CHAPTER 9 Right of Way Change: Change and Clearance Intervals

Purpose

In Chapter 9, you will learn about the vehicle change and clearance intervals, the timing intervals during which yellow and red, respectively, are displayed. Signalized intersections clearly and unambiguously assign right-of-way to specific movements in such a way that green is never displayed for conflicting movements at the same time. Thus, the transition from the green for one movement to another is an important process, one that must be done in way that maximizes safety for both the drivers that are currently being served and those about to be served. This is accomplished through the clearance and change intervals.

Like many parts of the signal timing process, technology and human factors must be considered together. How fast do drivers respond to a newly displayed yellow indication? What is the variation of this response among drivers? How does the variation in the approach speed of the drivers, and the distance that they are upstream from the intersection, affect their response? How much of a safety factor should be built into this change and clearance process? You will explore some of these questions in the activities that follow in this chapter.

Learning Objectives

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

- Describe the process for setting the yellow and red clearance times
- Describe the purpose and method of calculation of the vehicle change and clearance intervals
- Describe the different responses of drivers to the yellow indication based on their location upstream of the intersection
- Compare field data with the theoretical basis of stopping
- Describe driver behavior at the onset of the yellow interval
- Determine the vehicle change and clearance intervals
- Describe the factors considered when the yellow and red clearance intervals are set by practicing traffic engineers

Chapter Overview

This chapter begins with a *Reading* (Activity #52) on the change and clearance intervals. The chapter then proceeds to three activities including an assessment of your understanding of the change and clearance intervals (Activity #53) and activities in which you observe drivers responding to the yellow and red displays using field data (Activities #54 and #55). A design activity (Activity #56) follows in which you determine the change and clearance intervals for your design problem. The chapter concludes with an *In Practice* activity (Activity #57) in which you compare the results of your design work with the *Traffic Signal Timing Manual*.

Activity List

Number and Title	Type
52 The Theoretical Basis of the Yellow and Red Clearance Intervals	*Reading*
53 What Do You Know About the Change and Clearance Intervals?	*Assessment*
54 Drivers Responding to Yellow and Red Indications	*Discovery*
55 Vehicle Response to Displays at End of Green	*Field*
56 Determining Vehicle Change and Clearance Intervals	*Design*
57 Yellow and Red Clearance Intervals	*In Practice*

ACTIVITY 52

The Theoretical Basis of the Yellow and Red Clearance Intervals

READING

Purpose

The purpose of this activity is to show you some of the issues that must be considered when setting the yellow and red clearance intervals.

Learning Objective

- Describe the process for setting the yellow and red clearance intervals

Deliverables

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

Glossary

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

change interval	
clearance interval	
perception-reaction time (δ)	
stopping distance (x_s)	
v	

a	
w	
L	

CRITICAL THINKING QUESTIONS

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

1. What are the two factors that make up the stopping distance?

2. What are the two conditions that must be true in order for a driver to be able to safely stop or safely clear the intersection when the yellow is first displayed?

3. The value of *t* derived in the reading is the minimum value necessary to ensure that a driver will either be able to safely stop or safely clear the intersection when the yellow is displayed. What happens if the value is set higher than *t* just to provide an extra margin of safety? What would the trade-offs be in this decision?

Information

The ring barrier diagram defines which phases can time concurrently (those in different rings, on the same side of the barrier) and which must be timed sequentially (those in the same ring). Safety considerations require that a time separation be placed between the phases that must be timed sequentially. This time period consists of the change interval which is indicated by the yellow display and the clearance interval which is indicated by the red display. The theory that supports the determination of these intervals requires us to consider two factors:

- How long does it take a driver to perceive the need to stop and then to actually brake to a stop?
- How long does it take a driver to safely and completely clear the intersection?

As you will see, this theory makes several assumptions: vehicles arrive at the intersection at the same (and constant) speed, each vehicle has the same length, and all drivers have the same response characteristics to a change in the display from green to yellow. In reality, none of these assumptions is true: there is some variability in each of these three factors. So we will first develop the theory as a base for understanding how the change and clearance timing intervals are set, and then we will look at how the variability in these three parameters complicates the selection of the yellow time (change interval) and the red clearance time (clearance interval). Finally, we will consider the effects on driver behavior (how the driver responds to the change from green to yellow) when we increase or decrease the duration of the yellow indication.

We will first define what we will call the "choice point." It is the point upstream of which the driver will be able to safely stop at the intersection stop bar should he or she choose to do so. If the driver is any closer to the intersection than this choice point, he or she would not be able to safely come to a stop when the signal display changes from green to yellow. We can determine the location of this choice point by considering both the process that the driver must undergo to begin the stopping maneuver as well as the braking process. When the yellow is first displayed, it takes some time for the driver to perceive and react to this information. We call this the perception-reaction time (δ). If the driver decides to stop, he or she will apply the brakes and begin the deceleration process. The minimum stopping distance (x_s) is computed as the sum of (1) the distance traveled during the driver's perception-reaction time and (2) the braking distance (calculated using the basic equations of motion or kinematics).

