Laboratory 3
Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions
# CONTENTS (LABORATORY 3)

1. Introduction ................................................................................................................................................................ 117  
   1.1 Purpose................................................................................................................................................................. 117  
   1.2 Goals and Learning Objectives ......................................................................................................................... 117  
   1.3 Organization and Time Allocation ...................................................................................................................... 117  

2. Terms ........................................................................................................................................................................ 118  

3. Experiment #1: Determining The Effect Of Minor Street Vehicle Extension Time On Intersection Operations ................. 119  
   3.1 Learning Objective............................................................................................................................................. 119  
   3.2 Overview............................................................................................................................................................. 119  
   3.3 Questions to Consider ................................................................................................................................... 120  
   3.4 List of Steps ....................................................................................................................................................... 120  
   3.5 Running the Experiment ................................................................................................................................. 121  
   3.6 Discussion ......................................................................................................................................................... 126  

4. Experiment #2: Determining Pedestrian Timing Parameters .......................................................................................... 134  
   4.1 Learning Objectives ...................................................................................................................................... 134  
   4.2 Overview.......................................................................................................................................................... 134  
   4.3 Questions to Consider .................................................................................................................................. 134  
   4.4 List of Steps .................................................................................................................................................... 134  
   4.5 Running the Experiment ............................................................................................................................... 135  
   4.6 Discussion ....................................................................................................................................................... 139  

5. Experiment #3: Determining The Effect Of Maximum Green Time On Intersection Operations ................................................. 143  
   5.1 Learning Objective...................................................................................................................................... 143  
   5.2 Overview.......................................................................................................................................................... 143  
   5.3 Questions to Consider .................................................................................................................................. 143  
   5.4 List of Steps .................................................................................................................................................... 143  
   5.5 Running the Experiment ............................................................................................................................... 144
1. INTRODUCTION

1.1 Purpose
In the previous laboratory you studied the operation of the minor street approach and determined the value of the Vehicle Extension time and the Minimum Green time that would provide sufficient time for the queue to begin to move, and to extend the green for as long as a queue existed, but no longer. The focus was on the traffic flow and signal timing for the minor street only, with no consideration of the major street.

In this lab, you will consider the operation of both the major street and minor street approaches together. You will see how choosing the timing parameters on one approach affect the operation on the other approach as well as the intersection as a whole. We will again assume stop bar presence detection on both the major and minor streets, with moderate traffic volumes.

1.2 Goals and Learning Objectives
The goal for Laboratory 3 is to develop a timing plan for a signalized intersection with moderate traffic volumes.

When you have completed Laboratory 3 you will:
- Be able to compare the operation of the intersection with low and high values of Vehicle Extension time and understand the consequences of both alternatives.
- Be able to determine the effect of the minor street Vehicle Extension time setting on the efficiency of major street and intersection operations.
- Be able to determine pedestrian timing parameters using Manual of Uniform Traffic Control Devices (MUTCD) procedures.
- Be able to determine the Maximum Green time and understand its effect on intersection operations.
- Be able to set the timing parameters (Minimum Green time, Vehicle Extension time, and Maximum Green time) for both approaches of an intersection.

1.3 Organization and Time Allocation
Laboratory 3 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>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Approximate Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Terms</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Experiment #1: Determining the effect of minor street Vehicle Extension time on intersection operations</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>Experiment #2: Determining pedestrian timing parameters</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Experiment #3: Determining the effect of Maximum Green time on intersection operations</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>Experiment #4: Design exercise-setting timing parameters for both approaches of an intersection</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>Closure: Summary of key points learned</td>
<td>15</td>
</tr>
</tbody>
</table>
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.

**Actuated Signal Control:** A type of signal control in which the timing of each phase is at least partially controlled by detector actuations.

**Actuation:** The operation of any type of detector.

**Call:** An actuation of a phase by vehicle detection or by an internal signal controller setting (a “recall”). A phase that is not called will be skipped.

**Gap Out:** A method of terminating a phase resulting when the Passage Timer expires.

**Interval:** The duration of time during which the indications do not change their state (active or off). Typically, one or more timing parameters control the duration of an interval. The green interval duration is controlled by a number of parameters including minimum time, maximum time, and gap time.

**Isolated Intersection:** An intersection located outside the influence of and not coordinated with other signalized intersections, commonly one mile or more from other signalized intersections.

**Max Out:** A method of terminating a phase resulting when the Maximum Green time for the phase is reached.

**Maximum Green:** The maximum length of time that a phase can be green in the presence of a conflicting call.

**Minimum Green:** The minimum amount of time for a green indication that must be given to a phase.

**Movement:** A path of travel through an intersection that is regulated by a signal indication. Typical vehicle movements are left, through, and right.

**Passage Time:** A parameter that specifies the maximum allowable duration of time between vehicle calls on a phase before the phase is terminated (Also called Vehicle Interval, Gap, Passage Gap, or Unit Extension) [Note: the term Vehicle Extension (in lieu of “Phase Time”) is used in this text, as this is the terminology used by the Econolite ASC/3 traffic controller, the controller that is part of the MOST simulation environment.]

**Pedestrian Clearance Interval:** The first clearance interval for the pedestrian signal following the pedestrian Walk indication.

**Phase:** A timing unit associated with the control of one or more indications or movements.

**Serviceable Conflicting Call:** A call that occurs on a conflicting phase not having the right-of-way at the time the call is placed.

**Unoccupancy Time:** The time that a detection zone is unoccupied, measured from the downstream departure of the rear end of one vehicle to the upstream arrival of the front end of the following vehicle in the detection zone. [Note: This term is also referred to as Gap Time.]

**Walk Interval:** An indication providing right-of-way to pedestrians during a phase.
3. EXPERIMENT #1: DETERMINING THE EFFECT OF MINOR STREET VEHICLE EXTENSION TIME ON INTERSECTION OPERATIONS

3.1 Learning Objective

- Be able to determine the effect of the minor street Vehicle Extension setting on the efficiency of major street and intersection operations.

3.2 Overview

In this experiment you will observe the operation of both approaches at the intersection of State Highway 8 and Line Street. An aerial view of the intersection, looking toward the south, is shown in Figure 1. State Highway 8 has a five to six lane cross section, while Line Street has a three lane cross section (see Figure 2). In this experiment, both approaches have stop bar presence detection with a zone length of 22 feet. The volumes are moderate, with 1400 vehicles per hour on the EB approach and 600 vehicles per hour on the SB approach.

The intent here is to vary the Vehicle Extension time on phase 4 serving the SB Line Street (minor street) approach and to observe the effect of each setting on the queuing experienced by motorists on both the major and minor streets. The Minimum Green time has been set to 5 seconds and will not be varied in this experiment.

You will consider two different settings of Vehicle Extension time: 2 seconds and 5 seconds. Both queue length and green time duration will be considered in evaluating the performance of these alternatives. You will also learn the relationship of green time duration and cycle length on the delay experienced by motorists at the intersection.
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 do the EB and SB approach queue lengths vary given the two Vehicle Extension time values used for the SB approach?
- How does an increase in the SB approach Vehicle Extension time affect the EB green interval duration?
- How does the increase in the SB approach Vehicle Extension time affect the cycle length?
- What effect does the Vehicle Extension time have on the delay experienced for these two cases?

3.4 List of Steps

You will follow these steps during this experiment:

- Open the movie file.
- Adjust play speed setting.
- Observe the operation of both approaches at the intersection as well as the signal status data.
- Observe and record the queue lengths and start/end of green intervals.
- Summarize your data.
3.5 Running the Experiment

You will consider two different settings of Vehicle Extension time on the minor street (SB approach) and how these different settings affect the queuing and green time duration experienced on both approaches.

The animation file for this experiment (see Figure 3) shows side-by-side windows for the two different cases:

- Left window (case 1): the Vehicle Extension time for both the SB approach and EB approach is 2 seconds.
- Right window (case 2): the Vehicle Extension time for the SB approach is set to 5 seconds whereas the Vehicle Extension time for the EB approach remains at 2 seconds.

To assess the traffic operations quality in terms of queue length, duration of green time, and cycle length, you need to do the following:

- “Beginning of green” data collection: Once the signal indication for an approach turns green, pause the animation and record the length of the queue and the simulation time the signal indication turns green.
- “End of green” data collection: Once the signal indication for the approach turns red, pause the animation and record the simulation time the signal indication turns red.

**IMPORTANT REMINDER:**

*You will use these data collection steps frequently to assess the quality of traffic operations. It is important to pay attention to how these data are collected. To assist you, visual prompts have been added to the .wmv file to illustrate key events and times.*
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Step 1. Open the movie file.
- Locate the “MOST input files” folder.
- Go to the “Lab3” folder, then the “Exp1” folder.
- Open the file: “lab3-exp1.wmv.”

Step 2. Adjust play speed setting.
- In Windows Media Player, select “Now Playing,” then select “Enhancements,” and click on “Play Speed Settings” (Figure 4, top).
- A “Play Speed Setting” tool box will appear in the left lower corner of Windows Media Player. The sliding ruler will allow you to adjust the speed of the animation (Figure 4, bottom).
- Select “Play” in Windows Media Player.
- Select the speed with which you are most comfortable. You may need to use trial and error to find the speed that is best for you.
- [Note: When an event of interest occurs, press the “Pause” button to record the pertinent information.]
- [Note: If you miss the time when you should begin collecting data, you can move the simulation backwards using Windows Media Player.]
Step 3. Observe the operation of both approaches at the intersection as well as the signal status data.

- [Note: Case 1 is in the left window and case 2 is in the right window.]
- Before starting the animation file, make sure you identify the simulation time clock in both windows (see red circles in Figure 5). You will use this clock to record the beginning and ending of green. This animation starts at the simulation time of \( t = 446.8 \) seconds and ends at \( t = 761.4 \), a total time of a little more than five minutes.
- Figure 6 shows the side-by-side animation that you will observe. Scales have been provided to show the length of the queues (in vehicles) along the SB and EB intersection approaches. The ASC/3 controller status windows are also shown so that you can follow the timing processes. Finally, notes will pop up periodically to point out points for you to observe. For example, for case 2, the note in Figure 6 shows that cycle 1 is timing, the EB green begins at 450.9 seconds, and there are 31 vehicles in the queue.
- Don’t collect any data during this first observation. Just watch and observe. Note especially the differences that you see between case 1 (the left window) and case 2 (the right window). Make notes regarding your observations in the box at right.
Step 4. Observe and record the queue lengths and start/end of green intervals.
- Start the animation at the beginning. The VISSIM simulation time clock should read $t = 446.8$.
- Record the queue length at the beginning of green and the simulation times for the beginning and ending of green for case 1 (in Table 2) and case 2 (in Table 3).
- For example, for case 2, the green indication for the EB approach turns green at $t = 450.9$ seconds (see Figure 6). If you pause the animation at this point you will see that there are 31 vehicles in the queue at the beginning of green. These two data points have been recorded for you in Table 3.
- Continue recording the queue length and the start and end of green time for each phase for both cases until the final SB phase ends at $t = 752.8$ seconds. You have space to record data for five cycles for case 1 and four cycles for case 2.
- Compute the green duration by taking the difference between the Green end and the Green begin times.
- Compute mean values for the green duration and queue length and record these values in the last row of each table.
Step 5. Summarize your data.

- Copy the “green start” data for the SB and EB approaches from Table 2 and Table 3, into the appropriate cells in Table 5 and Table 5. Compute the length for each cycle, by taking the difference between the “green start” for each pair of consecutive cycles. Then compute the mean cycle length for each case.
- Based on the data that you recorded in Table 2, Table 3, Table 5 and Table 5, use Table 6 to summarize the average green duration, cycle length, and queue length for cases 1 and 2.
- Study the results shown in the tables and prepare a summary of your observations in the box on the right.

### Table 4 Data summary, SB approach

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Case 1</th>
<th></th>
<th>Case 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start</td>
<td>Cycle length</td>
<td>Green start</td>
<td>Cycle length</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean⇒</td>
<td></td>
<td>Mean⇒</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5 Data summary, EB approach

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Case 1</th>
<th></th>
<th>Case 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start</td>
<td>Cycle length</td>
<td>Green start</td>
<td>Cycle length</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean⇒</td>
<td></td>
<td>Mean⇒</td>
<td></td>
</tr>
</tbody>
</table>

### Table 6 Mean values for Cases 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>SB</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case 1</td>
<td>Case 2</td>
</tr>
<tr>
<td>Green duration, sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle length, sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue length, vehicles</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Observations:**

---
3.6 Discussion
Let’s now consider each of the four questions that were presented at the beginning of this experiment.

- How do the EB and SB approach queue lengths vary given the two Vehicle Extension time values used for the SB approach?
- How does an increase in the SB approach Vehicle Extension affect the EB green interval duration?
- How does the increase in the SB approach Vehicle Extension affect the cycle length?
- What effect does the Vehicle Extension time have on the delay experienced for these two cases?

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.
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Before we discuss the answers that you prepared for the four questions considered on the previous page, let’s first look at the data that you collected.

Table 7 and Table 8 show the individual queue length and green duration measurements for case 1 (Table 7) and case 2 (Table 8). The tables also show the mean values for these two parameters.

As expected for an actuated traffic signal system, there is some variation in the green duration from cycle to cycle. For example, for the SB approach for case 2, the green duration ranges from 20.4 seconds to 45.4 seconds. You may recall that with the longer Vehicle Extension time for this (SB) approach for case 2, the green indication extended sometimes inefficiently long to serve vehicles arriving after the queue had cleared.

Table 7 Data collection table for queue and display status for case 1 (SB Vehicle Extension time of 2.0 seconds)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>SB</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start, sec</td>
<td>Green end, sec</td>
</tr>
<tr>
<td>1</td>
<td>461.8</td>
<td>483.3</td>
</tr>
<tr>
<td>2</td>
<td>514.0</td>
<td>531.0</td>
</tr>
<tr>
<td>3</td>
<td>558.4</td>
<td>570.3</td>
</tr>
<tr>
<td>4</td>
<td>603.2</td>
<td>615.2</td>
</tr>
<tr>
<td>5</td>
<td>649.6</td>
<td>661.1</td>
</tr>
<tr>
<td>Mean→</td>
<td>5.6</td>
<td>14.8</td>
</tr>
</tbody>
</table>

Table 8 Data collection table for queue and display status for case 2 (SB Vehicle Extension time of 5.0 seconds)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>SB</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start, sec</td>
<td>Green end, sec</td>
</tr>
<tr>
<td>1</td>
<td>507.3</td>
<td>552.7</td>
</tr>
<tr>
<td>2</td>
<td>603.3</td>
<td>623.7</td>
</tr>
<tr>
<td>3</td>
<td>654.1</td>
<td>676.9</td>
</tr>
<tr>
<td>4</td>
<td>720.9</td>
<td>752.8</td>
</tr>
<tr>
<td>Mean→</td>
<td>7.3</td>
<td>30.1</td>
</tr>
</tbody>
</table>
The longer green durations lead directly to longer cycle lengths, as shown in Table 9 and Table 10. For both the SB and EB approaches, the longer Vehicle Extension time for the SB approach (case 2) produces a longer cycle length.

The comparison between case 1 and case 2 is more directly evident in Table 11. The values of green duration, cycle length, and queue length are longer for case 2 than for case 1. An inefficiently long Vehicle Extension time (here, 5 seconds for case 2) significantly affects all three parameters.

### Table 9 Data summary, SB approach

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start</td>
<td>Cycle length</td>
</tr>
<tr>
<td>1</td>
<td>461.8</td>
<td>52.2</td>
</tr>
<tr>
<td>2</td>
<td>514.0</td>
<td>44.4</td>
</tr>
<tr>
<td>3</td>
<td>558.4</td>
<td>44.8</td>
</tr>
<tr>
<td>4</td>
<td>603.2</td>
<td>46.4</td>
</tr>
<tr>
<td>5</td>
<td>649.6</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>47.0</td>
<td></td>
</tr>
</tbody>
</table>

### Table 10 Data summary, EB approach

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green start</td>
<td>Cycle length</td>
</tr>
<tr>
<td>1</td>
<td>488.3</td>
<td>47.7</td>
</tr>
<tr>
<td>2</td>
<td>514.0</td>
<td>39.3</td>
</tr>
<tr>
<td>3</td>
<td>575.3</td>
<td>44.9</td>
</tr>
<tr>
<td>4</td>
<td>620.2</td>
<td>45.9</td>
</tr>
<tr>
<td>5</td>
<td>666.1</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>44.5</td>
<td></td>
</tr>
</tbody>
</table>

### Table 11 Mean values for cases 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>SB</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case 1</td>
<td>Case 2</td>
</tr>
<tr>
<td>Green duration, sec</td>
<td>14.8</td>
<td>30.1</td>
</tr>
<tr>
<td>Cycle length, sec</td>
<td>47.0</td>
<td>71.2</td>
</tr>
<tr>
<td>Queue length, vehicles</td>
<td>5.6</td>
<td>7.3</td>
</tr>
</tbody>
</table>
Let’s now consider the questions that were posed at the beginning of this experiment.

To provide a basis for discussion of these questions, we’ve constructed four charts, each representing the “average” of the conditions that you’ve observed for the five minutes of simulation. Each chart shows the average cycle length, red and green times, and queue length for cases 1 and 2 for both the EB and SB approaches. Figure 7 shows the queue accumulation polygon (QAP) for the SB approach for cases 1 and 2. Figure 8 shows the QAP for the EB approach for cases 1 and 2.

1. How do the EB and SB approach queue lengths vary given the two Vehicle Extension time values used for the SB approach?
   → (Increased queue length) Relative to case 1, the case 2 average queue length for the SB approach is only slightly longer, but it has more than doubled for the EB approach.

2. How does an increase in the SB approach Vehicle Extension time affect the EB green interval duration?
   → (Longer green duration) The green duration for the EB approach increases with a longer Vehicle Extension time on the SB approach.

3. How does the increase in the SB approach Vehicle Extension time affect the cycle length?
   → (Increased cycle length) The average cycle length increased from 45 seconds (when the Vehicle Extension time is 2 seconds) to 77 seconds (when the Vehicle Extension time is 5 seconds).

Figure 7 Queue lengths, SB approach

Figure 8 Queue lengths, EB approach
4. What effect does the Vehicle Extension time have on the delay experienced for these two cases?
  → You didn’t measure delay, but you collected the information that you need to estimate delay. How is this done?

First, let’s look at the queue accumulation polygons again (see Figure 9 and Figure 10). The area of the polygon (in this case a triangle), is the total delay experienced by all vehicles arriving during the cycle.
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Table 12 and Table 13 show the basis for calculating delay. For each case, the delay is one half the product of the cycle length and the queue length (the formula for the area of a triangle, one half the base times the height).

The difference in the delay is significant. The total delay for the SB approach is 96 percent higher for case 2 than for case 1. And for the EB approach, the delay is 307 percent higher!

Table 12 Total delay estimation for SB approach

<table>
<thead>
<tr>
<th>SB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cycle</td>
<td>47.0</td>
<td>71.2</td>
<td>73%</td>
</tr>
<tr>
<td>Average queue</td>
<td>5.6</td>
<td>7.3</td>
<td>29%</td>
</tr>
<tr>
<td>Total delay</td>
<td>131.5</td>
<td>258.1</td>
<td>96%</td>
</tr>
</tbody>
</table>

Table 13 Total delay estimation for EB approach

<table>
<thead>
<tr>
<th>EB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average cycle</td>
<td>44.5</td>
<td>77.0</td>
<td>73%</td>
</tr>
<tr>
<td>Average queue</td>
<td>8.2</td>
<td>19.3</td>
<td>135%</td>
</tr>
<tr>
<td>Total delay</td>
<td>182.2</td>
<td>741.1</td>
<td>307%</td>
</tr>
</tbody>
</table>

Table 14 Average delay, SB approach

<table>
<thead>
<tr>
<th>SB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delay</td>
<td>131.5</td>
<td>258.1</td>
<td>96%</td>
</tr>
<tr>
<td>Average vehicles per cycle</td>
<td>7.6</td>
<td>12.5</td>
<td>64%</td>
</tr>
<tr>
<td>Average delay per vehicle</td>
<td>17.3</td>
<td>20.6</td>
<td>19%</td>
</tr>
</tbody>
</table>

Table 15 Average delay, EB approach

<table>
<thead>
<tr>
<th>EB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delay</td>
<td>182.2</td>
<td>741.1</td>
<td>307%</td>
</tr>
<tr>
<td>Average vehicles per cycle</td>
<td>18.0</td>
<td>35.8</td>
<td>99%</td>
</tr>
<tr>
<td>Average delay per vehicle</td>
<td>10.1</td>
<td>20.7</td>
<td>105%</td>
</tr>
</tbody>
</table>

Remember, however, that we are not yet comparing apples with apples, as the time durations for the two cases are different. We need to compute the average delay per vehicle, not the total delay experienced by all vehicles during cycles of different average lengths.

The number of vehicles that arrived on each approach during each cycle is shown in Table 14 and Table 15. The average delay is computed as the total delay divided by the number of vehicles that arrive during the cycle. The average delay is 19 percent higher for the SB approach for case 2 as compared to case 1. But a more significant effect is shown for the EB approach, where the delay for case 2 is 105 percent higher than for case 1.

Table 14 Average delay, SB approach

<table>
<thead>
<tr>
<th>SB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delay</td>
<td>131.5</td>
<td>258.1</td>
<td>96%</td>
</tr>
<tr>
<td>Average vehicles per cycle</td>
<td>7.6</td>
<td>12.5</td>
<td>64%</td>
</tr>
<tr>
<td>Average delay per vehicle</td>
<td>17.3</td>
<td>20.6</td>
<td>19%</td>
</tr>
</tbody>
</table>

Table 15 Average delay, EB approach

<table>
<thead>
<tr>
<th>EB approach</th>
<th>Case 1</th>
<th>Case 2</th>
<th>%Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delay</td>
<td>182.2</td>
<td>741.1</td>
<td>307%</td>
</tr>
<tr>
<td>Average vehicles per cycle</td>
<td>18.0</td>
<td>35.8</td>
<td>99%</td>
</tr>
<tr>
<td>Average delay per vehicle</td>
<td>10.1</td>
<td>20.7</td>
<td>105%</td>
</tr>
</tbody>
</table>

Clearly the longer (and very inefficient) Vehicle Extension time for the SB approach for case 2 has a significant effect on the EB approach. The Vehicle Extension time on one approach affects the overall operation of the entire intersection.
The results that we observed in the data presented above relate directly to what we would observe in general.

The *Highway Capacity Manual* [5] provides an equation for estimating delay for an approach at a signalized intersection. For moderate traffic volumes, the first term of this equation (known as the uniform delay term) provides a reasonable estimate of delay. The first delay term is given below, as a function of cycle length (C), green time (g), volume (v), and saturation flow rate (s).

\[ d_1 = \frac{0.5C(1 - g/C)^2}{1 - (v/s)} \]

Another view, substituting \( r/C \) for \( (1-g/C) \), is given below:

\[ d_1 = \frac{0.5C(r/C)^2}{1 - (v/s)} \]

In both formulations, we can see the effect of green time (g), red time (r), and cycle length (C). Delay increases as the cycle length increases and as the red time increases.

Consider an example intersection for which there are two intersecting one-way streets. Figure 11 shows the delay for one approach, assuming a green ratio of 0.5, volume of 500 veh/hr, and a saturation flow rate of 1800 veh/hr/green. As the cycle length increases, the delay increases in a linear manner.

![Figure 11 Delay vs. cycle length for one approach](image)
How does this relate to efficient phase termination? To understand this relationship, let’s consider two examples, each with different green interval durations. We will consider the interplay between the timing on two conflicting approaches, the first case with a green interval twice as long as the second case.

Consider two cases, one in which the queue clears in half the time as the other. A plot of queue length vs. time for case 1 (the longer queue clearance time) is shown in Figure 12, while the same plot for case 2 (the shorter queue clearance time) is shown in Figure 13. In both instances, the green terminates when the queue has been cleared.

The point is that as the green interval extends for one direction, the corresponding red interval extends for the conflicting direction. The result is an increase in the queue on this conflicting approach, and the longer the overall delay.

How do we know the delay is longer? The area of the triangles of Figure 12 and Figure 13 equal the delay experienced by all vehicles arriving during the time portrayed. We can see in Figure 14 that the area of the larger triangle is twice as large as the sum of the two smaller triangles. Thus the delay for case 1 is twice as high as for case 2. We can conclude that more efficient timing that produces shorter green intervals will result in shorter delays.

These results are consistent with what you just observed in this experiment.
4. EXPERIMENT #2: DETERMINING PEDESTRIAN TIMING PARAMETERS

4.1 Learning Objectives
- Be able to determine the pedestrian clearance interval and understand its effect on intersection operations.

4.2 Overview
Traffic control systems serve not only vehicles, but other users as well. In this experiment you will consider how to serve pedestrians at a signalized intersection. You will learn the procedure for calculating the pedestrian clearance interval, observe the pedestrian timing process, and see the effect of the pedestrian timing parameters on the operation of the intersection.

There are two basic pedestrian timing parameters: the Walk interval and the pedestrian clearance interval. The Walk interval gives the pedestrian enough time to see and react to the Walk indication and start crossing the street. The Manual of Uniform Traffic Control Devices (MUTCD) suggests several values for the duration of the walk interval depending on the pedestrian volume.
- The duration of the Walk interval should be 4 seconds for negligible pedestrian volumes.
- For typical pedestrian volume and shorter cycle lengths, the Walk interval should be 7 seconds long.
- For typical pedestrian volumes and longer cycle lengths, the Walk interval should be between 7 and 10 seconds.
- For high pedestrian volumes areas, such as schools, central business districts, and sports venues, the Walk interval should be between 10 and 15 seconds.

Once the Walk interval times out, the pedestrian clearance interval begins. The purpose of the pedestrian clearance interval is to give a pedestrian leaving the curb at the end of the Walk interval enough time to reach at least the center of the farthest traveled lane or a median of sufficient width for the pedestrian to wait.

The duration of the pedestrian clearance interval depends on the street width that the pedestrian must cross. It is calculated as the ratio of the crossing distance and walking speed. The MUTCD recommends a walking speed of 4 feet per second for this calculation.

Please see section 4E.10 of the MUTCD for specific details regarding pedestrian timing.

4.3 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 duration of the pedestrian clearance interval do you recommend for each approach?
- What are the components of the pedestrian timing process and how do they relate to the concurrent vehicle timing process components?
- What effect do the pedestrian timing parameters have on the duration of the green indication?

4.4 List of Steps
You will follow these steps during this experiment:
- Compute the pedestrian clearance interval.
- Start the MOST software tool and open the input file.
- Enter the pedestrian timing parameters.
- Observe the pedestrian and vehicle timing processes for one green interval.
- Observe the SB approach (phase 4) for two green intervals.
4.5 Running the Experiment

Step 1. Compute the pedestrian clearance interval.
- We will assume a walk interval of 7 seconds and a walking speed of 4 ft/sec.
- Based on the dimensions shown in Figure 15, calculate the length of the pedestrian clearance interval for both intersection approaches.
- Record your results in Table 16.

<table>
<thead>
<tr>
<th>State Highway 8</th>
<th>Line Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach width (ft)</td>
<td></td>
</tr>
<tr>
<td>Assumed walk speed, ft/sec</td>
<td></td>
</tr>
<tr>
<td>Pedestrian clearance interval (sec)</td>
<td></td>
</tr>
</tbody>
</table>
Step 2. Start the MOST software tool and open the input file.
- Start the MOST software tool and select “Open File.”
- Locate the “MOST input files” folders.
- Go to the “Lab3” folder, then the “Exp2” folder.
- Open the file: “lab3-exp2.inp.”

Step 3. Enter the pedestrian timing parameters.
- Select “Open ASC/3 Database Editor.”
- Select controller number 2021 to edit.
- Select the “Controller” tab on the ASC/3 Database Editor. (See Figure 16.)
- Check that the correct settings have been entered for the pedestrian timing parameter values for phase 4.
- Save and close the database editor.

Figure 16 ASC/3 Database Editor screen, "Controller" tab
Step 4. Observe the pedestrian and vehicle timing processes for one green interval.

- Set “Pause At” to 14.3.
- Start the simulation using the “Run Mode” button.
- Select the status screen on the ASC/3 controller.
- Restart the simulation using the “Run Mode” button when the simulation reaches t = 14.4.
- Set “Simulation Speed” to 0.5.
- Set “Pause At” to 76.2.
- Observe the timing processes that are active for phase 4 beginning at t = 14.4, through the end of the green indication (t = 41.4). Record the timing processes that you observe in the box at right. You can pause the simulation at appropriate times during this interval to note the current status of the controller. Or, you can “Single Step” the simulation to allow better observation of the timing processes.
  
  o What pedestrian timing components are visible in the ASC/3 status screen while phase 4 is timing?
  
  o What vehicle timing components are visible while phase 4 is timing?
  
  o How are pedestrian calls for service shown in the ASC/3 status screen?

Observations:
Step 5. Observe the SB approach (phase 4) for two green intervals.

- Make sure that the simulation time is 76.3, the start of the green indication of the SB approach (phase 4). This time is recorded in Table 17. [Note that the green time for the next interval, interval 3, has been recorded also in the table.]
- Start the simulation using the “Run Mode” button.
- Observe the vehicle and pedestrian flows for the SB approach; also observe the timing processes for both the vehicle and pedestrian timing components.
- Record the following data:
  - The number of vehicles in the queue at the start of green for both intervals.
  - The number of pedestrians crossing the street.
  - The time that the last vehicle in the queue enters the intersection.
- Calculate the following:
  - The green duration (difference between the “yellow start” and the “green start”).
  - The unused green time, the time interval from the last vehicle entering the intersection and the “yellow start.”

### Table 17 Data collection table

<table>
<thead>
<tr>
<th>Phase 4</th>
<th>Interval 2</th>
<th>Interval 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green start</td>
<td>76.3</td>
<td>141.6</td>
</tr>
<tr>
<td>Vehicles in queue at start of green</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pedestrians crossing during green</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time last vehicle enters intersection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow start</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green duration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interval from last vehicle entering intersection to yellow start</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.6 Discussion
Let’s now consider the questions that were presented at the beginning of this experiment.
- What duration of the pedestrian clearance interval do you recommend for each approach?
- What are the components of the pedestrian timing process and how do they relate to the concurrent vehicle timing process components?
- What effect do the pedestrian timing parameters have on the duration of the green indication?

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 duration of the pedestrian clearance interval do you recommend for each approach?

Table 18 shows the results of the calculation of the pedestrian clearance interval for State Highway 8 and Line Street. The value for State Highway 8 is for the pedestrian phase that runs concurrently with the vehicle phase that serves phase 4.

If this intersection served a high number of older pedestrians, a value of 3.5 ft/sec could be used for the assumed walk speed, and the resulting pedestrian clearance intervals would be 23 seconds and 10 seconds, respectively.

<table>
<thead>
<tr>
<th></th>
<th>State Highway 8</th>
<th>Line Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach width (ft)</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>Assumed walk speed, ft/sec</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Pedestrian clearance interval (sec)</td>
<td>20</td>
<td>9</td>
</tr>
</tbody>
</table>
2. What are the components of the pedestrian timing process and how do they relate to the concurrent vehicle timing process components?

The pedestrian timing components include the walk timer and the pedestrian clearance interval timer, while the vehicle timing components include the Minimum Green timer and the Vehicle Extension timer.

Figure 17 shows four snapshots of the timing processes for phase 4.

- At $t = 14.4$ seconds, the phase is beginning to time, with the “T” noting that the phase is active and timing; the Minimum Green timer value is 5.0, and the walk timer value is 7.0.
- At $t = 19.4$ seconds, the phase is still timing (“T”), the Minimum Green timer has just expired (current value is 0.0), and the walk timer is timed down to 2.0.
- At $t = 21.4$ seconds, the walk timer has expired, and the pedestrian clearance timer has just started timing, with a value of “20.0.”
- At $t = 41.4$ seconds, the pedestrian clearance timer has just expired, the phase has gapped out, and the yellow timer is just starting (with a current value of 3.0).

The vehicle timing process shown here consists of the Minimum Green timing process timing down from 5.0 to 0.0. Actually, the Vehicle Extension timer also timed down, but it had expired before the Minimum Green timer, so it doesn’t appear in the status screen. The pedestrian timing process shown here consists of the walk timer and the pedestrian clearance timer, one timing first and the other following.

The vehicle and pedestrian processes occur in parallel, and the phase timing is governed by the longer of the two, in this case the pedestrian timing process.

While not shown in the figure, the pedestrian call for service is indicated with an “A” in the ASC/3 status screen.
Section 4. Experiment #2: Determining Pedestrian Timing Parameters

Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

3. What effect do the pedestrian timing parameters have on the duration of the green indication?

Table 19 shows the results of the data collected during intervals 2 and 3. In both cases the duration of the green indication is governed by the pedestrian timing process and not the vehicle timing process. For interval 2, for example, the green extends for a period of nearly 25 seconds beyond the time that the last vehicle crosses the stop bar and enters the intersection.

And, if the green is extended because of these pedestrian requirements, there will be a resulting increase in queue length and delay on the other approaches.

Providing service to all users is an important function of the signal timing process. While the green indication does extend longer when pedestrians are being served, this observation should in no way imply that the efficiency of the intersection is somehow compromised.

<table>
<thead>
<tr>
<th></th>
<th>Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interval 2</td>
</tr>
<tr>
<td>Green start</td>
<td>76.3</td>
</tr>
<tr>
<td>Vehicles in queue at start of green</td>
<td>1</td>
</tr>
<tr>
<td>Number of pedestrians crossing during green</td>
<td>2</td>
</tr>
<tr>
<td>Time last vehicle enters intersection</td>
<td>78.6</td>
</tr>
<tr>
<td>Yellow start</td>
<td>103.3</td>
</tr>
<tr>
<td>Green duration</td>
<td>27.0</td>
</tr>
<tr>
<td>Interval from last vehicle entering intersection to yellow start</td>
<td>24.7</td>
</tr>
</tbody>
</table>
5. EXPERIMENT #3: DETERMINING THE EFFECT OF MAXIMUM GREEN TIME ON INTERSECTION OPERATIONS

5.1 Learning Objective
- Understand the advantages and disadvantages of increasing Maximum Green time on intersection operations.

5.2 Overview
In the two previous experiments, you observed the effects of minor street timing parameters and the pedestrian timing parameters on the operation of the intersection.

In this experiment, you will observe two cases, each focusing on the westbound approach of the major street, State Highway 8. In the first case, the Maximum Green time is set to 40 seconds. The demand is relatively high (1700 vehicles per hour across two lanes) on the westbound approach and the green time displayed is not sufficient to serve the demand. In the second case, the Maximum Green time is set at 60 seconds in an effort to serve more of the demand. But this change also has implications that must be considered for the operation of the intersection.

5.3 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:
- Are all of the vehicles in the initial queue on the WB approach served before the end of each green interval?
- What is the mechanism for termination of the phase serving the westbound approach?
- What are the advantages and disadvantages of the 40 second maximum green time for the operation of case 1?
- What are the advantages and disadvantages of the 60 second Maximum Green time for the operation of case 2?
- Which Maximum Green time setting would you select and why?

5.4 List of Steps
You will follow these steps during this experiment:
- Open the movie files.
- Observe the operation of case 1 and record your observations.
- Observe the operation of case 2 and record your observations.
- Identify the pros and cons of the two different maximum green time settings on the westbound approach and on the overall performance of the intersection.
5.5 Running the Experiment

In this experiment, you will observe the operation of two cases, each with different Maximum Green times. Each case includes four cycles, focusing on the westbound approach. You will be asked to look at three things:

- What is the length of the queue at the beginning of each of the four green intervals on the westbound approach?
- How does the westbound phase terminate during each of the four cycles in each case?
- Are there vehicles from the westbound queue still unserved at the end of the green interval?

Step 1. Open the movie file.
- Locate the “MOST input files” folder.
- Go to the “Lab3” folder, then the “Exp3” folder.
- Open the file: “lab3-exp3-40sec.wmv.”

Step 2. Observe the operation of case 1 and record your observations.
- Watch the entire video. It is nearly 3.5 minutes in length. Pay attention to the three questions listed at the top of this page.
- Note your observations in the box provided on the right.

Step 3. Open the movie file.
- Locate the “MOST input files” folder.
- Go to the “Lab3” folder, then the “Exp3” folder.
- Open the file: “lab3-exp3-60sec.wmv.”

Step 4. Observe the operation of case 2 and record your observations.
- Watch the entire video. It is nearly 4 minutes in length. Pay attention to the three questions listed at the top of this page.
- Note your observations in the box provided on the right.
Step 5. Identify the pros and cons of the two different Maximum Green time settings on the westbound approach and on the overall performance of the intersection.

- Consider what you observed for both cases and recorded in the boxes on the previous page. Summarize the pros and cons of each case in the box on the right.

Pros and cons of each Maximum Green time setting:
5.6 Discussion
Let’s now consider the questions that were presented at the beginning of this experiment.
- Are all of the vehicles in the initial queue on the WB approach served before the end of each green interval?
- What is the mechanism for termination of the phase serving the westbound approach?
- What are the advantages and disadvantages of the 40 second Maximum Green time for the operation of case 1?
- What are the advantages and disadvantages of the 60 second Maximum Green time for the operation of case 2?
- Which Maximum Green time setting would you select and why?

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:
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Before we review the answers to these questions, let’s look closer at the data that were collected from these videos.

Table 20 and Table 21 show the green interval durations for cases 1 and 2, respectively. The Maximum Green time for the WB approach has been set to 40 seconds, and for three of the cycles the phase extends to this limit. For case 2, the phase extends to 60 seconds for two cycles, the Maximum Green time for this phase.

Figure 19 shows the variation of the green intervals for each movement with Maximum Green time. The most significant increase in green interval duration is for the EBTH and the WBTH movements, not surprising since the Maximum Green time is higher for these movements.

<table>
<thead>
<tr>
<th>Table 20 Case 1, green interval durations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cycle</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 21 Case 2, green interval durations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cycle</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Figure 19 Variation of green time with Maximum Green
What is the effect on delay of the increase in Maximum Green time, and the duration of the green intervals? Figure 20 shows that delay on the minor street approaches (NBTH and SBTH) increases with the Maximum Green time on the WB approach. This increase in delay comes directly from the longer green intervals on the WB and EB approaches, which means longer red times for the minor street approaches. And, longer red times mean higher delay.

![Figure 20 Variation of delay with Maximum Green time](image-url)
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Let’s now review these data and consider again the questions that were asked at the beginning of this experiment.

1. Are all of the vehicles in the initial queue on the WB approach served before the end of each green interval?
   ➔ Table 22 and Table 23 show more details for the green interval duration, the method of phase termination, and whether the queue cleared or not. For the 40 second Maximum Green, the queue was not fully served in two of the four cycles. For the 60 second Maximum Green, the queue was fully served for all four cycles. Increasing the Maximum Green time is one method of reducing phase failure.

2. What is the mechanism for termination of the phase serving the westbound approach?
   ➔ The WB phase maxes out for three cycles for the shorter Maximum Green time (40 seconds). While the WB phase maxes out for two of the cycles for the 60 second Maximum Green time, the queue has been fully served significantly before this occurs.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Green begins (simulation time, sec)</th>
<th>Green ends (simulation time, sec)</th>
<th>Method of phase termination</th>
<th>Queue status</th>
<th>Green interval duration (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96.2</td>
<td>136.2</td>
<td>Max Out</td>
<td>Cleared</td>
<td>40.0</td>
</tr>
<tr>
<td>2</td>
<td>194.7</td>
<td>234.7</td>
<td>Max Out</td>
<td>Not Cleared</td>
<td>40.0</td>
</tr>
<tr>
<td>3</td>
<td>295.3</td>
<td>335.3</td>
<td>Max Out</td>
<td>Not Cleared</td>
<td>40.0</td>
</tr>
<tr>
<td>4</td>
<td>379.0</td>
<td>414.2</td>
<td>Gap Out</td>
<td>Cleared</td>
<td>35.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Green begins (simulation time, sec)</th>
<th>Green ends (simulation time, sec)</th>
<th>Method of phase termination</th>
<th>Queue status</th>
<th>Green interval duration (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96.2</td>
<td>156.2</td>
<td>Max Out</td>
<td>Cleared</td>
<td>60.0</td>
</tr>
<tr>
<td>2</td>
<td>224.8</td>
<td>284.8</td>
<td>Max Out</td>
<td>Cleared</td>
<td>60.0</td>
</tr>
<tr>
<td>3</td>
<td>346.2</td>
<td>385.3</td>
<td>Gap Out</td>
<td>Cleared</td>
<td>39.1</td>
</tr>
<tr>
<td>4</td>
<td>417.0</td>
<td>465.1</td>
<td>Gap Out</td>
<td>Cleared</td>
<td>48.1</td>
</tr>
</tbody>
</table>
3. What are the advantages and disadvantages of the 40 second Maximum Green time for the operation of case 1?
   → The primary disadvantage of the 40 second cycle is that the queue on the WB approach doesn’t clear during two of the cycles.

4. What are the advantages and disadvantages of the 60 second Maximum Green time for the operation of case 2?
   → The primary advantage of the 60 second cycle is that the queue on the WB approach clears during each of the four cycles. The disadvantage is that, as a result of the longer red times on the minor street approaches, the delay has increased for the NB and SB movement.

5. Which Maximum Green time setting would you select and why?
   → The main purpose of the Maximum Green time for a given phase is to limit the delay experienced by all other movements at the intersection and to keep the cycle length to some maximum value. The importance of Maximum Green time usually becomes evident during the peak hours. During the peak hours a phase should occasionally terminate by reaching the Maximum Green time in order to accommodate the higher traffic demand found during this time period. This is especially true for the major movements at the intersection. Inadequate Maximum Green time could cause a phase failure resulting in increased queue lengths. Favoring vehicles on the major street approaches over the minor approaches by increasing Maximum Green could be considered during the peak hours. But as we’ve observed, there are trade-offs, often in the form of longer delays to the minor street traffic. We should also note that the pedestrian traffic can be accommodated by this setting.
6. EXPERIMENT #4: DESIGN EXERCISE-SETTING TIMING PARAMETERS FOR BOTH APPROACHES OF AN INTERSECTION

6.1 Learning Objective

• Be able to set the primary timing parameters (Minimum Green time, Vehicle Extension time and Maximum Green time) for both approaches of an intersection, balancing the performance of both the minor street and major street.

6.2 Overview

In previous experiments in this laboratory, you learned:

• How to assess the impact of the timing parameter settings of one phase on the performance of the other phases and on the overall intersection.
• That using a longer Vehicle Extension time for one phase increased the green interval duration for the same phase, and increased the delay on approaches served by other phases.
• That increasing the Maximum Green time solves the phase failure problem for one approach causing higher delay on the other.

Previously, in Laboratory 2, you learned:

• The effect that detection zone length had on the duration of the green indication.
• The effect that the Minimum Green time has in ensuring that a queue has sufficient time to begin to move at the beginning of the green indication.
• The importance of Vehicle Extension time in ensuring that the green indication extends long enough to serve a queue but not any longer.

In this experiment, you will consider these timing parameters, the traffic flow on the intersection approaches, and the length of the detection zone. You will set the Minimum Green time and the Vehicle Extension time for both approaches, balancing the performance of both minor street and major street approaches to achieve efficient intersection operations. You will also investigate the necessity of adjusting the Maximum Green time.

The traffic conditions in the experiment are similar to those you might find in the real world, with a mix of passenger cars and heavy vehicles, and a range of driver behavior characteristics. The detection zone length for the SB approach is 22 feet. The detection zone length for the EB approach is 66 feet, a longer zone length than you have considered in previous experiments.

How do you fine tune the timing parameters for both approaches to reach “efficient” operations, balancing the performance of both minor street and major street approaches? Additionally, and for each approach, how do you set the timing parameters to balance the risks of early termination of green and inefficiently long green time? Consider the criteria that you used in Laboratory 2 for efficient phase operations:

• The phase is not extended inefficiently for a very short queue.
• The phase extends long enough to clear the standing queue.
• The phase doesn’t extend beyond the time that it takes for the queue to clear.

In addition to these three criteria, the following criteria could also be considered to achieve intersection operational efficiency:

• The major street green time should be extended to serve vehicles arriving after the queue clears without causing excessive delay to the minor street traffic.
• The Maximum Green time should be increased in case of phase failure when a phase terminates by maxing out.
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 are the indicators of inefficient intersection operations? What are the indicators of efficient operations?
- Based on your observations of the conditions for this experiment, what specific changes would you make to the given signal timing settings?
- After implementing these changes, did you meet the criteria established in Section 6.2?

6.4 List of Steps
You will follow these steps during this experiment:
- Start the MOST software tool and open the input file.
- Observe the simulation of both intersection approaches using the given values of Minimum Green time, Vehicle Extension time and Maximum Green time.
- Experiment with the Minimum Green time setting for phases 2 and 4.
- Experiment with the Vehicle Extension time setting for phases 2 and 4.
- Experiment with the Maximum Green time setting for phases 2 and 4.
- Continue to experiment with the values of these three timing parameters until you reasonably meet the criteria listed above.
- Prepare a justification of your recommended parameters.
6.5 Running the Experiment

Step 1. Start the MOST software tool and open the input file.
- Start the MOST software tool and select “Open File.”
- Locate the “MOST input files” folder.
- Go to the “Lab3” folder, then the “Exp4” folder.
- Open the file: “lab3-exp4.inp.”

Step 2. Observe the simulation of both intersection approaches using the given values of Minimum Green time, Vehicle Extension time, and Maximum Green time.
- Verify that the vehicle timing parameters have been set correctly:
  - For phase 2: the Minimum Green time is set to 10 seconds, the Vehicle Extension time is set to 2 seconds and the Maximum Green time is set to 40 seconds.
  - For phase 4: the Minimum Green time is set to 10 seconds, the Vehicle Extension time is set to 5 seconds and the Maximum Green time is set to 40 seconds.
- Observe the operation of the EB and SB approaches for four cycles beginning at t = 32. Identify any problems with the operations of the intersection that you think can be solved with changes to the settings of the Minimum Green time, the Vehicle Extension time and the Maximum Green time. Record your observations in the box on the right.
- An example of an observation would be: “The green indication extended well beyond the time that the last vehicle demanded service on the SB approach.”

Observations:
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Step 2. Experiment with the Minimum Green time setting for phases 2 and 4.

- Based on your initial observations of the traffic flow characteristics, modify the value of the Minimum Green time setting for phases 2 and 4.
- Re-run the simulation.
- Do these changes make any difference in the traffic flow?
- Document the results of your experiment in the box on the right.

Observations:
Step 3. Experiment with the Vehicle Extension time setting for phases 2 and 4.
• Based on your initial observations of the traffic flow characteristics, modify the value of the Vehicle Extension time setting for phases 2 and 4.
• Re-run the simulation.
• Do these changes make any difference in the traffic flow?
• Document the results of your experiment in the box on the right.

Observations (Step 3):

Step 4. Experiment with the Maximum Green time setting for phases 2 and 4.
• Based on your initial observations of the traffic flow characteristics, modify the value of the Maximum Green time setting for phases 2 and 4.
• Re-run the simulation.
• Do these changes make any difference in the traffic flow?
• Document the results of your experiment in the box on the right.

Observations (Step 4):
Laboratory 3. Developing Timing Plans for Efficient Intersection Operations During Moderate Traffic Volume Conditions

Step 5. Continue to experiment with the values of these three timing parameters until you reasonably meet the criteria listed below.

- Re-run the simulation, making any further changes to the Minimum Green time and/or the Vehicle Extension time and Maximum Green time so that you meet the five criteria listed below.
- Document the results of your experiments in the box on the right.

Criteria:
- The phase is not extended inefficiently for a very short queue.
- The phase extends long enough to clear the standing queue.
- The phase doesn’t extend beyond the time that it takes for the queue to clear.
- The major street green time is extended to serve vehicles arriving after the queue clears without causing excessive delay to the minor street traffic.
- The Maximum Green time should be increased in case of phase failure when a phase terminates by maxing out.

Step 6. Prepare a justification of your recommended parameters.

- Document the values of Minimum Green time, Vehicle Extension time, and Maximum Green time that you recommend for this intersection.
- Write a brief justification of these recommended values in the box on the right.

Observations:

Justification:
6.6 Discussion
Let’s now consider the questions that were presented at the beginning of this experiment.

- What are the indicators of inefficient intersection operations?
- What are the indicators of efficient operations?
- Based on your observations of the conditions for this experiment, what specific changes would you make to the given signal timing settings?
- After implementing these changes, did you meet the criteria established in Section 6.2?

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. What are the indicators of inefficient intersection operations? What are the indicators of efficient operations?

Indicators of inefficient operations could include:
- Excessive Minimum Green time, especially when the initial queue is short. This is typically caused by a long Minimum Green time setting.
- Green time is too short to serve the initial queue, causing cycle failure where some vehicles in the queue have to wait for two cycles to clear the intersection. This is typically caused by a short Minimum Green time and/or a short Vehicle Extension time setting.
- Phase is extended too long after the last vehicle in the queue is served. This is typically caused by a long Vehicle Extension time setting.
- Frequent phase failures occur while a phase terminates with max out indicating a need for more Maximum Green time.

Indicators of efficient operations could include:
- Initial queue is fully served.
- Phase is efficiently extended on the major street after the initial queue is cleared to serve vehicle arriving during green without causing excessive delay to other approaches.

2. Based on your observations of the conditions for this experiment, what specific changes would you make to the given signal timing settings?

A set of three trials were run in this experiment and the results of these trials are discussed here. Your results may be different than those presented here if you selected different timing parameters to test. That is OK! Hopefully, you can combine the results of your work with the examples presented here to enhance what you learn from this experiment.

In trial #1, the Minimum Green time was set to 10 seconds for both phases 2 and 4. The Vehicle Extension time was set to 2 seconds for phase 2 and 5 seconds for phase 4. These are conservative values and are unrealistic for field operations. However, they do allow you to begin the process of identifying operational problems that result from these settings and to move to a more efficient timing plan.

One point is worth noting here, regarding the short length of the given setting for the Vehicle Extension time for phase 2. A 66 foot detector (as you learned from Laboratory 2) requires a shorter Vehicle Extension time since the unoccupancy times are shorter for the longer detection zone length.
The results for trial #1 are summarized in Table 24. One of the primary observations is that the Minimum Green time is too long. During several cycles, on both the EB and SB approaches, the phase extends long after the vehicles in the initial queue have been served, especially when the queues are short.

Phase 2 terminates by maxing out twice while phase 4 terminates by maxing out only once. For all three cases the queue is cleared.

While the conservatively long Vehicle Extension time also contributes to this inefficient operation, we will focus on only one parameter at a time. The recommendation for trial #2 is that the Minimum Green time be shortened to 5 seconds for both phases 2 and 4.

<table>
<thead>
<tr>
<th>Settings</th>
<th>Phase 2</th>
<th>Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Green time</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Vehicle Extension time</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Maximum Green Time</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

**Cycle** | **Notes/Observations**
--- | ---
1 | The 2 vehicles in queue for phase 2 and the 3 vehicles in queue for phase 4 were all served. Both phases terminate with gap out.
2 | The 11 vehicles in queue at the beginning of green for phase 2 and 12 vehicles for phase 4 were served. In addition, the phase continued to time to serve vehicles that arrived long after the queue had been served. Phase 2 terminates with gap out while phase 4 terminates with max out.
3 | The 19 vehicles in queue for phase 2 were served; the 5 vehicles were served for phase 4. Phase 4 continued to time well after the one vehicle in queue was served. Phase 2 terminates with max out. Phase 4 terminates with gap out.
4 | All vehicles in queue for phases 2 and 4 were served. Phase 4 terminates with max out. Phase 2 terminates with gap out.

**Recommendations for trial #2:**

The **Minimum Green time** is too long. There is unused green time for short queues and this problem can be reduced if the Minimum Green time is reduced.

While it is noted that the **Vehicle Extension time** is also too long (since vehicles are served after the queue clears, particularly for phase 2 where the detection zone is longer), we will focus only on changes to the Minimum Green time for the next trial.

No problems were observed with Maximum Green time set up. For all four cycles the queue was cleared for both phases.
In trial #2, the reduction of the Minimum Green time setting for both phases resulted in a more efficient operation, especially for instances of short queues. This result is shown in the summary presented in Table 25.

Table 25 Results from trial #2

<table>
<thead>
<tr>
<th>Settings</th>
<th>Phase 2</th>
<th>Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Green time</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Vehicle Extension time</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Maximum Green time</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Notes/Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The queues present at the start of green for approaches were served efficiently.</td>
</tr>
<tr>
<td>2</td>
<td>The queues present at the start of green for approaches were served efficiently. In addition, the phase continued to time to serve vehicles that arrived long after the queue had been served, indicating that the Vehicle Extension time is too long.</td>
</tr>
<tr>
<td>3</td>
<td>The queues present at the start of green for approaches were served efficiently. In addition, the phase continued to time to serve vehicles that arrived long after the queue had been served, indicating that the Vehicle Extension time is too long.</td>
</tr>
<tr>
<td>4</td>
<td>All vehicles in queue for phases 2 and 4 were served.</td>
</tr>
</tbody>
</table>

Recommendations for trial #3:

The reduced setting for the **Minimum Green time** accomplished its purpose. Settings will not be changed for trial #3.

For phase 4, the setting for the **Vehicle Extension time** will be reduced to 2.0 seconds as per results from Lab 2. For phase 2, the setting will be reduced to 1.0 seconds, since the longer detection zone will support this reduced time.

No problems were observed with Maximum Green time set up. For all four cycles the queue was cleared for both phases.

Shorter Vehicle Extension times are recommended for trial #3.
In trial #3, the shorter Vehicle Extension time resulted in more efficient operation. This was evidenced by a snappier operation, with the phase terminating sooner after the queue cleared.

But a potential conflict shows in several of the cycles, particularly for the EB approach, when there is a “second platoon” that arrives soon after the initial queue clears. Should these “following platoons” be served? How long an extension in the green indication should be allowed, especially on the major street, to serve these platoons? This is a trade-off that is a common one: too snappy or too sloppy? Which would you recommend?

Further trials could be run with a shorter Minimum Green time, especially for the EB approach with the longer detection zone. The longer detection zone allows both shorter Minimum Green times and Vehicle Extension times. How much shorter would you consider?

### Table 26 Results from trial #3

<table>
<thead>
<tr>
<th>Settings</th>
<th>Phase 2</th>
<th>Phase 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Green time</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Vehicle Extension time</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Maximum Green time</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Notes/Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The queues present at the start of green for approaches were served efficiently.</td>
</tr>
<tr>
<td>2</td>
<td>The queues present at the start of green for approaches were served efficiently. It should be noted for phase 2 that the initial queue is served but that a “following platoon” is not. It may be that the 1 second Vehicles Extension time setting results in a “too snappy” operation.</td>
</tr>
<tr>
<td>3</td>
<td>More efficient operation results with the shorter Vehicle Extension time. Again, for phase 2, a following platoon is at issue: phase terminates before platoon is served.</td>
</tr>
<tr>
<td>4</td>
<td>More efficient operation results with the shorter Vehicle Extension time.</td>
</tr>
</tbody>
</table>

### Recommendations for additional trials:

A shorter **Minimum Green time** could be tested to see if a more efficient operation is possible.

There are trade-offs in either a shorter or longer **Vehicle Extension time**, especially for the EB approach, where there is justification to continue to serve the “following platoons” on the major street.

No problems were observed with Maximum Green time set up. For all four cycles the queue was cleared for both phases.
3. After implementing these changes, did you meet the criteria established in Section 6.2?

Let’s review the criteria one more time.

Criteria:
- The phase is not extended inefficiently for a very short queue.
- The phase extends long enough to clear the standing queue.
- The phase doesn’t extend beyond the time that it takes for the queue to clear.
- The major street green time is extended to serve vehicles arriving after the queue clears without causing excessive delay to the minor street traffic.
- The Maximum Green time should be increased in case of phase failure when a phase terminates by maxing out.

The settings used for trial #3 resulted in an operation that meets the first three criteria. The 5 second Minimum Green time means that the green will terminate efficiently even with a short initial queue. The Vehicle Extension times produce, for the most part, a green indication that serves the initial queue, and terminates at this point. However, in several instances, a second platoon on the major street is served, while in one case it is not. The results are mixed, showing the kind of trade-off that is often seen in real traffic operations. Thus the fourth criterion is not completely satisfied.

No problems were identified regarding the Maximum Green time setting. In all four cycles, queues were served for both phases.
In this laboratory, you examined the factors that should be considered when setting the timing parameters for both approaches of an intersection.

In Experiment #1, you observed the effect of long Vehicle Extension times: longer delay on both approaches, an inefficient result.

In Experiment #2, you learned how to set the pedestrian clearance interval, and observed its effect on the duration of the green (vehicle) interval.

In Experiment #3, you learned the pros and cons of increasing the Maximum Green time in order to solve the problem of phase failure. You observed that there are pros and cons with increasing the Maximum Green time, particularly as it affects the delay on the other approaches.

Finally, in Experiment #4, you observed the intersection operations with a range of settings for the Minimum Green time, the Vehicle Extension time, and the Maximum Green time. You observed the trade-offs in the setting of the Vehicle Extension time, especially on the major street, in serving "following platoons," vehicles that arrive with short headways soon after the initial queue has been served. Again, you observed the importance in concurrently considering the detection zone length, the Minimum Green time, and Vehicle Extension time to produce an efficient operation. The effect of the zone length on these timing parameter settings is clear: a longer zone length means shorter unoccupancy times and thus short values for both the Minimum Green time and the Vehicle Extension time.

In Laboratory 4, you will learn how higher speeds on the major street approach sometimes require a different approach to detection and timing.