Laboratory 5
Selecting Left Turn Phasing for Various Traffic Volume Conditions

CONTENTS (LABORATORY 5)

1. Introduction 235
1.1 Purpose 235
1.2 Goals and Learning Objectives 235
1.3 Organization and Time Allocation 235
2. Terms 236
3. Experiment #1: Permitted Left Turn Operations 237
3.1 Learning Objective 237
3.2 Overview 237
3.3 Questions to Consider 238
3.4 List of Steps 238
3.5 Running the Experiment 239
3.6 Discussion 240
4. Experiment #2: Comparing Permitted And Protected Left Turn Phasing 242
4.1 Learning Objective 242
4.2 Overview 242
4.3 Questions to Consider 242
4.4 List of Steps 242
4.5 Running the Experiment 243
4.6 Discussion 244
5. Experiment #3: Comparing Protected/Permitted And Protected Left Turn Phasing 246
5.1 Learning Objective 246
5.2 Overview 246
5.3 Questions to Consider 246
5.4 List of Steps 246

5.5 Running the Experiment 247
5.6 Discussion 248
6. Experiment #4: Design Exercise- Determining Appropriate Left Turn Treatment 250
6.1 Learning Objective 250
6.2 Overview 250
6.3 Questions to Consider 250
6.4 List of Steps 250
6.5 Running the Experiment 251
6.6 Discussion 254
7. Closure: Summary Of Key Points Learned 258

1. INTRODUCTION

1.1 Purpose

In previous laboratories, you focused primarily on the operation of the through movements at a signalized intersection. While left turn phasing was considered, we paid little attention to the type of left turn phasing and its effect on the operations of the intersection.

In Laboratory 5, you will explicitly consider several left turn phasing types, including:

- Permitted left turn phasing
- Protected left turn phasing
- Protected plus permitted left turn phasing

You will learn how, under various volume conditions, each type of left turn phasing performs.

1.2 Goals and Learning Objectives

The goal of Laboratory 5 is to determine the appropriate left turn phasing for a given volume condition.

When you have completed Laboratory 5 you will:

- Be able to compare the performance of different left turn phasing alternatives.
- Understand the efficiency of different left turn phasing alternatives.
- Be able to determine an efficient left turn treatment.

1.3 Organization and Time Allocation

Laboratory 5 is divided into seven sections, including this introduction. The six sections that follow and the approximate time allocated to each section are listed Table 1.

Table 1 Laboratory sections and approximate completion times

Section	Title	Approximate Time (min)
1	Introduction	5
2	Terms	10
3	Experiment #1: Permitted left turn operations	15
4	Experiment #2: Comparing permitted and protected left turn phasing	15
5	Experiment #3: Comparing protected/permitted and protected left turn phasing	30
6	Experiment #4: Design exercise-determining appropriate left turn treatment	45
7	Closure: Summary of key points learned	15

2. TERMS

Standard definitions for traffic signal terminology are provided by the National Electrical Manufacturers Association (NEMA) [9] and by the National Transportation Communications for ITS Protocol (NTCIP) 1202 document, "Object Definitions for Actuated Traffic Signal Controller Units" [2]. Definitions are also provided in the Federal Highway Administration's *Traffic Signal Timing Manual* [5]. The definitions presented here are adapted from these sources.

Leading Left Turns: A traffic phase serving a left turn movement whose green leads the opposing through phase green.

Permitted Left-Turn Phasing: A type of left turn phasing such that drivers must yield to opposing through traffic until safe gaps in the opposing traffic become available.

Protected Left-Turn Phasing: A type of left turn phasing such left turning drivers have exclusive right of way. A green arrow is usually displayed to indicate protected left turn phasing.

Protected/Permitted Left-Turn Phasing: A type of left turn phasing that is a combination of protected and permitted left turn phases. In this type of operation, drivers have right-of-way during the protected phase but can complete their maneuver on the permitted phase as opposing through movements permit.

3. EXPERIMENT #1: PERMITTED LEFT TURN OPERATIONS

3.1 Learning Objective

- Be able to determine the efficiency of permitted left turn operations under various opposing through traffic volumes.

3.2 Overview

In this experiment 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, looking toward the south, is shown in Figure 1. 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, with two 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 (NB and SB through movements) have the same volume, 600 vehicles per hour.