$$x_s = v\delta + \frac{v^2}{2a}$$

where: v = initial velocity of the vehicle at the onset of yellow (ft/sec)

a = maximum comfortable acceleration rate (ft/sec/sec)

δ = perception-reaction time (sec)

Now, suppose that instead of stopping in response to the yellow indication, the driver at the choice point decides to continue through the intersection. The distance that the vehicle would have to travel from the choice point to the point where the rear bumper of the vehicle clears the far side of the intersection is given by the clearance distance (x_c):

$$x_c = x_s + w + L$$

where: x_s = minimum stopping distance as defined previously (ft)

w = intersection width (ft)

L = vehicle length (ft)

The time that it takes for a vehicle to travel the clearance distance (x_c) must equal the sum of the yellow (Y) and red clearance (RC) times:

$$Y + RC = \frac{x_c}{v} = \frac{x_s + w + L}{v}$$

where v is the speed of the vehicles approaching the intersection.

Why must this be true? In theory, our goal for a vehicle that continues through the intersection without stopping is to provide sufficient yellow time (Y) for the vehicle to travel from the choice point to the stop bar and sufficient red clearance time (RC) for the vehicle to travel from the stop bar to clearing its rear bumper through far side of the intersection. Thus:

$$Y = \frac{x_s}{v} \qquad RC = \frac{w + L}{v}$$

To illustrate this model, let's consider an intersection that is 40 feet wide. The location of the choice point is calculated using the equation for the minimum stopping distance (x_s). Suppose that drivers approaching the intersection travel at 35 miles per hour (51.33 feet per second) and have a perception-reaction time of 1 second. The minimum comfortable deceleration rate of 10 feet per second per second is also assumed.

$$x_s = v\delta + \frac{v^2}{2a} \qquad x_s = (51.33)(1) + \frac{(51.33)^2}{2(10)} = 184\,ft$$

In this case the choice point is located 184 feet upstream of the intersection as shown in Figure 170.

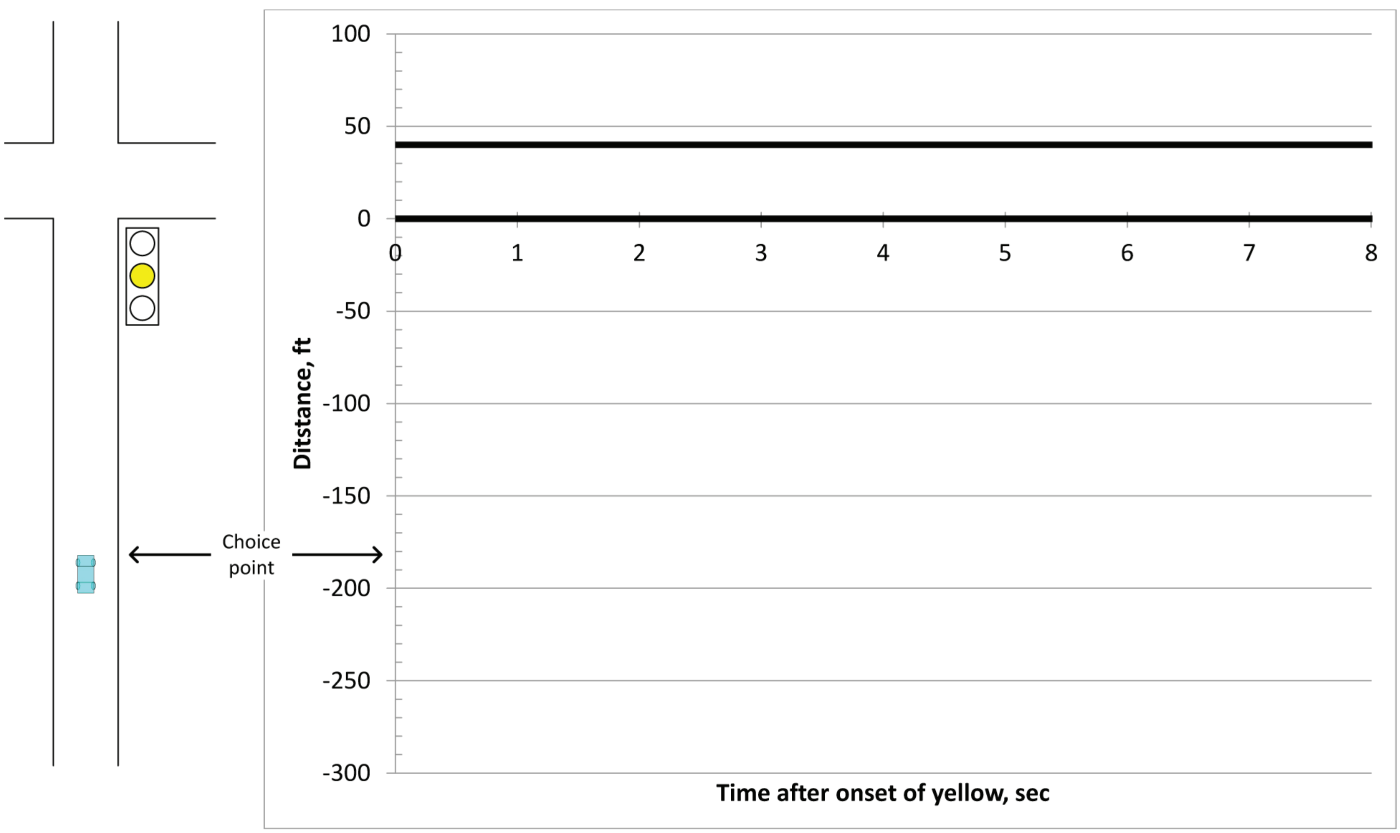

Figure 170. Vehicle position at onset of yellow indication

The time required for a vehicle to stop (t_s) when it is at the choice point and yellow is first displayed is the sum of the perception-reaction time and the braking time, in this case:

$$t_s = \delta + \frac{v}{a} = 1 + \frac{(51.33\ ft / sec)}{10\ ft / sec^2} = 6.2\,sec$$

The trajectory of this vehicle is shown in Figure 171. The trajectory is linear during the one second of the perception-reaction process, and curvilinear during the braking time.

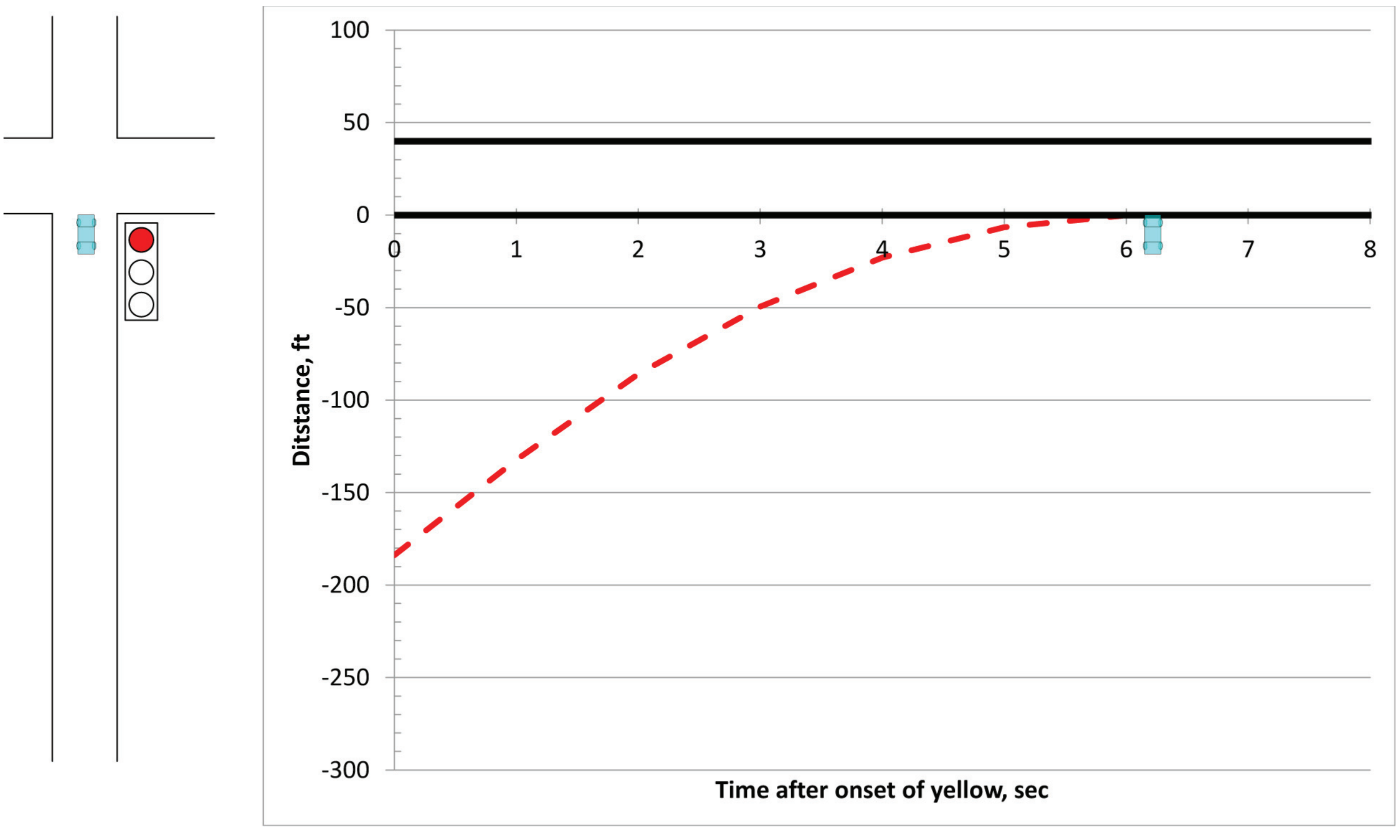

Figure 171. Vehicle trajectory stopping in response to yellow indication

Now let's look at the trajectory of a vehicle starting at this choice point (184 feet upstream of the intersection), and continuing through the intersection until its rear bumper clears the far side of the intersection (as shown in Figure 172). This is the clearance distance (x_c) and is equal to sum of the stopping distance (x_s), the width of the intersection (w), and the length of the vehicle (L). We know from the discussion above that the sum of the yellow and red clearance times must be equal to the time that it takes to travel the clearance distance (x_c). Assuming in this example that the intersection width is 40 feet and the vehicle length is 20 feet, then:

$$Y + RC = \frac{x_s + w + L}{v} = \frac{184\,ft + 40\,ft + 20\,ft}{(51.33\,ft/sec)} = \frac{248\,ft}{51.33\,ft/sec} = 4.7\,sec$$

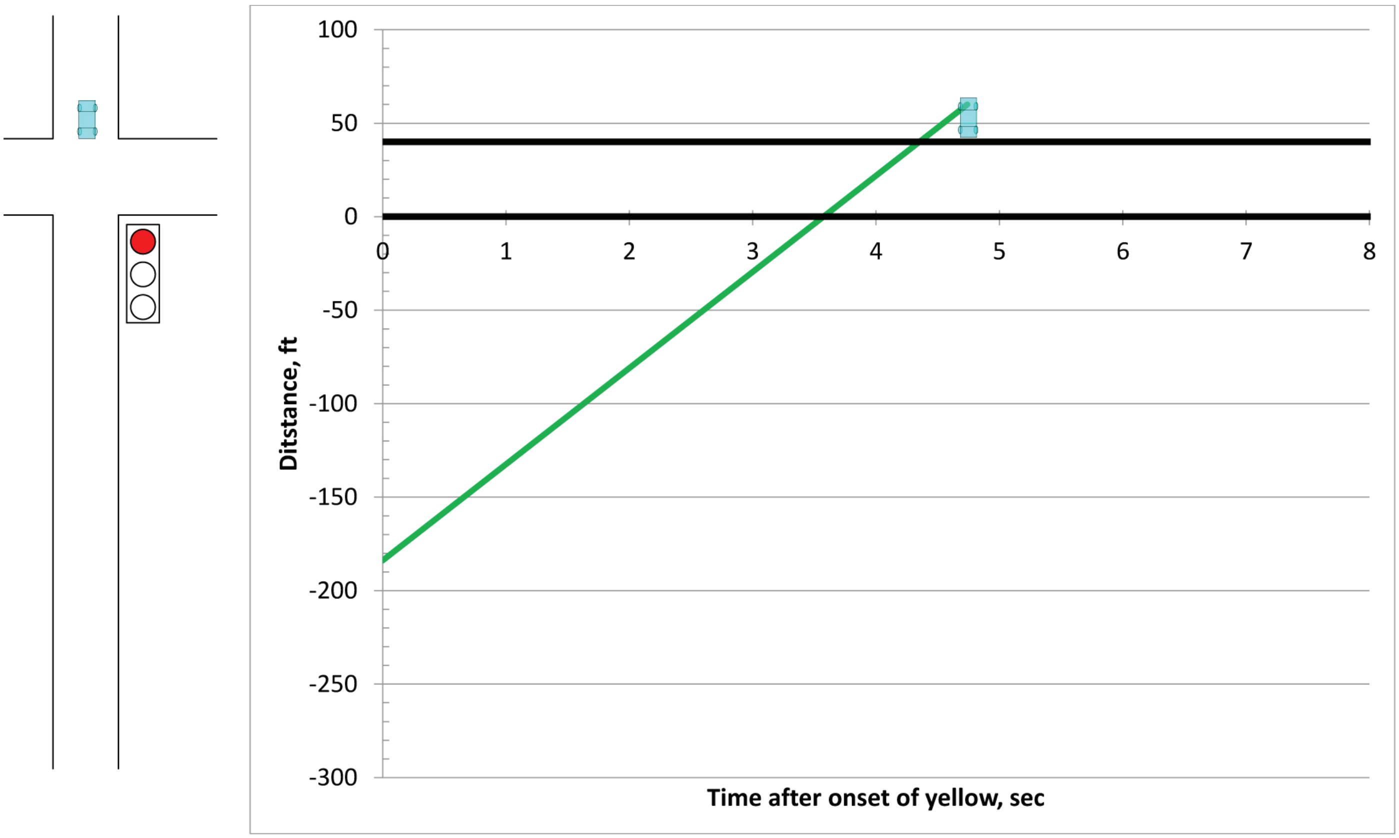

Figure 172. Vehicle trajectory safely passing through the intersection

After reviewing the trajectories from Figure 171 and Figure 172, we can see that it makes sense to allocate the sum of the yellow and red clearance times calculated above (4.7 seconds) into two parts. The yellow time (3.6 seconds in this example) is the travel time from the choice point to the stop bar for a driver that chooses not to stop, a result that puts the vehicle at the entry point to the intersection (at the stop bar) just as the display changes from yellow to red. The red clearance time (1.1 seconds) is the travel time from the entry of this vehicle into the intersection until its rear bumper clears the far side of the intersection.

$$Y = \frac{x_s}{v} = \frac{184\,ft}{(51.33\,ft/sec)} = 3.6\,sec$$

$$RC = \frac{w + L}{v} = \frac{40\,ft + 20\,ft}{(51.33\,ft/sec)} = \frac{60\,ft}{51.33\,ft/sec} = 1.1\,sec$$

Figure 173 shows a compilation of these results. If the sum of the yellow and red clearance times is set to 4.7 seconds, a vehicle (vehicle 3 in the figure) will be able to safely clear the intersection if it is at the choice point (or closer to the stop bar) when yellow is first displayed. And, if a vehicle is at the choice point (or further upstream from the stop bar), it will be able to safely stop when the yellow is displayed (vehicle 2).

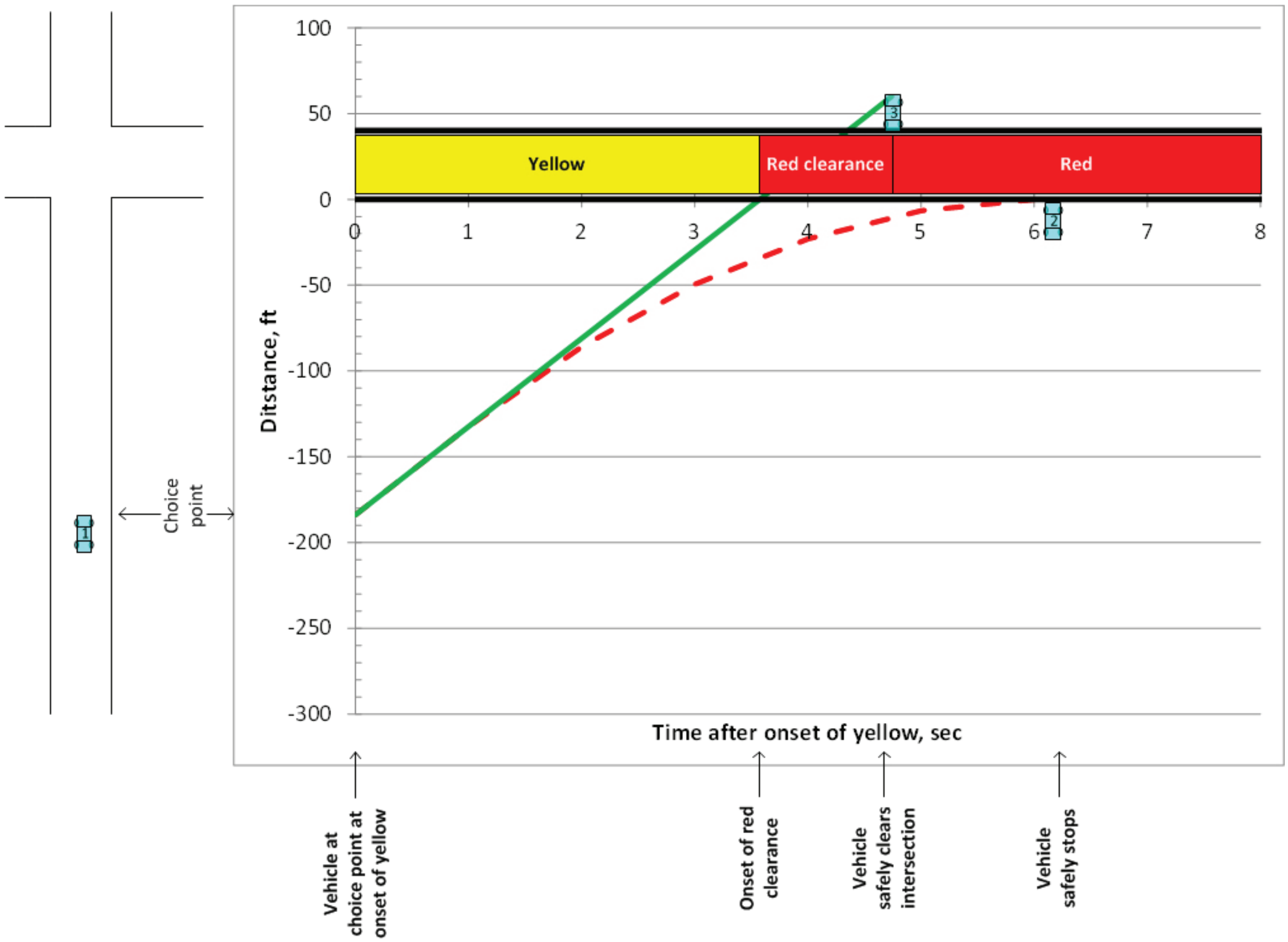

Figure 173. Vehicle trajectories with yellow and red clearance times

But as we noted at the beginning of this reading, there is a big step from the theoretical calculations presented here and the reality of traffic conditions in the field. What if a driver takes longer than one second to perceive and react to the display change from green to yellow? What if the driver's speed is lower (or higher) than the assumed approach speed? How does this model apply to longer vehicles such as trucks or buses? You will have the chance to work through some of these issues as you develop your design for the change and clearance intervals in the activities that follow.

Student Notes:

ACTIVITY
53 What Do You Know About the Change and Clearance Intervals?

