding about the advantages and applicability of permitted-protected left turn phasing. In the previous activity, students considered the efficiency of permitted left turn operations. They 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". In this activity, students will again observe the LT operation on State Highway 8. Both cases that will be observed have through volumes of 1450 vehicles per hour and LT volumes of 100 vehicles per hour. The only difference is in the LT phasing. Case 1 is permitted LT phasing (similar to case 2 in the previous activity) while case 2 is protected LT phasing.

Options for Use

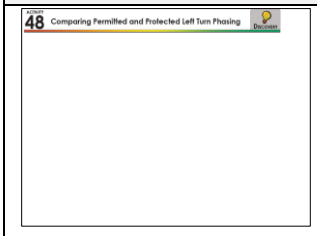
- Activity #48 can be conducted either during class or as homework.
- Activity #48 is often conducted together with Activities #47 and #49.

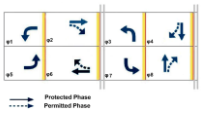
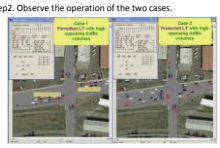
Preparing for the Activity

Watch the video to understand the key concepts shown in the video. Review the learning outcomes for this activity. Note that it is important to talk them through the activity so that they know what is important as they are watching the video; what are they supposed to observe?

Doing the Activity

[Slides: slides48.pptx]
The following slides can be used to conduct the activity.

Slide	Text
	This activity compares permitted LT and protected LT operation, for the high volume case from Activity #49. [Draw sketch of two volume scenarios] LO: Understand that protected LT phasing is more efficient than permitted LT under some conditions.
	What to observe (read instructions) • EB/WB traffic • Observe LT vehicles on EB and WB approaches for two cases • Observe the queue length for EBLT and WBLT for case 1, and the waiting time for these vehicles. • Observe same for case 2. • Summarize your observations.
	Reflections to consider:

Slide	Text
	How does changing from permitted LT to protected LT phasing affect LT operation and operation of entire intersection?
	[Do activity] 10-15 minutes [one group to answer questions]
[delay slide]	What do you notice about delays? -LT decrease, others increase..why? -Queue clearance
Comparing Permitted And Protected Left Turn Phasing • Learning outcomes • Overview • Questions to consider • Steps  Protected Phase Permitted Phase	**Tell:** Review the learning outcome for this experiment, an overview of the experiment, the questions that you will answer once you've finished the experiment, and the list of steps that you will complete during the experiment. Take about two minutes to read this page. [Once they have completed reading the page] **Ask:** Do you have any questions on this material? **Tell:** Emphasize the learning outcome for this lesson. Understand that protected LT phasing is more efficient than permitted LT phasing under some conditions
Running the Experiment • Step 1. Open the movie file. • Step2. Observe the operation of the two cases. 	**Tell:** Review the instructions for running the experiment. The conditions for this experiment include: • The left turn volume is 100 • The through volume is 1450 • Case 1 is permitted left turn • Case 2 is protected left turn
Considering the Questions • How does changing from permitted to protected left turn phasing affect the LT operation and the operation of the entire intersection?	**Tell:** Once you have completed step 2, review the "questions to consider." **Tell:** Be ready to discuss your answers with the class.
Question 1 • How does changing from permitted to protected left turn phasing affect the LT operation and the operation of the entire intersection?	**Tell:** Let's now discuss the questions that were asked at the beginning of this lesson. **Ask:** How does changing from permitted to protected left turn phasing affect the LT operation and the operation of the entire intersection?

Slide	Text
Question 1 • Table 2 Average delay for each movement. Movements / Average delay (sec) / Permitted LT / Protected LT EBTH 12.3 19.7 WBTH 13.9 24.9 SBTH 19.1 27.1 NBTH 20.2 29.0 WBLT 72.6 54.5 EBLT 172.6 46.3 Intersection 18.0 24.7	**Answer:** In case 1, you have observed long queues with long waiting time (some vehicles waiting more than one cycle) because left turn vehicles need to wait to find accepted gaps to complete their maneuver which is not available with high opposing through traffic volumes. In case 2, protected LT phasing provides right-of-way for left turn vehicles so their waiting time is shorter than case 1. Protected left turn phasing removes the need for gap acceptance, because LT vehicles are assigned the right-of-way. This table shows average delay for each movement for each case. For EBLT the average delay decreases from 172.6 seconds to 46.3 seconds (73 percent) while the WBLT average delay decreases from 72.6 seconds to 54.5 seconds (25 percent). On the other hand, average delay for all other through movements increase, as does the delay for the intersection. This happens because an additional phase causes an increase in the lost time experienced within a cycle length and reduces the green splits for the existing phases. These negative impacts increase delay for the existing phases. Protected left turn phasing has important benefits that must be weighed against possible costs.

Solutions

Critical Thinking Questions and Answers

Task 2: Observe the operation of the two cases. Summarize your observations.

- In case 1, students will observe long queues with long waiting time (some vehicles waiting more than one cycle) because left turn vehicles need to wait to find acceptable gaps to complete their maneuver which is not available with high opposing through traffic volumes. In case 2, protected LT phasing provides right-of-way for left turn vehicles so their waiting time is shorter than case 1.
- Protected left turn phasing removes the need for gap acceptance, because LT vehicles are assigned the right-of-way. For EBLT the average delay decreases from 172.6 seconds to 46.3 seconds (73 percent) while the WBLT average delay decreases from 72.6 seconds to 54.5 seconds (25 percent). On the other hand, average delay for all other through movements increases, as does the delay for the intersection. This happens because an additional phase causes an increase in the lost time experienced within a cycle length and reduces the green splits for the existing phases. These negative impacts increase delay for the existing phases. Protected left turn phasing has important benefits that must be weighed against possible costs.

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

- In case 1, you have observed long queues with long waiting time (some vehicles waiting more than one cycle) because left turn vehicles need to wait to find accepted gaps to complete their maneuver which is not available with high opposing through traffic volumes.

In case 2, protected LT phasing provides right-of-way for left turn vehicles so their waiting time is shorter than case 1.

- Protected left turn phasing removes the need for gap acceptance, because LT vehicles are assigned the right-of-way. Table 1 shows average delay for each movement for each case. For EBLT the average delay decreases from 172.6 seconds to 46.3 seconds (73 percent) while the WBLT average delay decreases from 72.6 seconds to 54.5 seconds (25 percent). On the other hand, average delay for all other through movements increases, as does the delay for the intersection. This happens because an additional phase causes an increase in the lost time experienced within a cycle length and reduces the green splits for the existing phases. These negative impacts increase delay for the existing phases. Protected left turn phasing has important benefits that must be weighed against possible costs.

Table 1 Average delay for each movement

Movements	Average delay (sec)	
	Permitted LT	Protected LT
EBTH	12.3	19.7
WBTH	13.4	24.4
SBTH	19.1	27.1
NBTH	20.2	29.0
WBLT	72.6	54.5
EBLT	172.6	46.3
Intersection	18.0	24.7

Using Activity #49: Comparing Protected/Permitted and Protected Left Turn Phasing (Discovery)

Overview

The purpose of this activity is to teach students about protected/permitted left turn phasing. In the previous activity, students considered permitted and protected left turn phasing. Protected/permitted left turn phasing has two separate green intervals, protected operations followed by permitted operations. Students will be watching a video of the intersection of State Highway 8 and Line Street. Students will be able to understand the trade-offs and relative efficiencies between protected/permitted and protected left turn phasing.

Options for Use

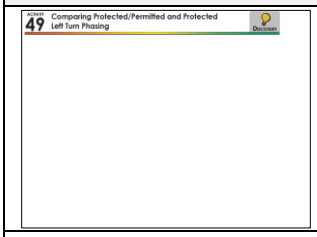
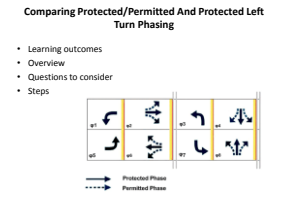
- Activity #49 can be conducted either during class or as homework.
- Activity #49 is often conducted together with Activities #47 and #48.

Preparing for the Activity

Watch the video to understand the key concepts shown in the video. Review the learning outcomes for this activity. Note that it is important to talk them through the activity so that they know what is important as they are watching the video; what are they supposed to observe?

Doing the Activity

[Slides: slides49.pptx]
The following slides can be used to conduct the activity.

Slide	Text
	The students will observe a movie file that shows two left turn phasing cases: protected left turn phasing and protected/permitted left turn phasing.
	**Tell:** Review the learning outcome for this experiment, an overview of the experiment, the questions that you will answer once you've finished the experiment, and the list of steps that you will complete during the experiment. Take about two minutes to read this page. [Once they have completed reading the page] **Tell:** Do you have any questions on this material? **Tell:** Emphasize the learning outcome for this lesson.

Slide	Text
	Understand the trade-offs and relative efficiencies between protected/permitted and protected left turn phasing
Running the Experiment • Step 1. Open the movie file. • Step2. Observe the operation of both simulations. 	**Tell:** Follow the instructions for running the experiment. Read through the instructions before beginning the lesson. When you have completed the steps for running the experiment, record your observations in the box provided on page 5-6.
Considering the Questions • Why do the EBLT and WBLT movements have lower delay when they are operating as protected/permitted phasing as compared to the protected left turn case?	**Tell:** Once you have completed step 2, review the "questions to consider." Be ready to discuss your answers with the class.
Question 1 • Why do the EBLT and WBLT movements have lower delay when they are operating as protected/permitted phasing as compared to the protected left turn case?	**Ask:** Why do the EBLT and WBLT movements have lower delay when they are operating as protected/permitted phasing as compared to the protected left turn case?
Question 1 • Table 3 Average delay for each movement. Movements / Average delay (sec/veh): Protected LT / Protected/Permitted LT EB TH: 24.9 / 25.2 WB TH: 27.0 / 29.5 SB TH: 31.9 / 31.2 NB TH: 30.4 / 28.6 WBLT: 56.0 / 32.4 EBLT: 52.5 / 38.9 Intersection: 29.3 / 26.9	**Answer:** From the animation file, you have observed: • In case 1, vehicles on EBLT and WBLT arrive and wait for the protected LT phase to be served. [Note: the waiting time is too long.] In case 2, some of the vehicles that arrive on EBLT and WBLT are served during the permitted LT phase, so those vehicles do not wait for the protected phase and their waiting time is short. • You also observed that some vehicles in case 2 (sneakers) start crossing the intersection on yellow and finish their maneuver on red. This table shows the average delay for each movement for each case. These delay results represent averages of ten simulations, each with 900 seconds of simulation time. For the EBLT movement, the average delay decreases from 52.5 seconds to 38.9 seconds (26 percent) and for the WBLT movement, the average delay decreases from 56.0 seconds to 32.4 seconds (42 percent). The average delay decreases for all other movements and the intersection as well.
Question 1 • Table 4 Average green duration for each phase. Phase / Average Green Duration (sec): Protected LT / Protected/Permitted LT EB TH: 44.3 / 45.7 WB TH: 44.2 / 44.7 SB TH: 28.7 / 30.1 NB TH: 28.7 / 30.1 WBLT: 10.4 / 7.7 EBLT: 10.6 / 8.9	**Answer:** This table shows the average green duration for each phase for each case. For the EBLT movement, the average green duration decreases from 10.6 seconds to 8.9 seconds (16 percent), and for the WBLT movement, the average green duration decreases from 10.4 seconds to 7.7 seconds (26 percent). On the other hand, the average green duration increases for all other through movements.

Slide	Text
	In this example, and for all movements, protected/permitted left turns provide more efficient operation than protected left turns only.

Solutions

Critical Thinking Questions and Answers

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

- In case 1, vehicles on EBLT and WBLT arrive and wait for the protected LT phase to be served. [Note: the waiting time is too long.] In case 2, some of the vehicles that arrive on EBLT and WBLT are served during the permitted LT phase, so those vehicles do not wait for the protected phase and their waiting time is short.
- You also observed that some vehicles in case 2 (sneakers) start crossing the intersection on yellow and finish their maneuver on red.
- Table 3 shows the average delay for each movement for each case. These delay results represent averages of ten simulations, each with 900 seconds of simulation time. For the EBLT movement, the average delay decreases from 52.5 seconds to 38.9 seconds (26 percent) and for the WBLT movement, the average delay decreases from 56.0 seconds to 32.4 seconds (42 percent). The average delay decreases for all other movements and the intersection as well.
- Table 3 shows the average green duration for each phase for each case. For the EBLT movement, the average green duration decreases from 10.6 seconds to 8.9 seconds (16 percent), and for the WBLT movement, the average green duration decreases from 10.4 seconds to 7.7 seconds (26 percent). On the other hand, the average green duration increases for all other through movements.
- In this example, and for all movements, protected/permitted left turns provide more efficient operation than protected left turns only.

Table 2 Average delay for each movement

Movements	Average delay (sec/veh)	
	Protected LT	Protected/Permitted LT
EBTH	24.9	25.2
WBTH	27.0	24.5
SBTH	31.9	31.2
NBTH	30.4	28.6
WBLT	56.0	32.4
EBLT	52.5	38.9
Intersection	29.3	26.9

Table 3 Average green duration for each phase

Phase	Average Green Duration (sec)	
	Protected LT	Protected/Permitted LT
EBTH	44.3	45.7
WBTH	44.2	44.7
SBTH	28.7	30.1
NBTH	28.7	30.1
WBLT	10.4	7.7
EBLT	10.6	8.9

Using Activity #50: Analysis and Design of Left Turn Treatment (Design)

Overview
In this activity, students will select a left turn treatment for their design intersection. The purpose of this activity is to have students compare protected and permitted left turn phasing treatments for their assigned intersection, and to select a left turn treatment.

While the performance of the intersection is likely to increase as a result of changing from protected left turns to permitted left turns, students should be encouraged to consider the safety impacts of the change in addition to the performance impacts. However, because VISSIM does not generate safety data, students should be encouraged to use their common sense when assessing the safety impacts.

A final thing that students could be encouraged to consider is the implementation of protected plus permitted phasing, where there is a dedicated protected left turn phase, followed by a permitted left turn phase.

One discussion point that should be brought up is that switching to permitted left turn treatment can increase performance for non-turning movements because there is less lost time due to the elimination of the turning phases, and consequently the yellow and all red time of the turning phases.

Options for Use
This activity is done in the classroom, supervised by the instructor.

Preparing for the Activity
Review the activity and the tasks that the students will have to complete.

Doing the Activity
Review the tasks with the students.

Solutions
[Excel file with example results: solution50.xlsx]

Answers to task questions
Task 2: Observe the simulation for the two left turn options. Make notes on your observations of both simulations.

- Students should be observing the process involved for drivers desiring to complete a left turn maneuver. After the signal turns green, drivers must wait for an acceptable gap in the opposing through traffic before completing their turning maneuver. This is significantly different than protected left turn treatments where left turning vehicles are given a dedicated phase and therefore do not have to yield to opposing traffic.

Task 3: 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.

- In most cases, vehicles are able to turn left without issue. If the max green time is too low, students may observe cycle failures occurring as the left turn queue may not be fully served before the phase maxes out, causing delay to increase. Students should also be able to observe that left turning vehicles must yield to oncoming traffic.
- Example tables comparing protected and permitted left turn treatments are shown below in Table 4 and Table 5. For all movements, delay and queue length decreased or remained constant. Because of this improvement, and because visually, vehicles were able to safely complete their left turn maneuver, the recommended left turn treatment would be permitted left turns.

Table 4. Delay and Queue Length Comparison for Permitted and Protected Left Turn Treatments

Movement	Delay (seconds) Comparison			Queue Length (feet) Comparison		
	Protected Left Turns	Permitted Left Turns	Decrease	Protected Left Turns	Permitted Left Turns	Decrease
NBRT	19.9	9.1	10.8	25.9	12.2	13.7
NBTH	19.9	9.1	10.8	24.4	12.9	11.5
NBLT	20.7	9.6	11.1	30.3	18.2	12.1
WBTH	61.3	16.4	44.9	23.6	9.0	14.6
WBRT	61.3	16.4	44.9	21.2	8.5	12.7
WBLT	12.1	2.9	9.2	35.3	16.3	19.0
EBTH	31.6	12.3	19.3	14.8	7.8	7.0
EBLT	22.9	6.8	16.1	30.5	15.8	14.7
EBRT	0.8	0.8	0.0	12.0	11.7	0.3
SBRT	33.8	12.7	21.1	28.3	11.8	16.5
SBTH	33.8	12.7	21.1	26.6	13.2	13.4
SBLT	16.3	5.2	11.1	34.8	15.5	19.3
All	27.9	9.5	18.4	24.0	11.5	12.5

Table 5. Travel Time Comparison for Permitted and Protected Left Turn Treatments

Direction	Protected Left Turns	Permitted Left Turns	Decrease
EB	34.5	27.4	7.1
WB	42.1	27.5	14.6

Task 4: Prepare a ring barrier diagram for the phasing plan the students recommend in task 3.

- Because permitted left turn phasing was selected, the new ring barrier diagram must combine the through and left turn movements into one phase. This will eliminate the odd numbered phases, combining them with the even numbered phases which can be seen in **Error! Reference source not found.**.

Task 5: Prepare a brief report on the analysis and the conclusions that you made from this analysis, as per tasks 1 through 3. Include the performance data comparing both left turn treatments in this report. The report should be prepared in Excel.

- Examples Excel files for each group can be found in the solutions.

Using Activity #51: Left Turn Phasing Options (In Practice)

Overview
Students will again be exposed to the Traffic Signal Timing Manual and its treatment of left turn phasing options.

Options for Use
- The synthesis and discussion of the questions can be done as part of a group either during class or as homework.

Preparing for the Activity
- Review the relevant sections of the Traffic Signal Timing Manual.

Doing the Activity (Script)
1. Invite them to consider the critical thinking questions and their answers.
2. Ask for answers and discussions for selected questions.

Solution
Critical Thinking Questions and Answers
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.