Figure 2 shows the ring diagram for both cases. The permitted left turn movements are indicated with dashed lines.

Figure 1 Aerial photograph, State Highway 8 and Line Street

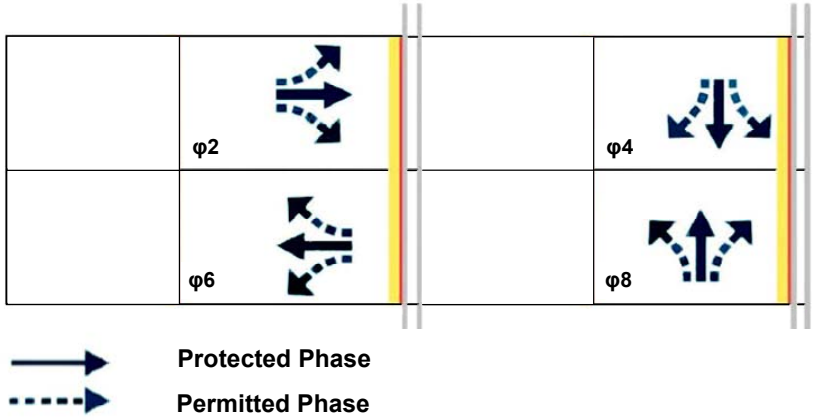

Figure 2 Ring diagram showing permitted left turn phasing, [5]

3.3 Questions to Consider

As you begin this experiment, consider the following questions. You will come back to these questions once you have completed the experiment.

- 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?

3.4 List of Steps

You will follow these steps during this experiment:

- Open the movie file.
- Observe the operation of the two cases.

3.5 Running the Experiment

Step 1. Open the movie file.

- Locate the "MOST input files" folder.
- Go to the "Lab5" folder, then the "Exp1" folder.
- Open the file: "lab5-exp1.wmv."

Step2. Observe the operation of the two cases.

- Observe the relative size of the gaps in the through traffic on State Highway 8. (See Figure 3.)
- Observe the EBLT and WBLT 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.
- Prepare a brief summary of the performance of the left turn movements for each case using the box at right. Consider the relative size of the queues that form and the relative delay experienced by the left turn movements.

Figure 3 Animation for Experiment #1

Observations:
For case 1:

For case 2:

3.6 Discussion

Let's now consider the questions that were presented at the beginning of this experiment.

- 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?

Take a few minutes to review each question and write brief answers to each question in the box on the right based on your observations from this experiment.

Answers to questions:

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. Table 2 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.

Table 2 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*	*12.3*
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*

4. EXPERIMENT #2: COMPARING PERMITTED AND PROTECTED LEFT TURN PHASING

4.1 Learning Objective

- Understand that protected LT phasing is more efficient than permitted LT phasing under some conditions.

4.2 Overview

In the previous experiment, 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 4 illustrates the ring diagram for full LT protection.

In this experiment you will again observe the LT operation on State Highway 8. Both cases that you will observe 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 Experiment #1) while case 2 is protected LT phasing.

4.3 Questions to Consider

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

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

4.4 List of Steps

You will follow these steps during this experiment:

- Open the movie file.
- Observe the operation of the two cases.

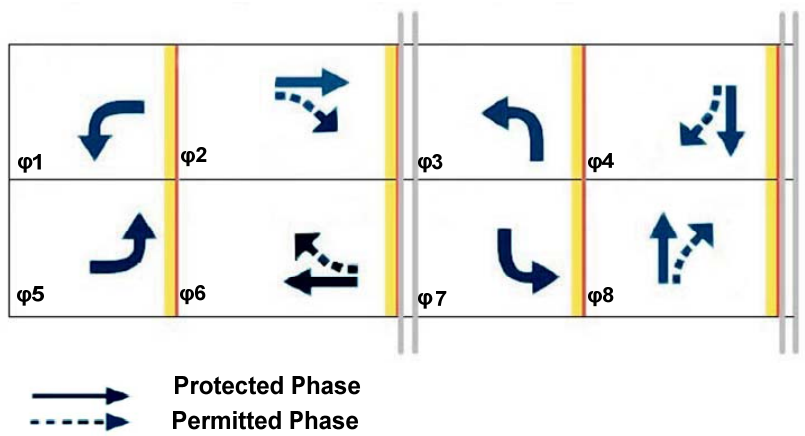

Figure 4 Ring diagram for protected left turn phasing, [5]

4.5 Running the Experiment

Step 1. Open the movie file.