ASSESSMENT

Purpose

The purpose of this activity is to help you build your base of understanding of the change and clearance intervals.

Learning Objective

- Describe the purpose and method of calculation of the vehicle change and clearance intervals

Deliverable

- Prepare a completed spreadsheet that includes the following:

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

  Tab 2: Calculations and results for Tasks 1 and 2

  Tab 3: Answers to the Critical Thinking Questions

Critical Thinking Questions

1. In addition to the values assumed in the example in the reading (v = 35 miles per hour, L = 20 feet, a = 10 feet per second per second) for passenger cars, what are the implications in setting the yellow and red clearance times if the traffic stream also includes trucks with L = 58 feet and a = 6.4 feet per second per second? What values for these two timing intervals would you recommend and why?

2. Experience should tell you that there is likely to be a variation in the speeds of vehicles and the perception-reaction times of their drivers arriving at an intersection. Describe and complete a sensitivity analysis that you would perform to test the implications of the variation in perception/reaction times and in actual approach speeds. What impact does this analysis have on your conclusions about the duration of the yellow and red clearance times?

TASK 1

How long does it take a vehicle to stop, given the following information? Prepare a time distance plot showing your results.

- Vehicle length = 15 feet
- Approach speed = 25 miles per hour
- Perception-reaction time = 1 second
- Deceleration rate = 10 feet per second per second

TASK 2

What is your recommendation for the yellow and red clearance times given the conditions in Task 1?

ACTIVITY

54 Drivers Responding to Yellow and Red Indications

DISCOVERY

Purpose

The purpose of this activity is to provide you with the opportunity to learn about the variability of how drivers respond to the yellow indication, including how distance and time from the intersection at the onset of yellow affects the driver's likelihood of stopping (or not).

Learning Objectives

- Describe the different responses of drivers to the yellow indication based on their location upstream of the intersection
- Compare field data with the theoretical basis of stopping

Required Resource

- Data file: A54.xlsx.

Deliverable

- Prepare a spreadsheet that includes the following information:

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

  Tab 2: Raw data for stopped and not-stopped vehicles

  Tab 3: Statistical summaries as required in Task 1

  Tab 4: Plot from Task 2

  Tab 5: Plot as required in Task 3

  Tab 6: Answers to the Critical Thinking Questions

Critical Thinking Questions

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

1. Based on the statistical summaries that you prepared in Task 1, how are the characteristics the same or different for vehicles that stop in response to yellow and those that don't?

2. What conclusions about driver behavior (the decision to stop or not) can you make based on the plots that you prepared in Tasks 2 and 3?

INFORMATION

It is important to learn about the connections (and, sometimes, differences) between theory and how drivers actually behave in the field. In this activity, you will work with a data set from the NGSIM project that includes observations of drivers along Lankershim Blvd. in Los Angeles (described earlier in Activities #3 and #10). This data set contains 303 records of vehicles responding to the onset of the yellow indication; each record includes whether the vehicle stopped or continued through the intersection, and, at the time of yellow onset, (1) how far the vehicle was from the stop bar, (2) its speed, and (3) how long it would take to reach the stop bar at this speed and from this distance. You will see that whether drivers decide to stop or not when the yellow is displayed, even when a set of drivers are the same distance or travel time upstream of the intersection, is a probabilistic outcome. When a driver is closer to the intersection, there is a higher probability that he or she will continue through the intersection without stopping; the farther away the driver is from the intersection, the probability increases that he or she will stop in response to the yellow indication.

TASK 1

Prepare statistical summaries of both the "stopped" and "didn't stop" data sets, including mean values of and frequency distributions for the distance and time from the intersection at the onset of yellow. Prepare a table showing the probabilities of vehicles stopping or not stopping in 50 foot "distance from the stop bar" bins.

TASK 2

Prepare a chart of "time from the stop bar" (x-axis) and "distance from the stop bar" (y-axis) for both data sets (vehicles that stop and those that don't). Include a vertical line on the chart that represents the onset of yellow (at $t = 2.9$ seconds).

TASK 3

Compute the trajectories for two vehicles that respond to the yellow indication at $t = 2.9$ seconds. Assume that one vehicle continues to travel at 25 miles per hour through the intersection. Assume that the second vehicle, after a one second perception-reaction time, begins to decelerate at 10 feet per second per second and comes to a stop at the stop line. Add these two lines to the chart that you prepared in Task 2.

ACTIVITY

55 Vehicle Response to Onset of Yellow

FIELD

Purpose

The purpose of this activity is for you to observe how vehicles in the field respond to a change in signal displays and to describe this behavior.

Learning Objective

- Describe driver behavior at the onset of the yellow interval

Required Resource

- Data file: A54.xlsx

Deliverable

- Prepare a spreadsheet that includes the following information:

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

  Tab 2: Answer to the Critical Thinking Question

  Tab 3: Aerial photo of intersection approach and distance grid

  Tab 4: Field data and calculations from Table 25

  Tab 5: Plot from Task 5

  Tab 6: Probability analysis from Task 5

Critical Thinking Question

1. What conclusions can you make about the differences or similarities between the data that you collected in Activity #54 and this current activity?

Task 1

Select one major street approach on your intersection. Using Google Earth (or another similar mapping tool), select an aerial view of the approach and identify points up to 300 feet upstream of the stop bar for that approach, in 50 foot increments. Print this aerial view with the "50 foot increment" points. An example of this aerial view with increments marked is shown in Figure 174.

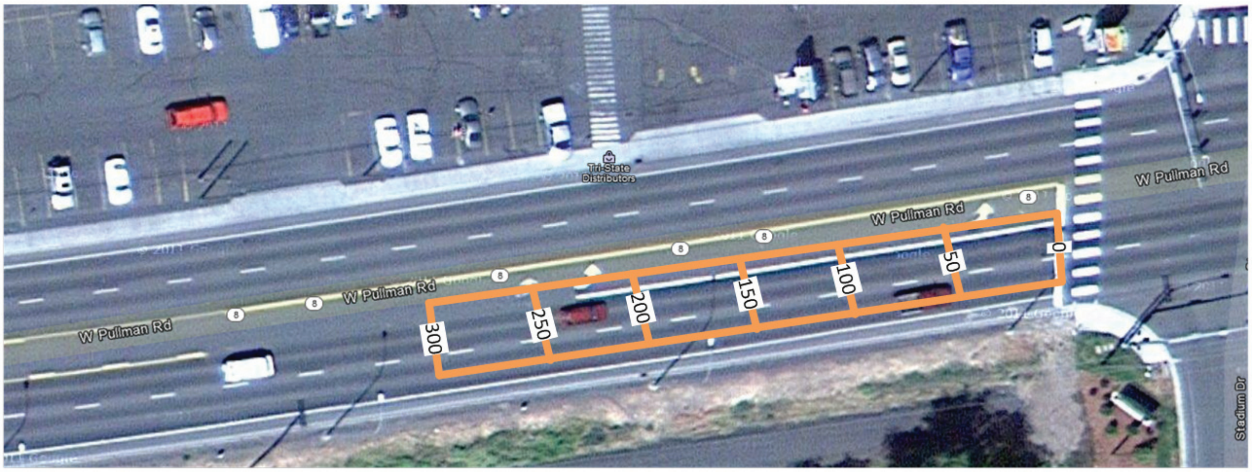

Figure 174. Example intersection approach showing 50 foot intervals upstream of the stop bar

Task 2

Observe the operation of the traffic stream and signal displays on this approach for five minutes, giving particular attention to the "onset of yellow" period when vehicles will be making decisions to stop or not.

Task 3

Using the aerial map that you prepared in Task 1, record the location of 20 vehicles that you observe at the beginning of the yellow interval by placing a number on the map corresponding to the location of each of the vehicles. When you select these 20 vehicles, make sure that there is no vehicle between them and the stop bar at the onset of yellow. Also, record (in Table 25) the response of the driver to the yellow display (either "Go" or "Stop").

Task 4

For each of these vehicles, record the following information in Table 25:

- Your estimate of the distance upstream from the stop bar
- The response of the driver to the yellow display (Go or Stop)
- Your estimate of the travel time from the observed location to the stop bar based on your estimated distance and the posted travel speed

Task 5

Prepare a plot of the "time from the stop bar" (x-axis) and "distance from the stop bar" (y-axis) at the onset of yellow segregating the data according to whether the vehicle stopped or continued through the intersection. Compare this plot with the equivalent plot that you made in Task 2 of Activity #54. Again, compute the probability of "stopping or not stopping", segregating the data into 50 foot intervals.

Table 25. Field observations and calculations

Vehicle number	Distance of vehicle from stop bar at onset of yellow	Response of driver to the yellow display (Go/Stop)	Estimated time for vehicle to travel to stop bar at onset of yellow
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Student Notes:

ACTIVITY

56 Determining Vehicle Change and Clearance Intervals

DESIGN

Purpose

The purpose of this activity is to give you the opportunity to determine the vehicle change and clearance intervals for your design.

Learning Objectives

- Determine the vehicle change and clearance intervals
- Describe how the variability of vehicle approach speeds affects the determination of the vehicle change and clearance intervals

Required Resource

- VISSIM input file from Activity #50

Deliverable

- Prepare a report using an Excel spreadsheet that includes your simulation data, your analysis, and your answers to the Critical Thinking Questions.

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

  Tab 2: Data from FZP file

  Tab 3: Parsed data for selected approach

  Tab 4: Chart showing speed vs. distance upstream from the stop bar

  Tab 5: Calculations for the yellow and red clearance times

  Tab 6: Table of measures of effectiveness for each approach and for the intersection

  Tab 7: Answers to Critical Thinking Questions

Critical Thinking Questions

1. What effect did the range in speeds that you observed for vehicles approaching the intersection have on the final result of the values of the yellow and red clearance times? Discuss your answer.

2. What effect would trucks have on your final result?

3. What are the implications of your work in Activities #54 and #55 on your final selection of the yellow and red clearance times? Discuss your answer.

INFORMATION

The reading in Activity #52 described the model used to calculate the yellow time and the red clearance time based on the width of the intersection, the length of the vehicle, and the speed of the vehicle as it approached the intersection.

$$Y = \delta + \frac{v}{2a} \qquad RC = \frac{w+L}{v}$$

In this activity you will select your yellow and red clearance times based on this model but recognizing the variability of the speeds of vehicles approaching the intersection.

TASK 1

Make a copy of the folder that includes your VISSIM files from Activity #50. Name this new folder "a56". Use this VISSIM file as the basis for the analysis and design of your change and clearance intervals. Select one of the approaches on the major street of this intersection for this activity, preferably the longest approach.

Task 2

Start VISSIM and open your simulation file. Set the simulation resolution and speed:

- Select "Simulation," then "Parameters"
- Set the "Simulation resolution" to 1 time step per second
- Set the "Simulation speed" to maximum speed
- Set the "Period" to 900 seconds

Task 3

Select "Evaluation," then "Files," then "Vehicle record" to create the file to store the vehicle trajectory data.

- From "Configuration", select vehicle number, simulation time, link number, "x" world coordinates (or "y" if your major street is oriented north-south), and speed (mph)
- From "Filter," select 0 to 900 seconds
- These data will be written to the output file with the extension "fzp"

Task 4

Complete the simulation run.

Task 5

Open and parse the FZP file into tab 2 of an Excel worksheet. Copy the parsed data to tab 3 of your worksheet. In tab 3, keep only the data for the link that corresponds to the approach that you selected in Task 1.

Task 6

Identify the relevant world coordinate location of the stop bar for your selected approach. Using the data from tab 5 (for your selected approach), prepare a plot of vehicle speed (y-axis) and the relevant world coordinate (x-axis) with the x-axis showing the range from the stop bar to 300 feet upstream of the stop bar. Visually identify those vehicles that continue through the intersection without stopping (noted by their relatively horizontal trajectory on your speed-distance plot. Based on this visual inspection, select an approach speed that you believe represents the 85th percentile of speeds for vehicles that continue through the intersection without stopping.

Task 7

Compute the yellow and red clearance times based on the speed that you determined in Task 6, the average vehicle length, and the width of your intersection.

Task 8

Using your final design values for yellow and red clearance times, run VISSIM to produce estimates of delay and queue length. Prepare a table of these measures of effectiveness for each approach and for the intersection.

Student Notes:

ACTIVITY

57 Yellow and Red Clearance Intervals

IN PRACTICE

Purpose

The purpose of this activity is to give you the opportunity to learn how the yellow and red clearance intervals are set in practice.

Learning Objective

- Describe the factors considered when the yellow and red clearance intervals are set by practicing traffic engineers

Required Resource

- *Traffic Signal Timing Manual*

Deliverables

Prepare a document that includes

- Answers to the Critical Thinking Question
- Completed Concept Map

Link to Practice

Read the section of the *Traffic Signal Timing Manual* relating to Vehicular Change and Clearance Intervals as assigned by your instructor.

The *Traffic Signal Timing Manual* notes that:

> "The intent of the vehicle phase change and clearance intervals is to provide a safe transition between two conflicting phases. It consists of a yellow change interval and, optionally, a red clearance interval. The intent of the yellow change interval is to warn drivers of the impending change in right-of-way assignment. The red clearance interval is used when there is some benefit to providing additional time before conflicting movements receive a green indication."

The yellow display warns the drivers that the right-of-way is about to change, while the red clearance display allows drivers to safely clear the intersection.

Critical Thinking Questions

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

1. Consider the method that you used in Activity #56 to set the yellow and red clearance intervals, as well as your results. How do they compare and contrast with the methods and recommendations described in the *Traffic Signal Timing Manual*?

2. How does your own driving experience compare with the material from the *Traffic Signal Timing Manual* relating to the yellow and red clearance intervals?

IN MY PRACTICE...

by Tom Urbanik

Clearance interval practice differs significantly among agencies. The result produced by the model that you read about in Activity #52, while being based on the laws of physics, is considered to be larger than necessary by some practitioners, resulting in a wide variability of clearance interval times used in practice. One issue is the interpretation of the meaning of yellow which is defined differently based on state laws. The intent is that yellow is notice to stop unless it is not possible. However, some drivers, due to many reasons, have over the years tended to use more and more of the yellow to avoid stopping. Adding to this the practical definition of violating the red as red light running, results in changed behavior of some to see the yellow as the amount of time to enter the intersection. Furthermore, the introduction of photo enforcement further complicates the issues by also defining red light running as entering on red. The end result has been longer clearance times and widespread use of red clearance time to account for drivers trying to maximize the use of the yellow to enter the intersection.

So, in practice, local clearance interval timings are often driven by historical local practices. As a signal timing engineer you need to resolve local practice against other agency practices in your area. Desirably, signal timing should be consistent in a local area as drivers in one jurisdiction may develop habits based on their agency's practice. This could become an issue if another local jurisdiction has different practices. Finally, the addition of red light running cameras may put pressure on adjusting local practices.

Concept Map

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

change interval	perception-reaction time (δ)	v	w
clearance interval	stopping distance (x_s)	a	L

Student Notes: