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.

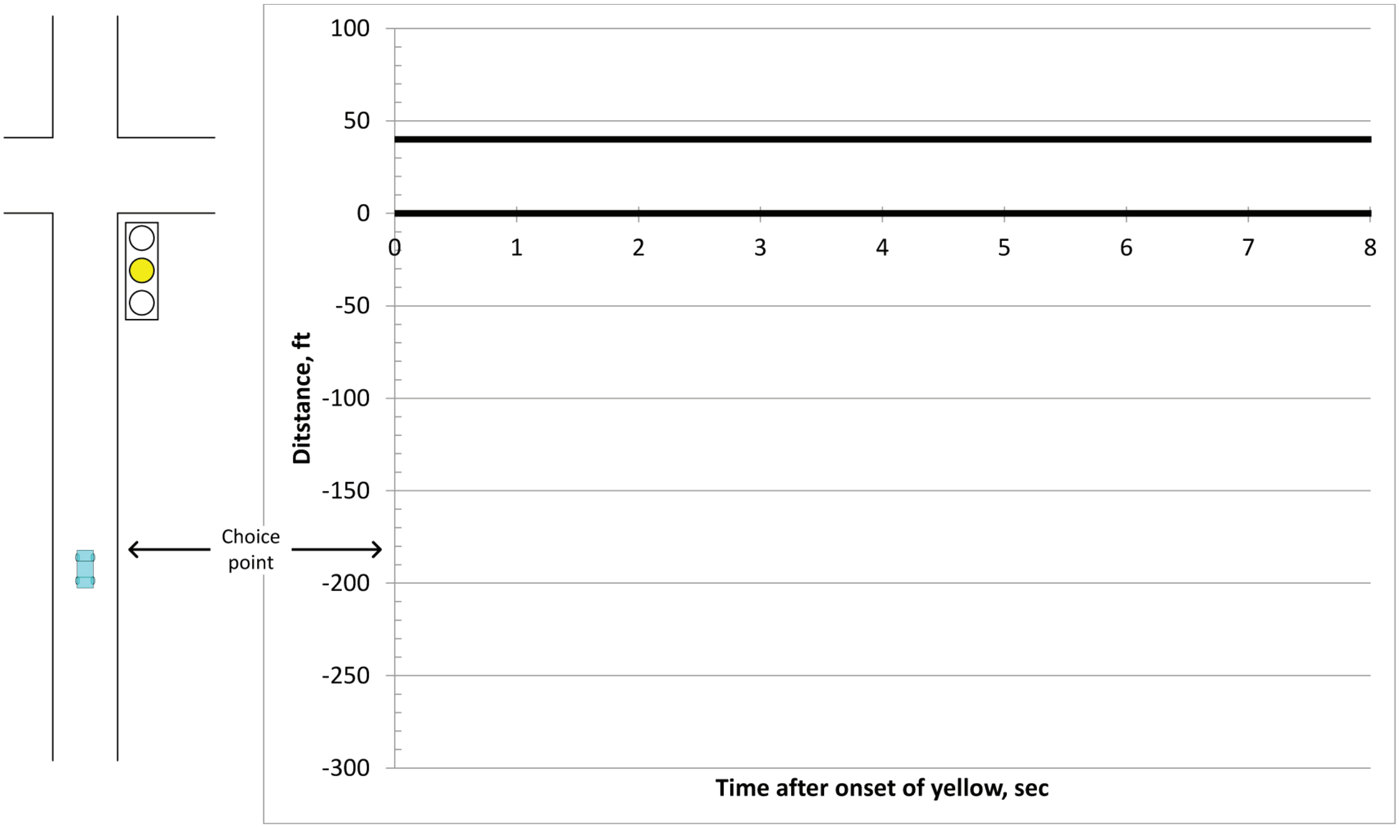

Figure 170. Vehicle position at onset of yellow indication

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.