- Locate the “MOST input files” folder.
- Go to the “Lab5” folder, then the “Exp2” folder.
- Open the file: “lab5-exp2.wmv.”

Step2. Observe the operation of the two cases

- Observe the LT vehicles on the EB and WB approaches for case 1 (permitted LT) and case 2 (protected LT). Observe the queue length for the EBLT and WBLT 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 LT. (See Figure 5.)
- Summarize your observations in the box on the right.

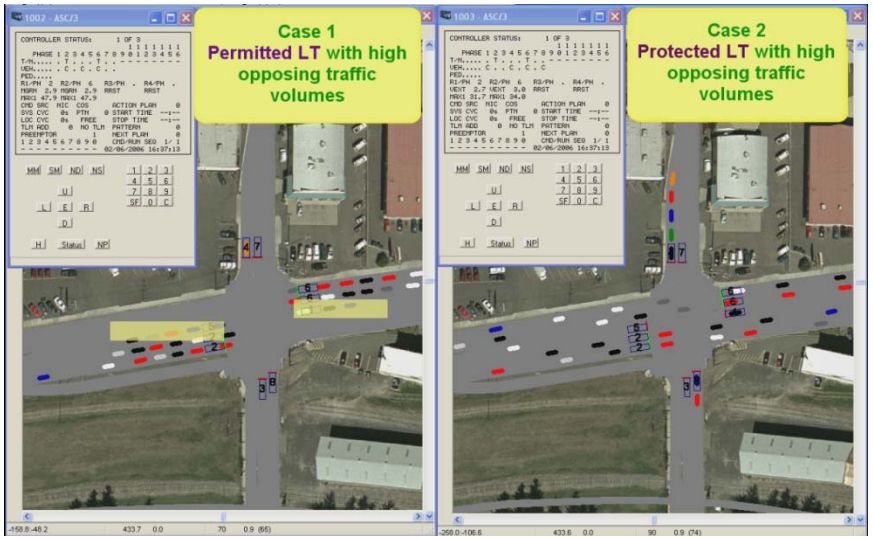

Figure 5 Animation for Experiment #2

Observations:

4.6 Discussion

Let's now consider the question that was presented at the beginning of this experiment.

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

Take a few minutes to review this question and write a brief answer to the question in the box on the right based on your observations from this experiment.

Answer to question:

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 3 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 3 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

5. EXPERIMENT #3: COMPARING PROTECTED/PERMITTED AND PROTECTED LEFT TURN PHASING

5.1 Learning Objective

- Understand the trade-offs and relative efficiencies between protected/permitted and protected left turn phasing.

5.2 Overview

In the previous experiments, you considered permitted and protected left turn phasing. Protected left turn phasing offers some benefits over permitted LT operations, such as reduced LT delay when opposing through volumes are high, but at the expense of increasing delay for other movements. In this experiment you will consider another type of LT 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/permitted phasing is shown in the ring diagram in Figure 6.

In this experiment, you will perform tasks similar to what you did in Experiment #1. You will observe the same intersection, State Highway 8 and Line Street, when it operates with protected and protected/permitted left turn phasing.

Traffic volumes for all movements are the same as for the previous experiment except for EBLT and WBLT.

- EBTH and WBTH: 1450 vph
- EBLT and WBLT: 200 vph.

5.3 Questions to Consider

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

- 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?

5.4 List of Steps

You will follow these steps during this experiment:

- Open the movie file.
- Observe the operation of both simulations.

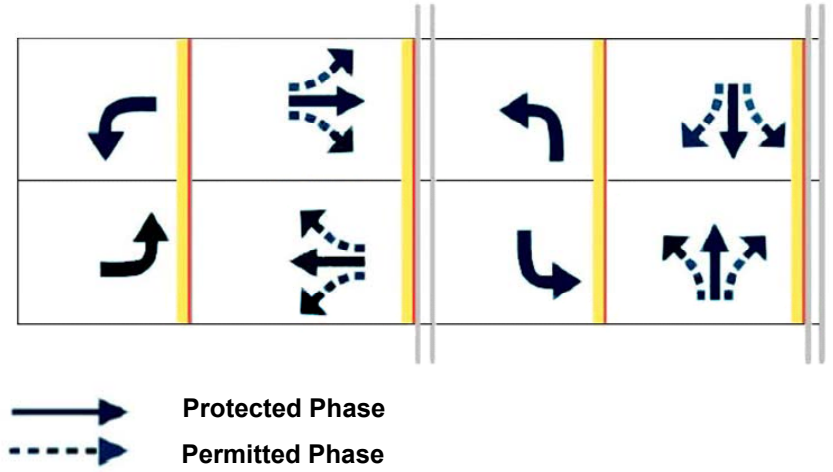

Figure 6 Ring diagram for protected/permitted left turn phasing

5.5 Running the Experiment

Step 1. Open the movie file.

- Locate the “MOST input files” folder.
- Go to the “Lab5” folder, then the “Exp3” folder.
- Open the file: “Lab5-exp3.wmv.”

Step2. Observe the operation of both simulations.

- Observe the left turn vehicles on the EB and WB approaches for case 1 (protected LT) and case 2 (protected/permitted LT). (See Figure 7.)
- 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 for both cases.
- Summarize your observations in the box on the right.

Figure 7 Animation for Experiment #3

Observations:

5.6 Discussion

Let's now consider the question that was presented at the beginning of this experiment.

- 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?

Take a few minutes to review this question and write a brief answer to the question in the box on the right based on your observations from this experiment.

Answer to 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?

→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.

Table 4 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 5 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 4 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 5 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

6. EXPERIMENT #4: DESIGN EXERCISE-DETERMINING APPROPRIATE LEFT TURN TREATMENT

6.1 Learning Objective

- Be able to select an efficient treatment for left turn movements.

6.2 Overview

In the previous experiments, you learned about three different left turn treatments and factors that affect the most appropriate treatment for a given set of volumes conditions:

- Permitted left turn only
- Protected left turn only
- Protected/permitted left turn

In this experiment, you will determine the appropriate left turn treatment for a new set of volume conditions. The volume for EB and WB through movements is 1000 vehicle per hour. The volume is 75 vehicles per hour for the EBLT while the volume for the WBLT is 150 vehicles per hour. You will observe each simulation file and record data to be able to judge which left-turn treatment provides the most efficient operation.

6.3 Questions to Consider

As you begin this experiment, consider the following questions. You will come back to these questions once you have completed the experiment.

- What did you observe for the queue length for each movement in each simulation?
- What did you observe for the cycle length for each simulation? Why is there a variation for each left turn treatment?
- Based on your observations, which left turn treatment would be the most efficient?
- What are the indicators of inefficient left turn operations and what are the indicators of efficient operations?

6.4 List of Steps

You will follow these steps during this experiment:

- Start the MOST software tool and open the permitted left turn simulation file.
- Observe the simulation of permitted left turn treatment for both intersection approaches.
- Start the MOST software tool and open the protected left turn simulation file.
- Observe the simulation of protected left turn treatment for both intersection approaches.
- Start the MOST software tool and open the protected/permitted left turn simulation file.
- Observe the simulation of protected/permitted left turn treatment for both intersection approaches.

6.5 Running the Experiment

Step 1. Start the MOST software tool and open the permitted left turn simulation file.

- Start the MOST software tool and select "Open File."
- Locate the "MOST input files" folder.
- Go to the "Lab5" folder, then the "Exp4" folder.
- Open the file: "lab5-exp4-permitted.inp."

This file uses permitted LT treatment for the EBLT and WBLT movements.

Step 2. Observe the simulation of permitted left turn treatment for both intersection approaches.

- Set "Pause At" to t = 65.
- Start the simulation using the "Run Mode" button.
- When the simulation reaches t = 65, use the "Run Mode Single Step" button to forward the simulation by 0.1 second. This will allow you to more easily observe and collect the required data.
- Record the number of vehicles standing in the queue at the beginning of green for each movement for two cycles. Use Table 6 to record your data.
- The green for cycle 1 starts at t = 67.2 seconds. Keep using the "Run Mode Single Step" button and when the green indication appears on an approach for any movement, record the number of vehicles standing in queue on this approach at that time. Collect data for cycle 2 as well, which starts at t = 116.7 seconds.
- When you have completed the data collection, stop the simulation.

Table 6 Queue lengths at the beginning of green for permitted left turn

Movement	Number of vehicles in queue at the beginning of green	
	Cycle 1 t = 67.2 sec	Cycle 2 t = 116.7 sec
EBTH		
WBTH		
SBTH		
NBTH		
WBLT		
EBLT		

Step 3. Start the MOST software tool and open the protected left turn simulation file.

- Start the MOST software tool and select "Open File."
- Locate the "MOST input files" folder.
- Go to the "Lab5" folder, then the "Exp4" folder.
- Open the file: "lab5-exp4-protected.inp."

This file uses protected LT treatment for the EBLT and WBLT movements.

Step 4. Observe the simulation of protected left turn treatment for both intersection approaches.

- Set "Pause At" to t = 60.
- Start the simulation using the "Run Mode" button.
- When the simulation reaches t = 60, use the "Run Mode Single Step" button to forward the simulation by 0.1 second. This will allow you to more easily observe and collect the required data.
- Record the number of vehicles standing in queue at the beginning of green for each movement for the two cycles. Use Table 7 to record your data.
- The green time for cycle 1 starts at t= 60.9 seconds. Keep using the "Run Mode Single Step" button and when the green indication appears on an approach for any movement, record the number of vehicles standing in queue on this approach at that time. Then collect data for cycle 2 as well which starts at t = 141.4 seconds.
- When you have completed the data collection, stop the simulation.

Table 7 Queue lengths at the beginning of green for protected LT

Movement	Number of vehicles in queue at the beginning of green	
	Cycle 1 t = 60.9 sec	Cycle 2 t = 141.4 sec
EBTH		
WBTH		
SBTH		
NBTH		
WBLT		
EBLT		

Step 5. Start the MOST software tool and open the protected/permitted left turn simulation file.

- Start the MOST software tool and select "Open File."
- Locate the "MOST input files" folder.
- Go to the "Lab5" folder, then the "Exp4" folder.
- Open the file: "lab5-exp4-protected permitted.inp."

This file uses protected/permitted LT treatment for the EBLT and WBLT movements.

Step 6. Observe the simulation of protected/permitted left turn treatment for both intersection approaches.

- Set "Pause At" to t =60.
- Start the simulation using the "Run Mode" button.
- When simulation has reached t =60, use the "Run Mode Single Step" button to forward the simulation by 0.1 second. This will allow you to more easily observe and collect the required data.
- Record the number of vehicles standing in queue at the beginning of green for each movement for two cycles. Use
- Table 8 to record your data.
- The green time for cycle 1 starts at t = 61.0 seconds. Keep using the "Run Mode Single Step" button and when the green indication appears on an approach for any movement, record the number of vehicles standing in queue on this approach at that time. Then collect data for cycle 2 as well which starts at t = 131.6 seconds.
- When you have completed the data collection, stop the simulation.

Table 8 Queue lengths at the beginning of green for protected/permitted LT

Movement	Number of vehicles in queue at the beginning of green	
	Cycle 1 t = 61.0 sec	Cycle 2 t = 131.6 sec
EBTH		
WBTH		
SBTH		
NBTH		
WBLT		
EBLT		

6.6 Discussion

Let's now consider the questions that were presented at the beginning of this experiment.

- What did you observe for the queue length for each movement in each simulation?
- What did you observe for the cycle length for each simulation? Why is there a variation for each left turn treatment?
- What are the indicators of inefficient left turn operations and what are the indicators of efficient operations?
- Based on your observations, which left turn treatment would be the most efficient?

Take a few minutes to review each question and write brief answers to each question in the box on the right based on your observations from this experiment.

Answers to questions:

1. What did you observe for the queue length for each movement in each simulation?

→Table 9, Table 10 and Table 11 show the queue lengths for each movement for the three different simulations (permitted LT, protected LT and protected/permitted LT). These results consider the first four cycles for each simulation. The first two cycles in each table should be the same as your recorded data. From the tables, when we compare queue lengths for each movement for each left turn treatment, it is clear that queue lengths increase more for protected and for protected/permitted LT than for permitted LT.

This happens because protected LT phase is an additional phase which 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 the red time for the existing phases which allows queue length to be increased for these phases. Protected left turn phasing has important benefits that must be weighed against possible costs.

Table 9 Queue lengths for permitted LT

Movement	Number of vehicles at the beginning of green			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4
EBTH	4	7	4	12
WBTH	5	4	7	6
SBTH	4	5	4	6
NBTH	5	5	6	4
EBLT	0	1	0	2
WBLT	1	0	0	0

Table 10 Queue lengths for protected LT

Movement	Number of vehicles at the beginning of green			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4
EBTH	10	11	15	16
WBTH	4	10	13	11
SBTH	8	10	11	8
NBTH	8	8	10	11
EBLT	0	2	2	0
WBLT	3	4	1	2

Table 11 Queue lengths for protected/permitted LT

Movement	Number of vehicles at the beginning of green			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4
EBTH	10	10	16	14
WBTH	4	8	11	9
SBTH	7	6	7	4
NBTH	7	9	8	8
EBLT	0	1	2	0
WBLT	2	4	1	1

2. What did you observe for the cycle length for each simulation? Why is there a variation for each left turn treatment?

→Table 12 shows the average delay for six movements for each simulation (permitted LT, protected LT and protected/permitted LT). These delay results represent averages of ten simulations, each with 900 seconds of simulation time.
The following points can be noted from the table:

- All through movements experience higher delay for protected only and protected/permitted LT cases than permitted LT.
- The average delay for EBLT and WBLT movements is lower for protected LT treatment than permitted LT, and is the lowest for protected/permitted LT treatment.
- The average delay for the intersection is higher for the protected LT case and lower for the permitted/protected LT case and the lowest for the permitted LT case.

For the protected and protected/permitted LT treatment, a phase has been added to the protected LT phase of the cycle. When you add a left turn phase, this will reduce the green split for other phases and will increase cycle length (see Table 13,) which results in a higher delay on other approaches.

3. What are the indicators of inefficient left turn operations and What are the indicators of efficient operations?

→The indicators of inefficient left turn operations are:

- Long queue lengths on other approaches
- Long cycle lengths

The indicator of efficient left turn operations is:

- Lower delay for LT phases

Table 12 Average delay for each left-turn treatment

Movement	Average delay (seconds)		
	Permitted LT only	Protected LT only	Protected/Permitted LT
EBTH	9.6	15.6	14.7
WBTH	9.9	20.9	18.8
SBTH	17.0	22.6	22.9
NBTH	17.9	21.5	20.6
EBLT	22.9	33.1	14.7
WBLT	50.7	30.0	16.4
Intersection	13.3	20.3	18.3

Table 13 Cycle lengths for each LT treatment

Cycle #	Permitted LT only	Protected LT only	Protected/permitted LT
Cycle 1	49.5	80.5	70.6
Cycle 2	48	74.1	73.1
Cycle 3	46.4	70.4	65.2
Cycle 4	51.4	76.6	73.1

4. Based on your observations, which left turn treatment would be the most efficient?

→The permitted LT case provides the most efficient treatment for the intersection as a whole and for all through movement but it is not the most efficient operation for left turn movements.

7. CLOSURE: SUMMARY OF KEY POINTS LEARNED

In this laboratory, you considered various left turn phasing options and what conditions might be appropriate for permitted phasing, protected phasing, and a combination of protected plus permitted phasing.

In Experiment #1, you observed the operation of permitted left turns with two different opposing volumes. In Experiment #2, you compared the performance of permitted and protected left turn phasing. When opposing volumes are high enough, protected left turn phasing is sometimes needed. In Experiment #3, you learned that protected plus permitted phasing can provide an improvement in intersection performance.

Finally, in Experiment #4, you experimented with the three types of left turn phasing and identified the one that provided the best operation, given a set of volume conditions. While the permitted LT case provides the most efficient treatment for the intersection as a whole and for all through movement, it is not the most efficient operation for left turn movements. For specific situations that you encounter, it is important to consider both the operation of the left turn movement as well as the operation of the other movements that need to be served at the intersection.

In the first five laboratories, you considered the operation of a single intersection. In Laboratory #6, you will consider a coordinated system of intersections and a new set of signal timing issues.