CHAPTER 7: TIMING PROCESSES FOR THE INTERSECTION

This chapter includes information that you will need to prepare for, conduct, and assess each of the seven activities included in Chapter 7 of the student activity book. Support files shows the various files that are available to support your works as you use these activities, including mini-lecture slides, solution files, and student resource files.

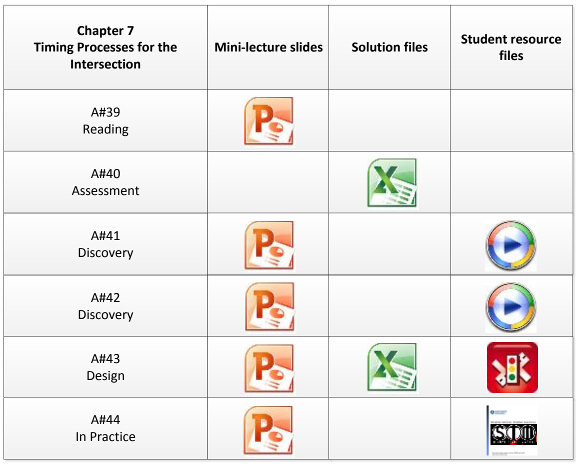


Figure 1. Support files

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

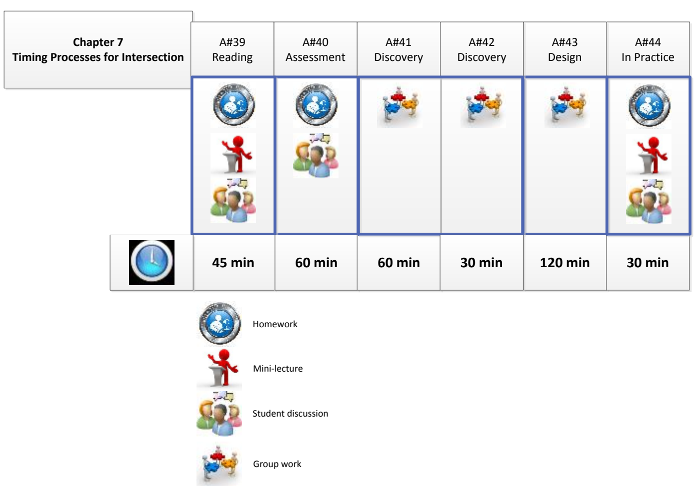


Figure 2. Activity work

Using Activity #39: Maximum Green Time, Cycle Length, and Delay

Overview
In this activity, students will learn the relationship between delay and cycle length. Students are asked to complete a reading which introduces them to the maximum green timer and how it affects cycle length and delay.

The purpose of this activity is for students to become more familiar with the maximum green timer function and process. By the end of the activity, students should understand why it is important to choose a maximum green time which is long short enough so that the phase does not extend unnecessarily, but long enough so that the phase does not terminate prematurely.

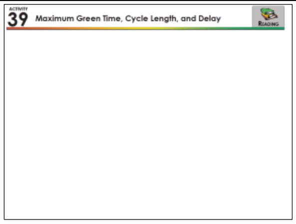
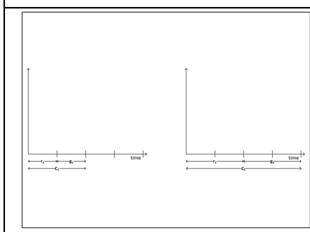
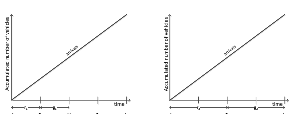
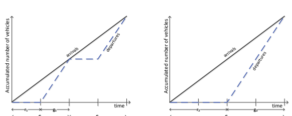
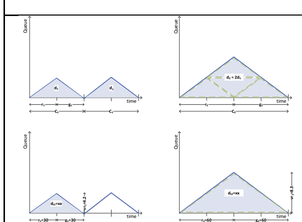
Options for Use
The reading, defining the terms in the glossary, and answering the critical thinking questions are usually done as homework, to prepare for class discussion. After the students complete this work, the instructor has several options for assessing and clarifying student understanding of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

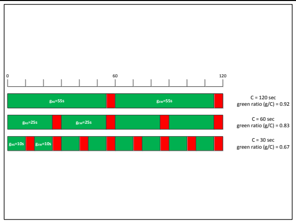
- Quiz to assess their understanding and to hold them accountable for the reading.
- Present mini-lecture summarizing key points from the reading, with active questioning of the students as the lecture material is presented.
- Discussion and synthesis of the answers to the quiz, the glossary definitions,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

Preparing for the Activity

- Decide which of the options you want to do during class.
- Prepare for class by reviewing Activity #39, including the "Information", the Glossary definitions, and the Critical Thinking Questions and answers. The list below provides some of the key concepts covered in the "Information".
    - Delay increases as cycle length increases.
    - Maximum green time helps to limit the time that one phase is served so that the overall cycle length doesn't increase without bounds

Doing the Activity (Script)
[Slides: slides39.pptx]
The following script can be used along with the PowerPoint slides for this activity. The script and slides can be modified based on your needs and what you decide to emphasize.

Slides	Notes
	In Chapter 6 the focus was on timing processes and parameters for one approach. You selected (or will select) the maximum allowable headway. In chapter 7, the focus will be on the overall intersection, how timing on one approach affects the operation of the other approaches, and how setting the maximum green time sets a limit on the cycle length and thus a limit on the delay experienced by the motorists using the intersection. We have to balance the timings on one approach with the timings on the other approach. If we set the passage time too high on one approach, delays will increase on the other approaches. And if the demand is high on one approach, unless we place some limits on the green duration, the delay will increase on the other approaches. So we do this with the maximum green time. [Ask them to interpret each of the following figures]
	Here is a quick overview on why the maximum green time is so important. We are going to compare two cases, one in which one cycle length is twice the other: $C_1 = 0.5C_2$
	The arrival rate is the same in both cases.
	The queues are served just before the end of green.
	And, the delay for C_2 is twice that for C_1.

Slides	Notes
	But there is also efficiency. What does this slide show?

Solutions

Included here are:

- Possible quiz and solution
- Critical thinking questions and answers
- Glossary and terms

Possible Quiz and Solution

1. Considering the timing process for one phase only, what happens when the vehicle extension timer (passage timer) expires?

- Depends on the state of the minimum green timer. If it has expired, the phase terminates. Else: the phase continues to time.

2. What is the purpose of the maximum green timer?

- Provide a limit on the cycle length and thus delay.

3. Describe the process followed by the maximum green timer?

- Starts with first conflicting call after the phase begins timing and times down to zero.

4. Considering only the uniform delay term for estimating (forecasting) delay, prepare a chart showing the relationship of delay as a function of cycle length?

- Linear increase in delay with cycle length.

Critical Thinking Questions and Answers

1. Why does delay increase as cycle length increases?

- Delay increases as cycle length increases because vehicles will have to wait for longer periods to receive a green indication.

2. What is the function of the maximum green time?

- The maximum green timer is used to limit the delay to any other movement at an intersection and to limit the cycle length to a specified maximum value. Additionally, the maximum green timer allows the intersection to operate if a detector is broken and is continuously placing a call.

3. What is the process followed by the maximum green timer?

- The maximum green timer becomes active once a call has been placed on an opposing detector. Once the opposing call is placed, the maximum green timer will time down until it reaches zero, at which time the phase will terminate.

Glossary and Terms (Answers)

Maximum green time	From Traffic Signal Timing Manual: "The maximum green parameter represents the maximum amount of time that a green signal indication can be displayed in the presence of conflicting demand."
Uniform delay	The delay experienced by vehicles at a signalized intersection if uniform arrival patterns are assumed.
Cycle length	The total time to serve all phases or movements at a signalized intersection.
d_1	The uniform delay term of the three term delay equation.
C	The cycle length.
G	The green time (or sometimes the effective green time).
g/C	The green ratio, or the ratio of the green time to the cycle length.
V	The approach volume or demand.
S	The saturation flow rate.
R	The red time (or sometimes the effective red time).

Using Activity #40: What Do You Know About Maximum Green Time, Cycle Length, and Delay? (Assessment)

Overview

This activity tests student understanding of the basic concepts relating to the maximum green time and its effect on cycle length and delay.

Options for Use

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

Preparing for the Activity

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

Because students are asked to write a short visual basic function to calculate delay, it would be good for the instructor to review how to do this prior to class. Detailed steps on how to create the function as well as an example function are shown in the solution.

Doing the Activity (Script)

1. Invite the students to read through the activity. Review the learning objectives, the deliverables, and the tasks.
2. After they complete the tasks, review their results, discussing some of the key points that they learned.

Solution

[Excel data sheet: solutions40.xlsx]

Included here are:

- Answers to task questions
- Critical thinking questions and answers

Answers to task questions

Task 1: A model for computing the average delay when traffic is arriving at a signalized intersection in a uniform rate was developed in Activity 8. It is reproduced below. Using an Excel spreadsheet, develop a VBA function to compute average uniform delay as a function of red time, green time, cycle length, volume, and saturation flow rate.

$$d_a = \frac{0.5r^2}{(r+g)(1-v/s)} = \frac{0.5r(1-g/C)}{1-v/s} = \frac{0.5C(1-g/C)^2}{1-X(g/C)}$$

To write the Visual Basic code, the following steps should be followed:

1. Open a new Excel file

2. Click on the ribbon tab titled “File” in the top left and then select “Options” from the bottom left of the menu
3. In the new Excel Options window, select “Add-Ins”
4. Select “Analysis ToolPak – VBA” from the Add-ins selection box
5. Click the “Go…” button at the bottom of the page
6. The Excel Options window should close and a new Add-Ins window should open
7. Check the box next to “Analysis ToolPak – VBA” and then click “OK”
8. The Add-Ins window should close, returning you to the Excel workbook
9. In the workbook, click the ribbon tab titled “Developer”, which should be the last tab on the ribbon
10. Click “Visual Basic”, the first button on the left of the developer ribbon
11. This will open the Microsoft Visual Basic for Applications window
12. In the new window, click “Insert” and then select “Module”
13. In the new module, the following information can be entered to create the visual basic function

```
Function d_average(r, g, C, v, s)
'This function calculates the average delay of an intersection given
red time, green time, cycle length, volume, and saturation flow rate.
'd_average_1,2,3, and 4 were added to simplify the equation.  While the
average delay equation can be written in one equation, it can be easier
to not make mistakes in the equation when it is split down into
multiple parts.
d_average_1 = 0.5 * r
d_average_2 = 1 - (g / C)
d_average_3 = d_average_1 * d_average_2
d_average_4 = 1 - (v / s)
d_average = d_average_3 / d_average_4
End Function
```

Task 2: Assuming a volume from one of the major street approaches of your simulation network.

- Compute the average uniform delay per vehicle as a function of cycle length, with a range of cycle lengths from 40 seconds to 150 seconds. Prepare a graph of delay vs. cycle length for the range of values that you computed in task 2.
    - The resulting graph of average delay versus cycle length is shown in Figure 1. The activity xx Excel file contains the visual basic code used to calculate delay. It should be noted that average delay increases linearly with cycle length.

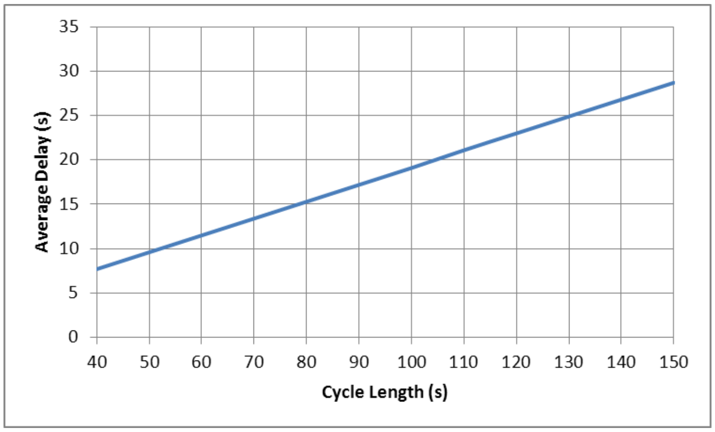


Figure 3. Average Delay versus Cycle Length

Critical Thinking Questions and Answers

1. Prepare a brief discussion of the implications of your analysis for the maximum green time setting for your network. What limitations exist in this analysis that must be considered when you set the maximum green time? Include the discussion and answer in your spreadsheet.

- When creating the network, the maximum green time should be considered to minimize the effect of random arrivals causing a large queue length. For each network, the maximum green time should be set minimize delay, while serving the majority of queues. To do this, queue length data will need to be known.

2. This activity has emphasized the importance of keeping the cycle length (and thus the maximum green time) as low as possible. But what happens when the cycle length becomes too short? List two possible downsides of very short cycle lengths.

- If the maximum green time is too short, queues will not be able to clear, causing the queue length to continue to grow. If queues are not able to clear, delay will significantly increase because vehicles will have to wait through multiple cycles before they are served.
- [Or] If the cycle length becomes too short, the chances of cycle failure increase which will increase delay. Additionally, with shorter cycle lengths, there will be more lost time because the amount of yellow and all red time will increase.

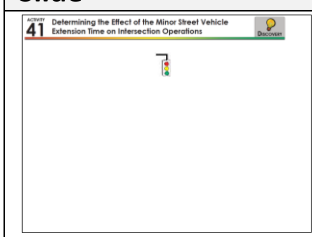
Using Activity #41: Determining the Effect of the Minor Street Vehicle Extension Time on Intersection Operations (Discovery)

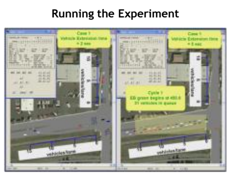
Overview
In this activity, students will learn about the effects of minor street vehicle extension times on the intersection operations. The purpose of this activity is to teach students the effects of the minor street Vehicle Extension setting on the efficiency of major street and intersection operations. Students will watch a video file named “A41.wmv” which shows the operations of a signalized intersection. Students will be asked to make observations on separate vehicle extensions time effects on queue lengths.

Options for Use
- Activity #41 can be conducted either during class or as homework.

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

Doing the Activity (Script)
[Slides: slides41.pptx]
The following script and the accompanying slides (slides41.pptx) can be used to lead the activity. Note that there are a lot of slides following; identify the key ones so that students focus on the key learning points.

Slide	Task
	**Tell:** Turn to Activity #41. These pages list the learning outcome for this experiment, an overview of the experiment, the questions that you will answer once you’ve finished the experiment, and the list of steps that you will complete during the experiment. [Note error in video: for case 2, Cycle 1 is shown in callout but should be cycle 3 (t = 2:07) EB green ends at 598.3; also cycle 4 not 2 SB green begins at 603.3 – 6 vehicles in queue] Take about two minutes to read this page. [Once they have completed reading the page] **Tell:** Do you have any questions on this material? **Tell:** Emphasize the learning outcome for this lesson. Be able to determine the effect of the minor street Vehicle Extension

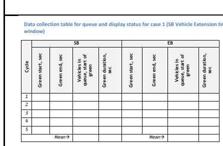
<table>
<tr><th>Slide</th><th>Task</th></tr>
<tr><td></td><td>setting on the efficiency of major street and intersection operations.</td></tr>
<tr><td>
</td><td>Tell You will consider two different settings of Vehicle Extension time on the minor street (SB approach) and how these different settings affect the queuing and green time duration experienced on both approaches.

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

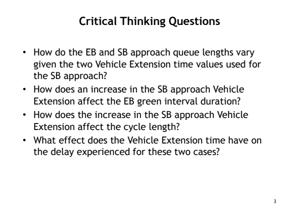
• Left window (case 1): the Vehicle Extension time for both the SB approach and EB approach is 2 seconds.
• Right window (case 2): the Vehicle Extension time for the SB approach is set to 5 seconds whereas the Vehicle Extension time for the EB approach remains at 2 seconds.

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.

Notes:
• When an event of interest occurs, press the “Pause” button to record the pertinent information.
• If you miss the time when you should begin collecting data, you can move the simulation backwards using Windows Media Player.</td></tr>
<tr><td>
Data collection table for queue and display status for case 1 (SB Vehicle Extension time of 2.0 seconds) (Left window)
<table>
<tr><th rowspan="2">Cycle</th><th colspan="4">SB</th><th colspan="4">EB</th></tr>
<tr><th>Green start, sec</th><th>Green end, sec</th><th>Vehicles in queue, start of green</th><th>Green duration, sec</th><th>Green start, sec</th><th>Green end, sec</th><th>Vehicles in queue, start of green</th><th>Green duration, sec</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Mean→</td><td></td><td></td><td colspan="2">Mean→</td><td></td><td></td></tr>
</table></td><td>Here are the data that you will be collecting for both cases.
• Green start time
• Green end time
• Vehicles in queue at start of green
[Elaborate as needed]</td></tr>
</table>

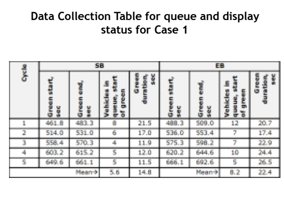
Slide	Task



Tell: You are presented again with the "questions to consider." Review the question with your partner (if you are working with a partner) and write your answer.

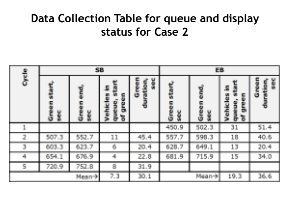
Be ready to discuss your answers with the class.

Take about 5 minute for this activity.



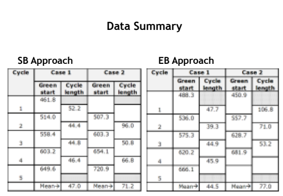
Tell: Before we discuss the answers that you prepared for the four questions considered on the previous page, let's first look at the data that you collected.

The table shows the individual queue length and green duration measurements for Case 1(Vehicle Extension time of 2.0 seconds for SB approach). The table also shows the mean values for theses two parameters.

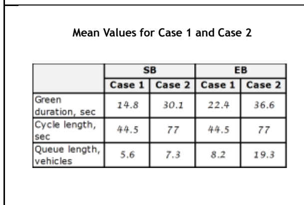


Tell: The table shows the individual queue length and green duration measurements for Case 2(Vehicle Extension time of 5.0 seconds for SB approach). The table also shows the mean values for theses two parameters.

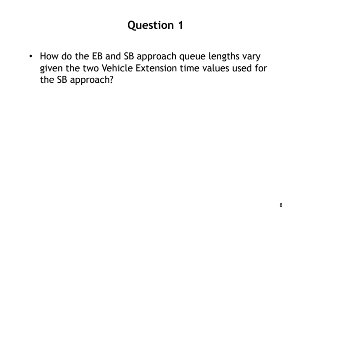
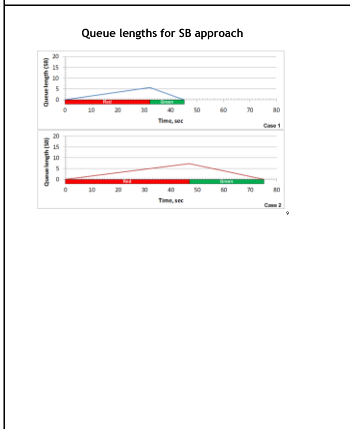
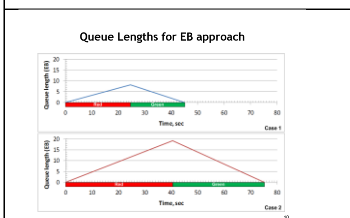
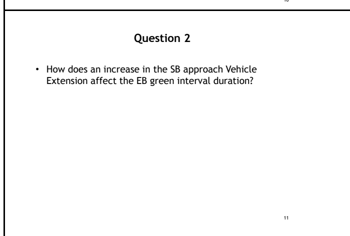
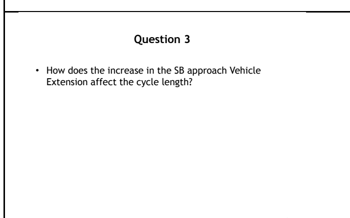
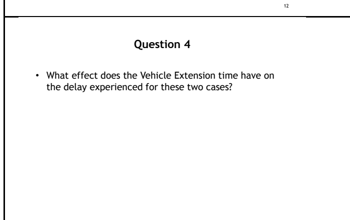
Ask: Why is there variation in the green durations?
[Answers} As expected for an actuated traffic signal system, there is some variation in the green duration from cycle to cycle. For example, for the SB approach for Case 2, the green duration ranges from 20.4 seconds to 45.4 seconds. You may recall 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.

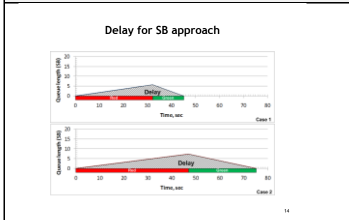


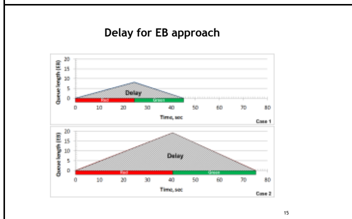
Tell: The longer green durations lead directly to longer cycle lengths as shown in the tables. For both the EB and SB approaches, the longer Vehicle Extension time for the SB approach (Case 2) produces a longer cycle length.

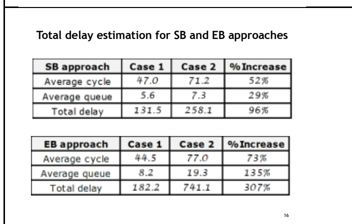


Tell: The comparison between Case 1 and Case 2 is more directly evident in the table. The values of green duration, cycle length, and queue length are longer for Case 2 than for Case 1. An inefficiently long Vehicle Extension time (here, 5 seconds for Case 2) significantly affects all three parameters.

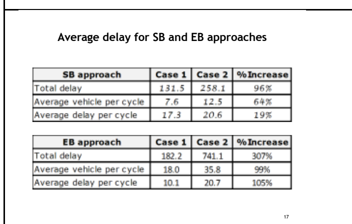
Slide	Task
	**Tell:** Let's now discuss the questions that were asked at the beginning of this lesson. **Ask: How do the EB and SB approach queue lengths vary given the two Vehicle Extension values used for the SB approach?** **Answer:** (Increased queue length) Relative to Case 1, the Case 2 average queue length for the SB approach is only slightly longer, but it has more than doubled for the EB approach.
	**Tell:** 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. These figures show the queue accumulation polygon (QAP) for the SB approach for Cases 1 and 2.
	**Tell:** These figures show the queue accumulation polygon (QAP) for the EB approach for Cases 1 and 2.
	**Ask: How does an increase in the SB approach Vehicle Extension affect the EB green interval duration?** **Answer:** (Longer green duration) The green duration for the EB approach increases with a longer Vehicle Extension time on the SB approach.
	**Ask: How does the increase in the SB approach Vehicle Extension affect the cycle length?** **Answer:** (Increased cycle length) The average cycle length increased from 45 seconds (when the Vehicle Extension is 2 seconds) to 77 seconds (when the Vehicle Extension is 5 seconds).
	**Ask: What effect does the Vehicle Extension time have on the delay experienced for these two cases?** **Answer:** You didn't measure delay, but you collected the information that you need to estimate delay. How is this done?

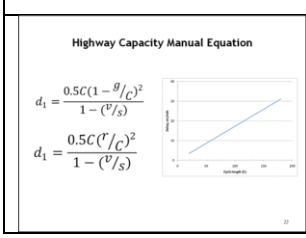
<table>
<tr><th>Slide</th><th>Task</th></tr>
<tr><td>
</td><td>Tell: Let’s look at the queue accumulation polygons again. The area of the polygon (in this case a triangle), is the total delay experienced by all vehicles arriving during the cycle.

This figure shows the total delay for SB approach for case 1 and 2.</td></tr>
<tr><td>
</td><td>Tell: The area of the polygon (in this case a triangle), is the total delay experienced by all vehicles arriving during the cycle.

The figure shows the total delay for EB approach for case 1 and 2.</td></tr>
<tr><td>
Total delay estimation for SB and EB approaches
<table>
<tr><th>SB approach</th><th>Case 1</th><th>Case 2</th><th>%Increase</th></tr>
<tr><td>Average cycle</td><td>47.0</td><td>71.2</td><td>52%</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>
</table>
<table>
<tr><th>EB approach</th><th>Case 1</th><th>Case 2</th><th>%Increase</th></tr>
<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>
</table>
16</td><td>Tell: The tables 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!

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.</td></tr>
<tr><td>
Average delay for SB and EB approaches
<table>
<tr><th>SB approach</th><th>Case 1</th><th>Case 2</th><th>%Increase</th></tr>
<tr><td>Total delay</td><td>131.5</td><td>258.1</td><td>96%</td></tr>
<tr><td>Average vehicle per cycle</td><td>7.6</td><td>12.5</td><td>64%</td></tr>
<tr><td>Average delay per cycle</td><td>17.3</td><td>20.6</td><td>19%</td></tr>
</table>
<table>
<tr><th>EB approach</th><th>Case 1</th><th>Case 2</th><th>%Increase</th></tr>
<tr><td>Total delay</td><td>182.2</td><td>741.1</td><td>307%</td></tr>
<tr><td>Average vehicle per cycle</td><td>18.0</td><td>35.8</td><td>99%</td></tr>
<tr><td>Average delay per cycle</td><td>10.1</td><td>20.7</td><td>105%</td></tr>
</table>
17</td><td>Tell: The number of vehicles that arrived on each approach during each cycle is shown in these tables. The average delay is computed as the total delay divided by the number of vehicles that arrive during the cycle. The average delay is 46 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.

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.</td></tr>
<tr><td>
</td><td>Tell: The results that we observed in the data presented above relate directly to what we would observe in general.

The Highway Capacity Manual provides an equation for estimating delay for an approach at a signalized intersection. For moderate</td></tr>
</table>

Slide	Task
	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. The figure 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.
	Tell: 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 (chart on the left), while the same plot for case 2 (the shorter queue clearance time) is shown in Figure 13 (chart on the right). 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.
	Tell: How do we know the delay is longer? In the previous slide, the area of the triangles equal the delay experienced by all vehicles arriving during the time portrayed. We can see in this slide (Figure

Slide	Task
	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.
	Possible tasks: Have them construct QAP from what they observe.

Solutions

Included here:

- Answers to task questions
- Critical thinking questions and answers

Answers to task questions

Task 3 asks students to fill out the following tables. The tables show the individual queue length and green duration measurements for case 1 and case 2. 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 1. Data collection table for queue and display status for case 1 (SB Vehicle Extension time of 2.0 seconds)

Cycle	SB				EB			
	Green start, sec	Green end, sec	Vehicles in queue, start of green	Green duration, sec	Green start, sec	Green end, sec	Vehicles in queue, start of green	Green duration, sec
1	461.8	483.3	8	21.5	488.3	509.0	12	20.7
2	514.0	531.0	6	17.0	536.0	553.4	7	17.4
3	558.4	570.3	4	11.9	575.3	598.2	7	22.9
4	603.2	615.2	5	12.0	620.2	644.6	10	24.4
5	649.6	661.1	5	11.5	666.1	692.6	5	26.5
Mean→			5.6	14.8	Mean→		8.2	22.4

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

	SB				EB			
Cycle	Green start, sec	Green end, sec	Vehicles in queue, start of green	Green duration, sec	Green start, sec	Green end, sec	Vehicles in queue, start of green	Green duration, sec
1	507.3	552.7	11	45.4	450.9	502.3	31	51.4
2	603.3	623.7	6	20.4	557.7	598.3	18	40.6
3	654.1	676.9	4	22.8	628.7	649.1	13	20.4
4	720.9	752.8	8	31.9	681.9	715.9	15	34.0
Mean→			7.3	30.1	Mean→		19.3	36.6

Task 4 asks students to fill out three tables. Longer green durations lead directly to longer cycle lengths, as shown in the tables below. 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 the table below. 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 3. Data summary, SB approach

Cycle	Case 1		Case 2	
	Green start	Cycle length	Green start	Cycle length
1	461.8		507.3	
2	514.0	52.2	603.3	96.0
3	558.4	44.4	654.1	50.8
4	603.2	44.8	720.9	66.8
5	649.6	46.4		
	Mean→	47.0	Mean→	71.2

Table 4. Data summary, EB approach

Cycle	Case 1		Case 2	
	Green start	Cycle length	Green start	Cycle length
1	488.3		450.9	
		47.7		106.8
2	514.0		557.7	
		39.3		71.0
3	575.3		628.7	
		44.9		53.2
4	620.2		720.9	
		45.9		
5	666.1			
	Mean→	44.5	Mean→	77.0

Table 5. Mean values for cases 1 and 2

	SB		EB	
	Case 1	Case 2	Case 1	Case 2
Green duration, sec	14.8	30.1	22.4	36.6
Cycle length, sec	47.0	71.2	44.5	77.0
Queue length, vehicles	5.6	7.3	8.2	19.3

Critical thinking questions and answers

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).

4. What effect does the Vehicle Extension time have on the delay experienced for these two cases?

- The delay is expected to be larger when the Vehicle Extension time is 5 seconds then compared to the case when the Vehicle Extension timer is 2 seconds. The reason the delay is expected to increase is based on the total number of vehicles in queue in case 2 over case 1.

Using Activity #42: Determining the Effect of the Maximum Green Time on Intersection Operations (Discovery)

Overview

Activity #42 is expands understanding and builds on the design started in Chapter 6. In this activity, students will be selecting the maximum green time for their design intersection. The purpose of this activity is for students to understand how the Maximum Green time settings affect intersection operations. In this activity, students 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.

Options for Use

This activity can be done either in class or as homework.

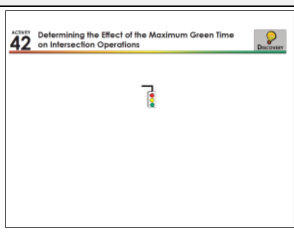
Preparing for the Activity

Watch the video before class. Help the students to focus on key points of the video.

Doing the Activity (Script)

[Slides: slides42.pptx]

You can use all or part of the following script, along with the PowerPoint slides, to guide the activity.

Slides	Notes
	**Tell:** Turn to Activity #42 of your book. It shows the learning outcome for this experiment, an overview of the experiment, the questions that you will answer once you've finished the experiment, and the list of steps that you will complete during the experiment. Take about two minutes to read this page. [Provide instructions on key parts of activity] [Once they have completed reading the page] **Ask:** Do you have any questions on this material? **Tell:** Emphasize the learning outcome for this lesson. Be able to describe the advantages and disadvantages of increasing Maximum Green time on intersection operations

<table>
<tr><th>Slides</th><th>Notes</th></tr>
<tr><td>

Running the Experiment

- Step 1. Open the movie file
- Step 2. Observe the operation of case 1 and record your observations.
- Step 3. Observe the operation of case 2 and record your observations.
- Step 4. 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.

2

</td><td>

Tell: Turn to pages xx of your book. Read through the instructions before beginning the lesson. When you have completed the steps for running the experiment, record your observations.

</td></tr>
<tr><td>

Critical Thinking Questions

- Are all of the vehicles in the initial queue on the EB 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?

3

</td><td>

Tell: You are presented again with the “questions to consider.”
Be ready to discuss your answers with the class.

</td></tr>
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**Data Collected
Green Interval Durations for case 1 and 2**

<table>
<tr><th rowspan="2">Cycle</th><th colspan="4">Green time, sec</th></tr>
<tr><th>NB/SB</th><th>EBLT</th><th>EBTH</th><th>WBTH</th></tr>
<tr><td>1</td><td>30</td><td>5</td><td>50</td><td>40</td></tr>
<tr><td>2</td><td>30</td><td>13</td><td>58</td><td>40</td></tr>
<tr><td>3</td><td>22</td><td>8</td><td>53</td><td>40</td></tr>
<tr><td>4</td><td>17</td><td>5</td><td>37</td><td>27</td></tr>
</table>

<table>
<tr><th rowspan="2">Cycle</th><th colspan="4">Green time, sec</th></tr>
<tr><th>NB/SB</th><th>EBLT</th><th>EBTH</th><th>WBTH</th></tr>
<tr><td>1</td><td>38</td><td>5</td><td>70</td><td>60</td></tr>
<tr><td>2</td><td>40</td><td>15</td><td>80</td><td>60</td></tr>
<tr><td>3</td><td>25</td><td>6</td><td>50</td><td>39</td></tr>
<tr><td>4</td><td>22</td><td>-</td><td>46</td><td>46</td></tr>
</table>

4

</td><td>

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

These tables 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.

</td></tr>
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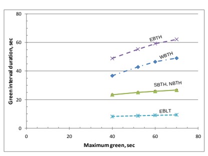
Variation of Green Time with Maximum Green



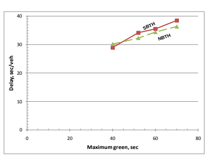
5

</td><td>

Tell: This figure 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.

</td></tr>
<tr><td>

Variation of Delay with Maximum Green



6

</td><td>

Tell: What is the effect on delay of the increase in maximum green time, and the duration of the green intervals? This figure 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.

</td></tr>
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Question 1

- Are all of the vehicles in the initial queue on the EB approach served before the end of each green interval?

7

</td><td>

Ask: Are all of the vehicles in the initial queue on the EB approach served before the end of each green interval?

</td></tr>
<tr><td>

Question 1

<table>
<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>
<tr><td>1</td><td>96.2</td><td>136.2</td><td>Max Out</td><td>Cleared</td><td>40</td></tr>
<tr><td>2</td><td>194.7</td><td>234.7</td><td>Max Out</td><td>Not Cleared</td><td>40</td></tr>
<tr><td>3</td><td>295.3</td><td>335.3</td><td>Max Out</td><td>Not Cleared</td><td>40</td></tr>
<tr><td>4</td><td>379</td><td>414.2</td><td>Gap Out</td><td>Cleared</td><td>35.2</td></tr>
</table>

<table>
<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>
<tr><td>1</td><td>96.2</td><td>156.2</td><td>Max Out</td><td>Cleared</td><td>60</td></tr>
<tr><td>2</td><td>224.8</td><td>284.8</td><td>Max Out</td><td>Cleared</td><td>60</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</td><td>465.1</td><td>Gap Out</td><td>Cleared</td><td>48.1</td></tr>
</table>

8

</td><td>

Answer: These tables 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.

</td></tr>
</table>

Slides	Notes
	Increasing the Maximum Green time is one method of reducing phase failure.
Question 2 • What is the mechanism for termination of the phase serving the westbound approach? 9	**Ask: What is the mechanism for termination of the phase serving the westbound approach?** **Answer:** 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.
Question 3 • What are the advantages and disadvantages of the 40 second maximum green time for the operation of case 1? 10	**Ask: What are the advantages and disadvantages of the 40 second Maximum Green time for the operation of case 1?** **Answer:** The primary disadvantage of the 40 second cycle is that the queue on the WB approach doesn't clear during two of the cycles.
Question 4 • What are the advantages and disadvantages of the 60 second maximum green time for the operation of case 2? 11	**Ask**: What are the advantages and disadvantages of the 60 second Maximum Green time for the operation of case 2? **Answer:** 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.
Question 5 • Which maximum green time setting would you select and why? 12	**Ask: Which Maximum Green time setting would you select and why?** **Answer:** 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 increasing queue lengths. Favoring vehicles on at 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.

Solutions

Included here are:

- Task questions and answers
- Critical thinking questions and answers

Task questions and answers
In this activity, students will observe the operation of two cases, each with different Maximum Green times. Each case includes four cycles, focusing on the westbound approach. Students 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?

Task 1: Observe the operation of case 1 and record your observations. Note your observations.

- For the 40 second Maximum Green, the queue was not fully served in two of the four cycles. For three of the cycles, the phase terminates due to a max out. The fourth phase terminates due to a gap out.

Task 2: Observe the operation of case 2 and record your observations. Note your observations.

- For the 60 second Maximum Green, the queue was fully served for all four cycles. All four phases terminate due to a gap out, indicating that increasing the Maximum Green time is one method of reducing phase failure.

Answers to Critical Thinking Questions

1. Are all of the vehicles in the initial queue on the WB approach served before the end of each green interval?

- Tables 1 and 2 show more details for the green interval duration, the method of phase termination, and whether the queue cleared or not.

Table 6 Data collection for WB approach (Max Green = 40 seconds)

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

Table 7 Data collection for WB approach (Max Green = 60 seconds)

Cycle	Green begins (simulation time, sec)	Green ends (simulation time, sec)	Method of phase termination	Queue status	Green interval duration (sec)
1	96.2	156.2	Max Out	Cleared	60.0
2	224.8	284.8	Max Out	Cleared	60.0
3	346.2	385.3	Gap Out	Cleared	39.1
4	417.0	465.1	Gap Out	Cleared	48.1

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.

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. 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 and documented for both cases. Summarize the pros and cons of each case.

- The primary disadvantage of the 40 second cycle is that the queue on the WB approach doesn't clear during two of the cycles. 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.

Other Notes

Response from student survey on Activities #41 and #42

Question: "You have completed two activities in which observation was a primary component. After completing these two activities, visual observation helped my understanding of the effect of vehicle extension time and maximum green time on intersection performance (delay).

Strongly agree	Agree	Neutral	Disagree	Strongly disagree
10	10	0	0	0

Written comments:

<table>
<tr><th>Strongly agree</th><th>Agree</th></tr>
<tr><td>

Seeing the simulation and making us collect certain data really helped with my understanding. I understood the concepts pretty well before this, but these activities reinforced it and made me more confident in my understanding.
They really helped bring together what we have discussed in class and in reading assignments. I definitely favor visual observation.
I strongly agree that using visual observations helps me with the understanding of the effects of vehicles, this is something that math and lots of reading doesn't really help much, is good for information.
We ran simulations to show us how an intersection works with given parameters. These parameters were modified to show how they affect the functionality of the intersection. The simulation models were very helpful! It was good to be able to see how the simulation worked!
It was useful to look at the two cases side by side so you can see what happens when certain parameters are changed.
If I had a little more time to do these activities, they would be beneficial.
Numbers only get you so far. To really understand how design affects the real world, one should experience the real world (or in this case a simulation).
I would have initially thought that a max green of 40 seconds would be more beneficial, but after doing the following activity, I think a 60 second max green is more efficient for the intersection (with higher approach volumes).

</td><td>

Visual observations helped….passage time, maximum green time, and delay. I didn't learn anything new from the videos but it was nice to reinforce ideas that I already knew.
Visual observation helped my understanding of passage time and max green time on delay. I already understand the concepts quite well but the visual observations helped to reinforce my knowledge.
This activity helped me to visually analyze the processes of intersections under different passage time and max green times. It helped me to talk and think over the concepts learned in the textbook and apply it to the visuals.
I feel like this activity was useful for helping me visualize what is going on visually rather than trying to picture it in my head.
It helped me by being able to see traffic movement at an intersection, especially looking down on it. The activities are good but need more explanation and time to finish.
The manual is too vague on the standards for detection and minimum green time.
I felt rushed to write down the data and therefore didn't get to pay attention to the effects of the changes of vehicle extension time and max green time as much as I would have liked.
Visual observations helped…these timing parameters are often difficult to fully understand without a visual. A definition out of an assigned reading does not give a very full understanding of the effects of these changes in these parameters.
In the introductory transportation class, all this work

</td></tr>
</table>

Strongly agree	**Agree**
• It was very helpful to understand traffic flow at intersections. You get a visual of traffic responses.	was done by reading and example problems, being able to relate what an equation is doing to the overall intersection is useful in understanding the concept. • I feel like I understand the concepts before the activities but doing them helped me to see how it actually affects traffic flow.

Using Activity #43: Setting the Maximum Green Timing Parameter for All Approaches of an Intersection (Design)

Overview

In this activity, students will be selecting the maximum green time parameter for their design intersection. The purpose of this activity is to allow students to set the maximum green time for their design network such that the delay is optimized for all approaches and for the intersection as a whole. Students are asked to select a maximum green time according to the following criteria:

- 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 consistently terminates by maxing out.

At the end of this activity, students will be able to set the maximum green time for both approaches of their intersection.

Options for Use

This activity is done during class time in the computer lab.

Preparing for the Activity

- Review the tasks that the students will do.
- Review the data set and solutions to get an understanding of what the students will be doing and observing.

Doing the Activity (Script)

Explain that this is part of the design process, here selecting the maximum green time. The data that they will collect include:

- Phase termination data so that they will know whether a phase terminates by gapping out or maxing out.
- Delay and queue length data
- Visual observations

The will select their value based on a “manual” optimization by looking at how the performance changes when they change the cycle length.

Solutions

[Excel data sheet: solution43.xlsx]

Task questions and answers

Tasks 1 through 3 do not have a deliverable therefore no solution was created. Students were asked to start an a maximum green time of 100 seconds and then record delay for each approach along will the total number of gap outs and max outs. Then students will repeat this process but lowering the maximum green time by 10 seconds until students reach a 20 second max green time.

Task 4 asks students to summarize their work for the previous 3 tasks. An example is shown below. Table 8 and shows the delay results for the intersection. Table 9 shows the percent of max outs and gap outs for the intersection. Figure 4 shows a graphical representation of the two tables. It is recommended to select a maximum green time of 60 seconds. The delay does not significantly change, while the max out percentage is at 0% at maximum green times of 60 seconds.

Table 8. Delay with respect to Max Green time

	Max Green Time (sec)								
Movement	**100**	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**
W-E	5.5	5.5	5.5	5.5	5.5	5.4	5.1	5.3	5.5
W-N	21.9	21.9	21.9	21.9	21.9	21.3	21.7	21.8	19.2
E-W	15.6	15.6	15.6	15.6	15.6	15.6	16.5	16.1	16.9
E-N	14.2	14.2	14.2	14.2	14.2	14.0	15.0	14.5	16.0
N-E	21.2	21.2	21.2	21.2	21.2	21.8	20.2	18.2	17.8
N-W	24.3	24.3	24.3	24.3	24.3	24.1	24.6	17.9	19.4
N-E	20.8	20.8	20.8	20.8	20.8	21.1	21.5	17.2	17.4
All	13.3	13.3	13.3	13.3	13.3	13.2	13.4	12.8	12.9

Table 9. Percent gap outs and max outs

Max Green Time (sec)	100	90	80	70	60	50	40	30	20
Gap Outs	100%	100%	100%	100%	100%	98%	94%	84%	71%
Max Outs	0%	0%	0%	0%	0%	2%	6%	16%	29%

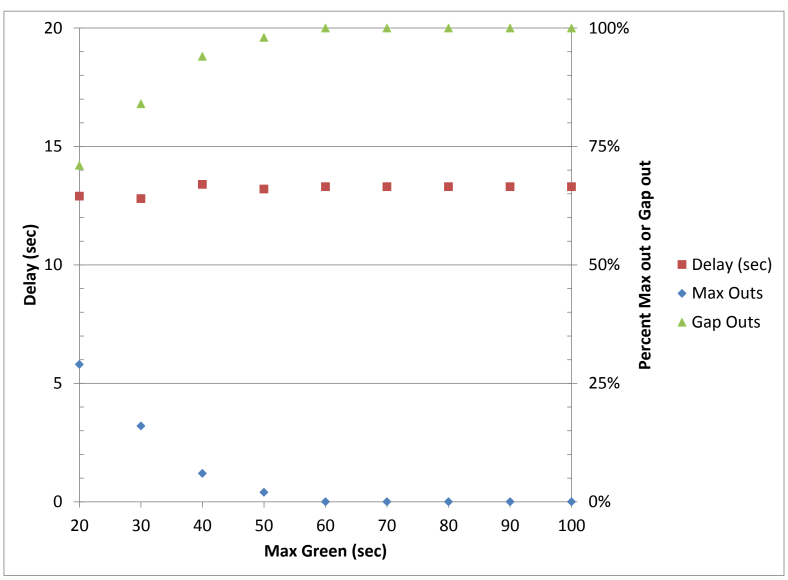

Figure 4. Intersection Performance vs. Max Green

Other Notes

The students often don't know how to select their maximum green time. Many often want to balance the number of gap outs and max outs, instead of focusing on two other relevant factors, including emphasizing the number of gap outs and using max green to keep the cycle length down. It is important to discuss the process for selecting the max green time.

Using Activity 44: Maximum Green Time (In Practice)

Overview
Students will again be exposed to the Traffic Signal Timing Manual and its treatment of the maximum green timer.

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

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

Doing the Activity (Script)
1. Describe the purpose of the "In Practice" activities and how they will be used to review and calibrate the work that they have previously done in each chapter.
2. Invite them to consider the CTQ and their answers.
3. Ask for answers and discussions for selected questions.

Solution
Critical Thinking Questions and Answers
1. What is the function of the maximum green timer?

2. What methods are used to set the maximum green time?

- There are two common methods for setting the maximum green timer. The first method is to set the timer so that the 85^{th} or 95^{th} percentile queue will have sufficient time to clear. The second method is to set the maximum green timer to an equivalent optimal pre-timed plan.

3. How do your design results from Activity #43 compare with the recommendations from the Traffic Signal Timing Manual?