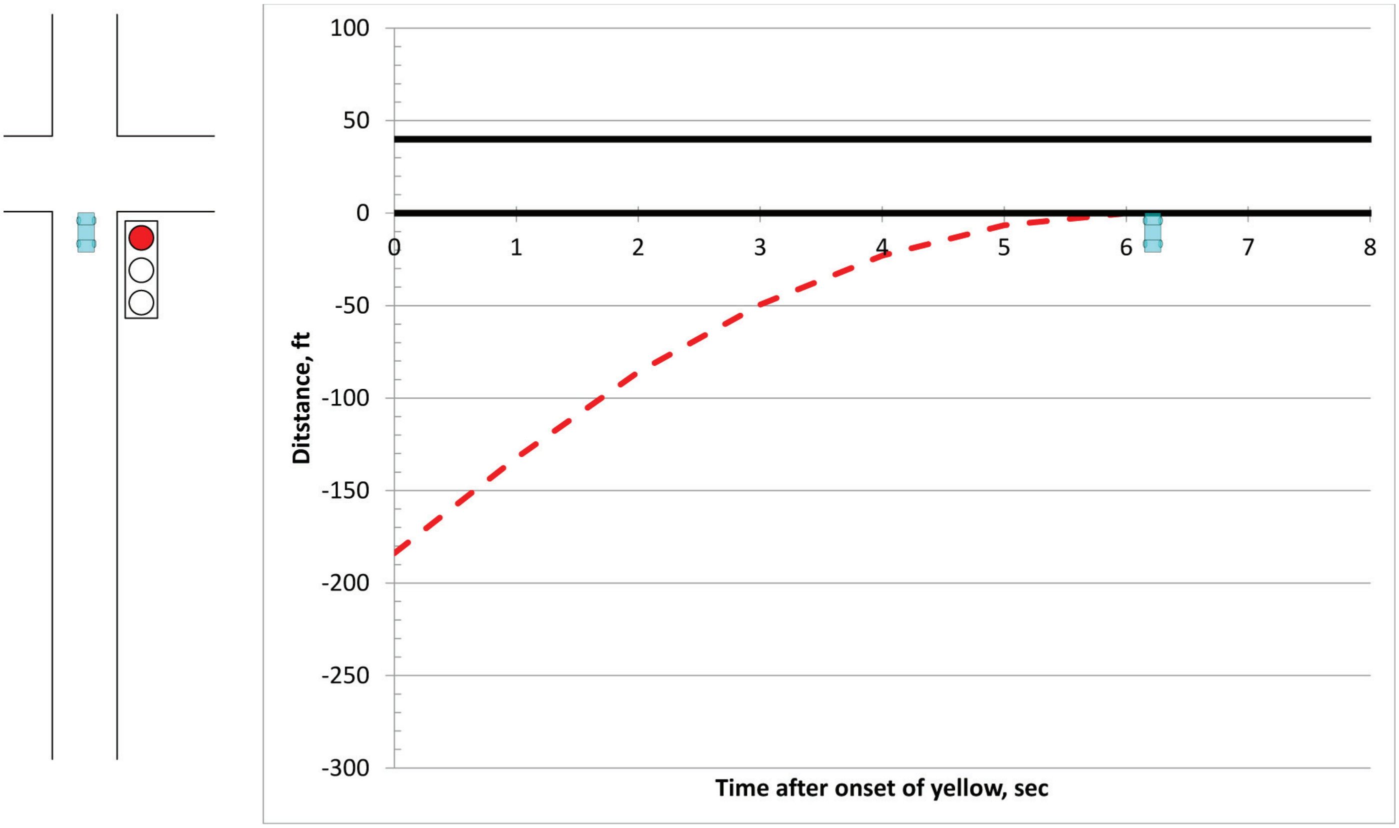

Figure 171. Vehicle trajectory stopping in response to yellow indication

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:

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

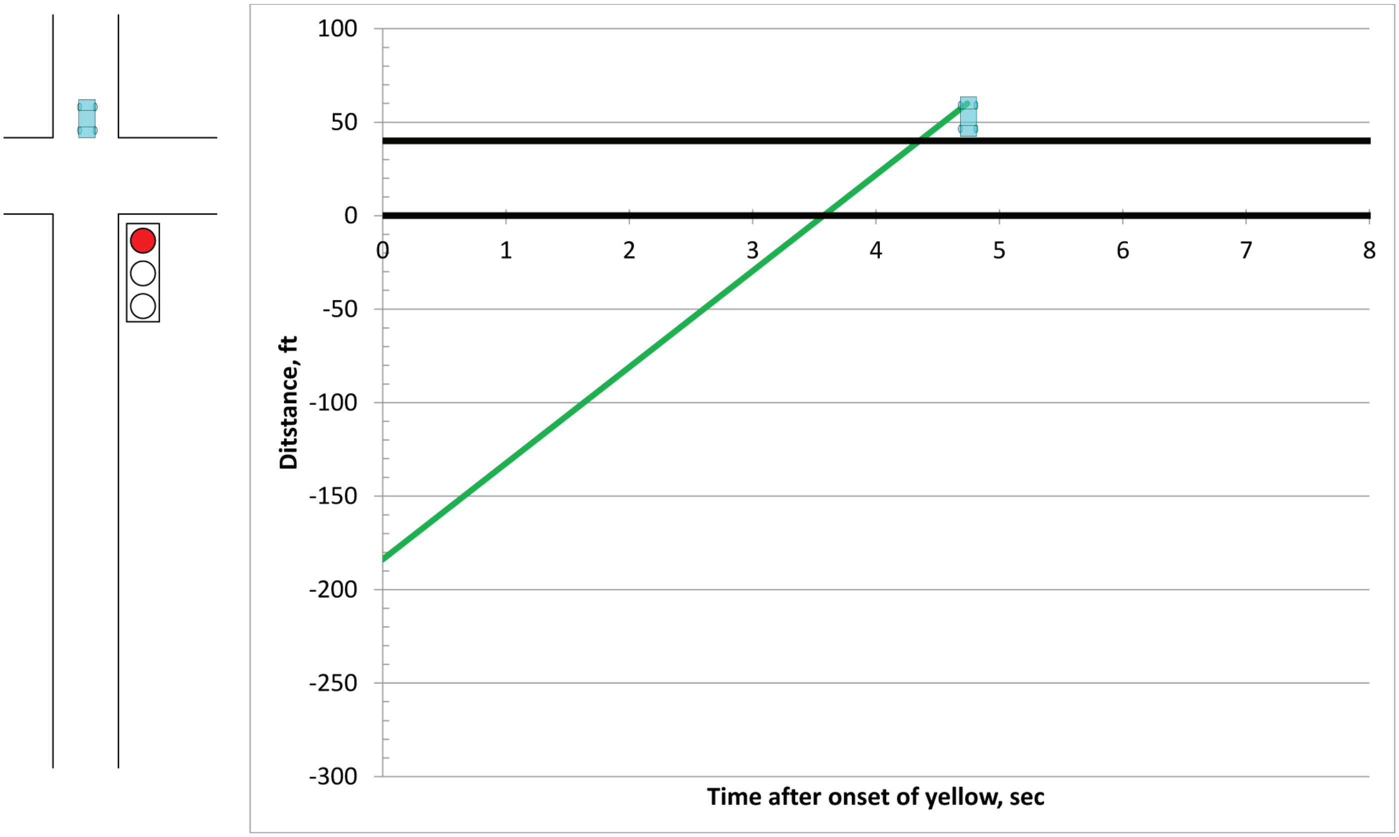

Figure 172. Vehicle trajectory safely passing through the intersection

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).

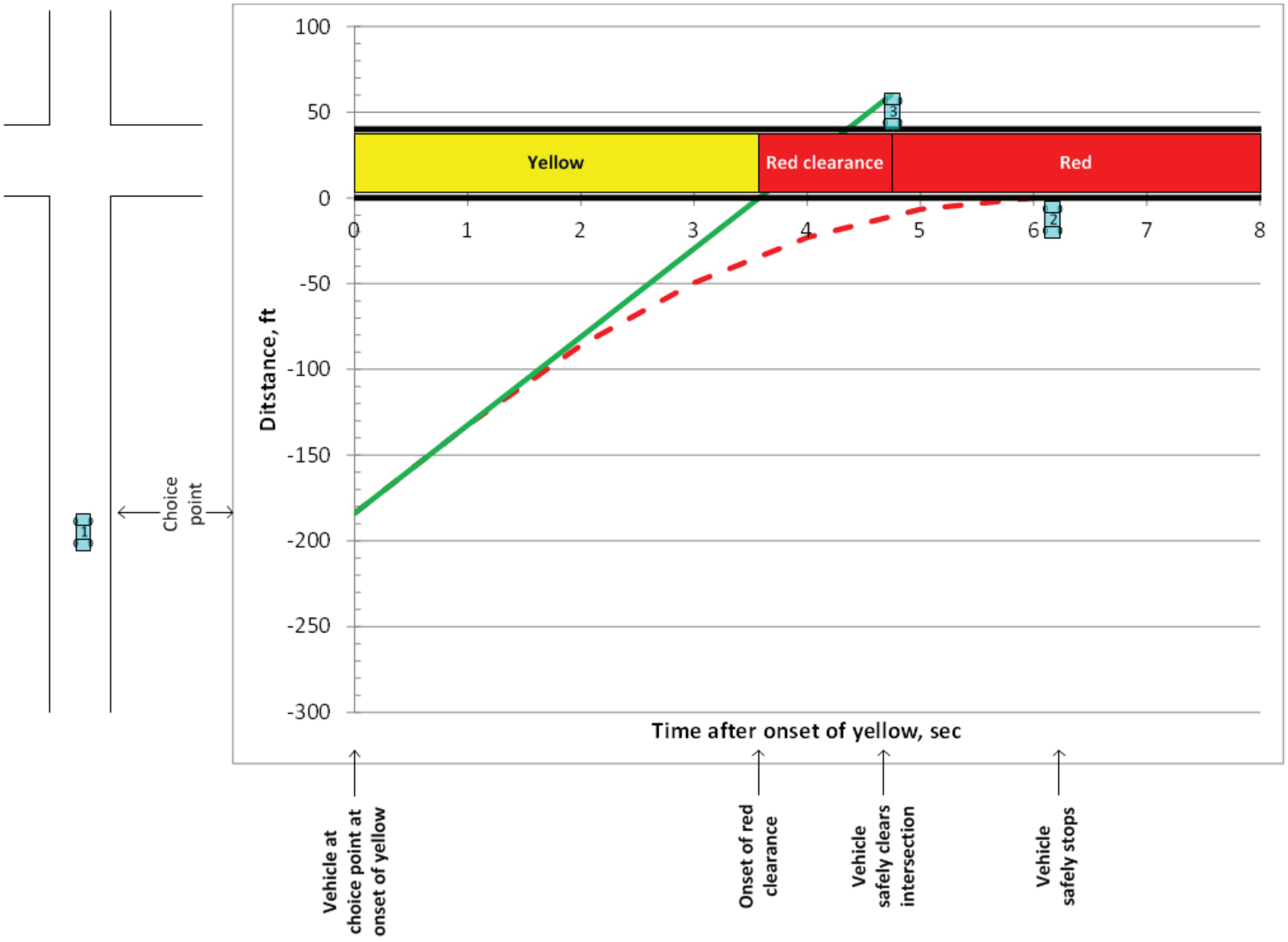

Figure 173. Vehicle trajectories with yellow and red clearance times

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: