On a downhill, however, gravity acts to increase the speed. Equation 6.17 is used.

\[ D = 2.5 + 1.47V + \frac{(50 \times 1.47)^2}{2 	imes 32.2 \times (0.30 - 0.03)} = 184 + 311 = 495 \text{ ft} \]

The difference when gravity is acting with you means that it takes 495 feet — 464 feet = 31 feet longer to stop. Table 6.13 shows how downhill grades up to 5 percent affect stopping distance.

<table>
<thead>
<tr>
<th>TABLE 6.13 Braking Distance for Downhill Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V ) (mph)</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>55</td>
</tr>
<tr>
<td>60</td>
</tr>
</tbody>
</table>

Example 6.13

The driving manual for the Department of Motor Vehicles in the State of Alaska states the braking distance for several speeds as indicated in Table 6.14. For the numbers given, what values have been assumed for driver response time and the coefficient of friction?

**Solution to Example 6.13**

The answers are given in the shaded portion of Table 6.14. For example, the calculations for \( V = 50 \) mph are

\[ t_r = \frac{\text{dist}}{\text{speed}} = \frac{55}{74} = 0.74 \text{ sec} \]

\[ f = \frac{V^2}{2 \times g \times \text{dist}} = \frac{74^2}{2 \times 32.2 \times 160} = 0.53 \]

**TABLE 6.14 Braking Distances**

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Speed (fps)</th>
<th>Thinking Distance</th>
<th>Braking Distance</th>
<th>Total Distance</th>
<th>Response Time</th>
<th>Friction Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>29</td>
<td>22</td>
<td>25</td>
<td>47</td>
<td>0.76</td>
<td>0.52</td>
</tr>
<tr>
<td>30</td>
<td>44</td>
<td>33</td>
<td>57</td>
<td>96</td>
<td>0.72</td>
<td>0.53</td>
</tr>
<tr>
<td>40</td>
<td>59</td>
<td>44</td>
<td>102</td>
<td>146</td>
<td>0.75</td>
<td>0.58</td>
</tr>
<tr>
<td>50</td>
<td>74</td>
<td>55</td>
<td>140</td>
<td>213</td>
<td>0.74</td>
<td>0.59</td>
</tr>
<tr>
<td>60</td>
<td>88</td>
<td>66</td>
<td>227</td>
<td>194</td>
<td>0.75</td>
<td>0.59</td>
</tr>
<tr>
<td>70</td>
<td>103</td>
<td>77</td>
<td>310</td>
<td>387</td>
<td>0.75</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**Example 6.14**

You are asked to investigate a crash in which a teenager driver hit a barricade traveling at about 25 mph. Your observations at the scene indicate that the road is posted with a 55 mph speed limit. The road is straight and level. The first sign warning of the barricade was located 1000 feet before the barricade, and the second sign was 600 feet before the barricade. The skid marks from the car begin 300 feet before the barricade. You are asked to testify to a jury about your findings. What will you tell them about braking and response time? According to the Weather Service, the road was wet but visibility was good.

**Solution to Example 6.14**

The car traveled 700 feet from the first warning sign to the initiation of the skid marks. If the teenager was traveling at the speed limit, her response time would have been 700/10(35'\times 1.47')/60 = 8.66 sec.

If the velocity at impact was 25 mph, the initial velocity \( v_i \) before 300 feet of skidding was

\[ v_i = \sqrt{v_f^2 - 2g \Delta s_i} = \sqrt{(25^2 \times 1.47^2)} + 2(32.2)(0.30)(300) = 84.5 \text{ fps} = 57.5 \text{ mph}. \]

From the data, it would appear that the young driver did not respond to the first sign and reacted slowly to the second sign, with a response time of about \( t_r = \frac{d_i}{v} = \frac{300}{57.5 \times 1.47} = 3.55 \text{ seconds}. \) Moreover, she was driving above the speed limit.

**6.4 TRAFFIC CONTROL DEVICES**

Among his many duties, the Myonica County Highway Engineer must ensure that roadway signs and markings in the County are properly installed and maintained (Figure 6.22). If a crash occurs where someone thinks that a sign should have been installed, the county may be sued. If the engineer installs signs wherever there is even the slightest justification for them, the County Highway Department will probably not have enough left in its annual budget to maintain them. If any sign is stolen, vandalized, or allowed to become unreadable, and a crash occurs, the county may be sued. In theory, the rules for installing traffic control devices (TCDs) is quite simple. In practice, placing and maintaining TCDs requires diligence and good management practices—or else the public safety may be compromised—and the county may get sued.
6.4 Traffic Control Devices

6.4.1 TCDs Needed for Safety

Traffic control devices (TCDs)—otherwise known as roadway signs and markings—are used to regulate, warn, and guide drivers as they operate their vehicles. Although roadway signs and markings are familiar to everyone who uses the roads, there are well-established procedures to determine where certain TCDs are needed and how they should be installed. This section introduces those procedures and the references on which they are based. In doing so, numerous examples (good and bad) are presented. Some of the material in this section is based on a slide show used in a Training Course on Placement of Traffic Signs and Markings, produced by the Institute of Transportation Engineers (1974). Other major sources are the Manual of Uniform Traffic Control Devices (FHWA, 2003) and Richard C. Moer’s excellent Web site (1998).

6.4.2 Rules Governing Traffic Control Devices

A traffic control device (TCD) is a sign or pavement marking that is used to regulate, warn, or guide drivers as they operate their vehicles. An effective TCD meets five basic requirements. The sign must:

1. Be needed. The transportation engineer must identify the need and select the most appropriate TCD. This section covers warrant analysis, which helps an analyst decide when a regulatory TCD is justified. Too often, the demands of citizen groups or politicians are so great that TCDs are installed where they are not warranted.

THINK ABOUT IT:

Have you ever seen a stop sign that is clearly unnecessary? What made you think it was unnecessary?

2. Command attention. To be effective, the sign or marking must be seen, and seen without distracting the driver from his/her driving task. A sign blocked by other vehicles or foliage (Figure 6.23) will not get the desired response.

3. Convey a clear, simple message. Using a standard combination of shape, color, and other graphic design elements, the TCD should be immediately recognizable to the driver, and its intended message should be unambiguous.

4. Command respect. Signs and markings that are poorly designed and fabricated (Figure 6.24) will not have the credibility of properly installed TCDs. Likewise, unwarranted TCDs can instill a greater degree of disregard for similar TCDs among some drivers. A common example is stop signs used in residential neighborhoods in an attempt to control speeds.

5. Be placed to get the proper response from the driver. Sign location is important. So is the placement of pavement markings. The advance warning sign must be placed far enough ahead of the potential hazard to allow the driver time to respond. The solid line that denotes a no-passing zone must not start too early or too late with respect to the actual section of highway that has inadequate passing sight distance.

FIGURE 6.22
Traffic signs.

FIGURE 6.23
Speed limit sign obscured by branches. Source ITE, 1974.
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FIGURE 6.23
Speed limit sign obscured by branches.
Source: ITE, 1974.
6.3 Signs as TCDs

Traffic control devices can be placed in three major categories, namely, regulatory, warning, and guide signs. A sample of signs from each category, organized by the chapters in which they appear in the MUTCD, are shown in Figure 6.25.

![Traffic signs](image)

**FIGURE 6.25**
Traffic signs [source: MUTCD (FHWA, 2000)].

6.4.4 Roadway Markings as TCDs

Although there are several exceptions, in general, traffic signs can also be categorized by shape and color:
- Regulatory: rectangular, black on white
- Warning: diamond, black on yellow
- School zone: Schoolhouse shape, black on yellow
- Work zone: Diamond, black on orange
- Recreational and cultural interest: rectangular, white on brown

**THINK ABOUT IT**

Besides the signs shown above, can you think of any other common signs that do not follow the standard shape or color for their category?

6.4 Traffic Control Devices

In addition to the signs categorized above, the other kind of TCDs are roadway markings. They consist of pavement markings, delineators, and object markings.

**Pavement Markings.** Pavement markings are used like roadway signs to warn, regulate, and inform motorists. Knowing what various pavement markings mean is important to the motorist, because they have the same force of law as signs. Dashed lines usually indicate that the driver has permission to pass, if it is safe to do so. Solid lines always indicate that maneuvering across them may bring risk to the driver. Figure 6.26 shows several common pavement markings for two-lane and multilane roadways.

**Yellow markings**
- Yellow markings, such as centerlines, separate traffic flow going in opposite directions. They always occur in pairs.
- Dashed yellow lines on the motorist's side indicate where passing is permitted on two-lane, two-way roads.

![Pavement markings](image)

**FIGURE 6.26**
6.4.3 Signs as TCDs

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- Dashed yellow lines on the motorist's side indicate where passing is permitted on two-lane, two-way roads.

**Examples of centerline markings on highways. Source: Florida Department of Highway Safety and Motor Vehicles, 2000.**

(a) Double Solid Yellow  
(b) Broken Yellow  
(c) Broken White  
(d) Solid and Broken
- Solid yellow lines indicate where passing is not permitted, although turning into a driveway across them is allowed where not prohibited.
- A single yellow line indicates the left edge of a divided roadway.

**White lines**

- White markings, such as lane lines, separate traffic going in the same direction on multilane or one-way roads.
- Dashed lines separate lanes of travel where changing lanes is not restricted and where the lane use is not restricted.
- Solid white lines are restrictive.
  1. They tell the driver to remain within a lane and do not move from it until it is safe to do so.
  2. They indicate the edges of lanes specified for certain uses where changing lanes is to be discouraged.
  3. They also mark the outside edge of the pavement or to indicate the edge of a shoulder. (See Figure 6.11.)

**Transverse pavement markings**

- Include crosswalks, stop lines, turn movement restrictions, and parking spaces.
- Whenever possible, turn movement restrictions marked on the pavement should be supplemented with signs over the respective lanes. (See Figure 6.10.)

**Delineators.** Delineators are used to guide drivers through turns, especially at night or at times of poor visibility. The reflecting head of a delineator (Figure 6.27(a)) should be 4 feet above the roadway, between 2 and 6 feet from the outer edge of the shoulder. In Figure 6.27(b), chevrons are used effectively to guide drivers through a right-hand curve on a one-way urban arterial.

**FIGURE 6.27**
Delineator: (a) New delineators along dangerous curve and (b) Good use of chevrons as delineators. Photos by Jan D. Fricker.

Object markers are used to mark obstructions within or adjacent to the roadway. The three types of object markers are designated as OM-1, OM-2, and OM-3, as illustrated in Figure 6.28. The type 3 object marker features diagonal yellow or white stripes on a black background. The stripes should slope downward and toward the vehicle being warned. Thus, as shown in Figure 6.28(c), an OM-3 on the left side of the roadway should have its stripes sloping from "northwest" to "southeast." The stripes on an OM-3R (R = right) would slope from "northeast" to "southwest," as shown in Figure 6.28(c).

**FIGURE 6.28**
Object markers: (a) OM-1, (b) OM-2, and (c) OM-3 and OM-3R. Source photos by Jan D. Fricker.
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FIGURE 6.28
Object markers. (a) OM-1, (b) OM-2, and (c) OM-3L and OM-3R. Source Photos by Jan D. Fricke.
6.4.5 Installation of Signs

The placement of traffic control devices is not an advanced engineering topic, but there can be serious consequences for incorrect installation. The Manual for Uniform Traffic Control Devices (MUTCD) (FHWA, 2003) is a valuable source of guidance, but some judgment may still be required. Figure 6.29 shows some examples. Figure 6.29(a) shows a shopping center exit that was "controlled" by a stop sign that not only was on a very short post but also it was placed behind the corner of a fence. In rural areas, the bottom of the sign should be at least 5 feet above the level of the pavement. In areas where cars are parked, the standard height becomes 7 feet. Although this sign was located on private property, for safety and liability reasons, the MUTCD requirements should be followed. After several years, the sign was replaced and the fence was removed, as shown in Figure 6.29(b).

FIGURE 6.29
Examples of obstructed sign. (a) Stop sign on short post is obstructed by fence and shrubs. (b) Taller post and removal of obstructions make stop sign visible at same site. Source: Photos Jan D. Fricker.

Signs that are "cute" as in Figure 6.30(a) should be used sparingly, if at all, because of their tendency to distract rather than inform. On the other hand, just because a sign is not in the MUTCD, does not mean that a minor variation on a standard sign cannot be used effectively as shown in Figure 6.30(b).

THINK ABOUT IT
Based on the "message" conveyed by the sign in Figure 6.30(b), what would you expect to see as you continue to drive along the road ahead?

Because of the many languages that may be involved in traveling ever modest distances in Europe, road signs there have relied more heavily on graphic representations than written text. Some of the European designs are being adopted by the

MUTCD. Examples of sign designs that originated in Europe but are now used throughout the United States are the DO NOT ENTER signs in Figure 6.30(c). Instead of words, a "slash" is used to indicate prohibited behavior, as shown by the second sign in Figure 6.30(c).

6.4.6 Stop Signs for Speed Control

When citizens get concerned about what they consider excessive speeds in their neighborhoods, they often call on their city engineer or elected officials to install stop signs at intersection approaches where they do not already exist. However, numerous studies have found that not only is such a strategy ineffective in reducing speeds, it also lessens the respect that motorists have for other stop signs in the vicinity. When Mytaca's City Engineer was faced with neighbors requesting stop signs for speed control, he mentioned it to the county engineer. Example 6.16 describes the subsequent study.

(Note: Some students may not have been exposed to previous courses to the hypothesis-testing procedure that is essential to this example's solution. In that case, the student will have to trust the method shown and concentrate on the interpretation of the results.)

Example 6.15

When the county engineer's son Darren was in sixth grade, he had to choose a science project. Even before his father mentioned it, Darren had heard his friends' parents complain about the speed of cars in their neighborhood, known as Archer. (See Figures 6.31 and 6.32.) Those parents wanted the city traffic engineer to install stop signs as a speed control measure. In response, the city traffic engineer said that it would be an improper use of stop signs and
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Evergreen and both directions on Dodge would give him a good basis for checking out the city traffic engineer’s theories. Then, Darren and his father went to those midblock locations in the Archer neighborhood, hooked the radar gun onto a side window of the family station wagon, and recorded vehicle speeds.

**THINK ABOUT IT**

Why did Darren choose the locations and directions he did? Would you have done anything differently?

A. Because there isn’t much traffic on the Archer neighborhood streets, it may take a long time to get an adequate sample. Darren wanted to determine the minimum sample size to (a) avoid spending any more time than necessary collecting data while (b) allowing the need to return to any sites in the study area. How many vehicles should Darren record at each site? Hint: Recall how the sample size for the speed study in Example 2.8 was determined. From previous speed studies on urban two-lane streets in Mythica, standard deviation \( \sigma = 4.8 \) mph.

B. The speeds Darren recorded are summarized in Table 6.15. Did Darren collect a large enough sample?

C. Darren’s dad explained hypothesis testing to him. Darren decided that the generic hypothesis should be: Vehicle speeds at midblock are the same, whether the block ends with a stop sign or not. After all, this seemed to be the city traffic engineer’s position. Did the data that Darren collected support this hypothesis?

**Solution to Example 6.15**

A. If the mean midblock speed is desired, Equation 2.4 applies. The standard deviation \( \sigma = 1.96 \) value is chosen from Table 2.6. The choice of \( E \) is less obvious. Knowing that the radar gun has a digital readout that only registers integer speeds, and guarding against the case in which mean speeds at different sites are not significantly different, a small value of \( E \) was chosen: \( E = 1.0 \) mph. Equation 2.4 becomes

\[
N = \frac{S^2}{E^2} = \frac{4.8^2}{1.0^2} = (9.408)^2 = 89 \text{ speeds}
\]

B. Table 6.15 shows that Darren was able to record only 39 midblock speeds on EB Dodge between Garfield and Allen before he and his dad had to go home. This was far fewer than the 89 speeds Darren wanted to collect. However, when Darren calculated the standard deviation for his sample, he found that \( S = 3.837 \). If he had used \( S = 3.837 \) in part A, he would have calculated \( N = 57 \). What if he relaxed the \( E = 1.0 \) requirement to say, \( E = 1.25 \) mph? Then \( N = 37 \). The good things about \( E = 1.25 \) are that it is only 0.25 mph higher than the \( E = 1.0 \) value originally chosen and it makes another trip to the neighborhood unnecessary. A problem, however, is that the mean speeds shown in Table 6.15 are about 0.9 mph apart. It is probably unwise to let your “precision parameter” be larger than the differences in the variables you are trying to compare. For a paid consultant’s job, more data might have to be collected. For a sixth grade science project, let us concentrate on the methodology and learn from the experience.

Furthermore, she said that it would not slow vehicles down. Darren wanted to verify or challenge the city traffic engineer’s last statement. He borrowed the county’s old radar detector—it was heavy, but it still was accurate—and asked his father help him design the data collection activity. After discussing it with his father, Darren decided that getting speeds for EB traffic on
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\[
N = \frac{S^2 \times E^2}{\epsilon^2} = \frac{(4.8)^2 \times 1.0^2}{1.0^2} = (9.408)^2 = 89 \text{ speeds}
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C. The first hypothesis Darren wants to test is \( \text{WB and EB mean speeds on Dodge are equal} \). This is of interest because, for the observed block, EB Dodge ends at a stop sign at Garfield, whereas WB Dodge at Allen has no stop sign. In Table 6.15, "WB" is stop sign and "EB" = uncontrolled intersection. Thus, the null hypothesis is that the mean speeds for WB and EB are equal. You may have to refer to the notes for the textbook from your probability and statistics course on two-sided tests. [The reference used here is *Hypothesis Testing for Comparing Two Means* in Lapin (1990), Section 12.3.] If you haven’t yet completed such a course, you will have to trust the method about to be demonstrated. The steps in the method are:

1. **Because the number of observations in each direction is greater than 30, compute the test statistic**:

   \[
   z = \frac{X_{\text{WB}} - X_{\text{EB}}}{\sqrt{\frac{\sigma^2_{\text{WB}}}{n_{\text{WB}}} + \frac{\sigma^2_{\text{EB}}}{n_{\text{EB}}}}} = \frac{23.410 - 22.559}{\sqrt{\frac{(3.837)^2}{39} + \frac{(2.841)^2}{34}}} = 1.986
   \]

   (6.18)

   where \( \bar{X} \) is the mean value of the speeds in the observed sample, \( \sigma^2 \) is the variance of the sample speeds, and \( n \) is the number of speeds observed in the sample.

2. **For a two-sided test at a 95 percent confidence level, the critical value of \( z \) is \( \pm 1.96 \).** If the test statistic falls outside the range \([-1.96, 1.96]\), the hypothesis must be rejected. Here, \( z = 1.986 \), which lies within the specified range, so the hypothesis \( H_0: \mu_{\text{WB}} = \mu_{\text{EB}} \) cannot be rejected.

As a result of this analysis, Darren can say that there is no statistically significant difference between the 23.410 mph average speed on EB Dodge (heading toward a stop sign) and the 22.559 mph average speed on WB Dodge (with no end-of-block stop sign). In fact, what little difference that exists between the EB and WB speeds is the opposite of what was expected by the Archer neighborhood parents: EB traffic heading toward a stop sign is the (slightly) faster traffic! Perhaps not having to stop at the previous intersection is an important factor. That is a second hypothesis that we can test in the guise of a homework problem.

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**Summary**

Improving safety on a roadway depends on the performance of three components: the vehicle, the driver, and the roadway itself. Each component can contribute to the safety (or lack of it) on a roadway. By understanding each of the three components, the transportation engineer can design roadways for safer performance. A framework called the Highway Safety Improvement Program establishes the basis for diagnosing roadway hazards, proposing solutions, and evaluating their efficacy. An appreciation for how individuals operate their vehicles in the roadway environment—a field of study known as human factors—can contribute to a better roadway design. Especially important is the recognition that drivers have a wide range of capabilities when it comes to vision, reaction time, and decision making. Designing for the least capable driver may actually induce less safe behavior on the part of other drivers. Vehicles can have a wide range of capabilities, too. Size, weight, acceleration, and other characteristics can vary significantly from vehicle to vehicle. Something as simple and familiar as
### Table 6.15

<table>
<thead>
<tr>
<th>Darren’s speed data for Archer neighborhood</th>
<th>Fri. 10 Apr 98, 3:30−4:30 PM</th>
<th>Sat. 4 Apr 98 and Mon. 20 Apr 98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dodge, bet. Garfield and Allen</td>
<td>Evergreen, bet. Allen and Garfield</td>
<td></td>
</tr>
<tr>
<td><strong>Eastbound (U−S)</strong></td>
<td><strong>Westbound (S−U)</strong></td>
<td><strong>Eastbound (S−S)</strong></td>
</tr>
<tr>
<td><strong>Intersection</strong></td>
<td><strong>Midblock</strong></td>
<td><strong>Midblock</strong></td>
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<td>31</td>
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<td>24</td>
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</tbody>
</table>

| Darren Mc. Anderson                        | 4/22/98                      |

* 1st S = stop-controlled intersection
* U = uncontrolled intersection

<table>
<thead>
<tr>
<th>Darren Speeds</th>
<th>Mean</th>
<th>Std Dev</th>
<th>95% Confidence Interval</th>
<th>Sample Size Desired</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB Midblock</td>
<td>23.410</td>
<td>2.559</td>
<td>21.600, 24.220</td>
<td>30</td>
</tr>
<tr>
<td>EB Midblock</td>
<td>4.378</td>
<td>3.837</td>
<td>3.841, 4.875</td>
<td>30</td>
</tr>
<tr>
<td>WB EB</td>
<td>1.96</td>
<td>1.96</td>
<td>1.96, 1.96</td>
<td>30</td>
</tr>
<tr>
<td>EB WB</td>
<td>73.6</td>
<td>30.1</td>
<td>39.0, 39.0</td>
<td>30</td>
</tr>
</tbody>
</table>

C. The first hypothesis Darren wants to test is \( WB = EB \) mean speeds on Dodge are equal. This is of interest because, for the observed block, EB Dodge ends at a stop sign at Garfield, whereas WB Dodge at Allen has no stop sign. In Table 6.15, \( S^* \) = stop and \( U^* \) = unsigned. Thus, EB is the "U^*" direction and WB is the "S^*" direction. To test the hypothesis \( H_0 : \mu_{WB} = \mu_{EB} \), you may have to refer to the notes or the textbook from your probability and statistics course on "two-sided tests." (The reference used here is Hypothesis Testing for Comparing Two Means in Lapin (1990), Section 12.3.) If you haven’t yet completed such a course, you will have to trust the method about to be demonstrated. The steps in the method are:

1. Because the number of observations in each direction is greater than 30, compute the test statistic:

\[
z = \frac{X_{EB} - X_{WB}}{\sqrt{\frac{S_{EB}^2}{n_{EB}} + \frac{S_{WB}^2}{n_{WB}}}} = \frac{23.410 - 22.559}{\sqrt{\frac{2.559^2}{30} + \frac{2.559^2}{30}}} \approx 1.086 
\]

(6.18)

where \( X^* \) is the mean of the speeds in the observed sample, \( \sigma^* \) is the variance of the sample speeds, and \( n^* \) is the number of speeds observed in the sample.

2. For a two-tailed test at a 95 percent confidence level, the critical value of \( z \) is \( ±1.96 \).

If the test statistic falls outside the range \( (−1.96, +1.96) \), the hypothesis must be rejected. Here, \( z = 1.086 \), which lies within the specified range, so the hypothesis \( H_0 : \mu_{WB} = \mu_{EB} \) cannot be rejected.

As a result of this analysis, Darren can say that there is no statistically significant difference between the 23.410 mph average speed on EB Dodge (heading toward a stop sign) and the 22.559 mph average speed on WB Dodge (with no end-of-block stop sign). In fact, what little difference exists between the EB and WB speeds is the opposite of what was expected by the Archer neighborhood parents: EB traffic heading toward a stop sign is the (slightly) faster traffic! Perhaps not having to stop at the previous intersection is an important factor. That is a second hypothesis that we can test in the guise of a homework problem.

**SUMMARY**

Improving safety on a roadway depends on the performance of three components: the vehicle, the driver, and the roadway itself. Each component can contribute to the safety (or lack of it) on a roadway. By understanding each of the three components, the transportation engineer can design roadways for safer performance. A framework called the Highway Safety Improvement Program establishes the basis for diagnosing roadway hazards, proposing solutions, and evaluating their efficacy. An appreciation for how individuals operate their vehicles in the roadway environment—a field of study known as human factors—can contribute to a better roadway design. Especially important is the recognition that drivers have a wide range of capabilities when it comes to vision, reaction time, and decision making. Designing for the least capable driver may actually induce less safe behavior on the part of other drivers. Vehicles can have a wide range of capabilities, too. Size, weight, acceleration, and other characteristics can vary significantly from vehicle to vehicle. Something as simple and familiar as
traffic signs can have an important impact on roadway safety. Following published
standards and adapting them to particular circumstances can assist motorists in operat-
ing their vehicles safely on a roadway.

**ABBREVIATIONS AND NOTATION**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_{acc}$</td>
<td>acceleration capability of a vehicle (usually a constant in this class)</td>
</tr>
<tr>
<td>A</td>
<td>annual cost</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>ADT</td>
<td>average daily traffic volume</td>
</tr>
<tr>
<td>AHEV</td>
<td>average hourly entering volume</td>
</tr>
<tr>
<td>AHC</td>
<td>average hourly traffic conflicts</td>
</tr>
<tr>
<td>C</td>
<td>crash rate, crashes per year</td>
</tr>
<tr>
<td>CAS</td>
<td>critical approach speed</td>
</tr>
<tr>
<td>$C_D$</td>
<td>coefficient of aerodynamic drag</td>
</tr>
<tr>
<td>CI</td>
<td>traffic conflict index</td>
</tr>
<tr>
<td>CPF(k)</td>
<td>crashes prevented (year)</td>
</tr>
<tr>
<td>CRF</td>
<td>crash reduction factor or percent reduction in crashes</td>
</tr>
<tr>
<td>DUI</td>
<td>driving under the influence of alcohol</td>
</tr>
<tr>
<td>$D_{brk}$</td>
<td>braking distance</td>
</tr>
<tr>
<td>$D_{proj}$</td>
<td>distance to an object</td>
</tr>
</tbody>
</table>
| EC           | expected number of crashes over a specified time (usually a year) if the counter-
measure is not implemented and the traffic volume remains the same |
| $F_1/F_r$    | engine force applied at the front and rear wheels, respectively |
| $f$          | dimensionless coefficient of friction of the road |
| $f_r$        | coefficient of rolling resistance at constant velocity (usually $f_r = 0.03 + V/47$) |
| $V$          | in fps |
| $f_{ps}$     | feet per second |
| FRA          | Federal Railroad Administration |
| $g$          | force of gravity 32.2 feet per second per second or 9.8 meters/second/second |
| HSIP         | Highway Safety Improvement Program |
| ICI          | intersection conflict index |
| MEV          | millions entering vehicles |
| MUCTD        | Manual for Uniform Traffic Control Devices |
| NJITSA       | National Highway Traffic Safety Administration |
| OAACS        | overall average conflict severity |
| OM           | object markers |
| P$c$         | initial cost or investment |
| PDO          | property damage only crashes |
| PI           | personal injury crashes |
| PPI          | time for perception/identification/emotion/ volition |
| PWC          | present worth of a series of costs |
| $R_i$        | sum of rolling resistance from each of the tires $R_i = R_{AD} + R_{AE} + R_{DB} + R_{EB}$ |
| RIMVM        | crash rate per million vehicle miles |
| $R_{proj}$   | component of gravity acting normal to the road |
| $R_{aero}$   | component of aerodynamic resistance or drag |
| RMEV         | crash rate per million entering vehicles |
| ROC          | rate of collision |

**GLOSSARY**

Collision diagram: A graphic summary of the collisions at an intersection for one year or
another appropriate time period.

Countermeasure: A project that is intended to reduce the crash rate at a site, especially in re-
response to causes identified as part of the HSIP.

Crash rate: Crashes per million entering vehicles at intersections; crashes per hundred million
vehicle miles on road sections.

Crash Reduction Factor: An estimate of how effective a certain countermeasure will be, based
on historical data on crash reductions after the countermeasure has been applied.

Critical rate analysis: A way to determine whether a particular site is dangerous, such as an in-
tersection. Use a representative sample of intersections or roadways to establish a crash rate
threshold, then determine whether the site’s crash rate exceeds the threshold.

Delineators: Roadside markers used to guide drivers through turns, especially at night or at
times of poor visibility.

Emotion: The time to consider the sign’s meaning and make a decision.

Expectancy: A design feature that helps motorists by giving them consistent clues and guidance.

Exposure: A measure of the amount of travel against which crashes, injuries, and fatalities can
be compared.

Highway Safety Improvement Program: A framework for planning, implementing, and evalu-
ating safety programs and projects.

Human factors: The study of how human beings function in their natural or constructed sur-
roundings.

Identification: The time to read and understand the sign.

Perception: The time it takes to see the sign.

Stopping sight distance: The distance needed by a driver to bring his/her vehicle to a safe stop,
given roadway grades, surface conditions, and operating speeds.

Traffic conflict analysis: A procedure to assess the potential for actual collisions by collecting
data on traffic conditions that are conducive to dangerous interactions between vehicles.
6.8 Crash Rates. The number of crashes at the intersection of US52 and SR26 increased from 39 in 1989 to 43 in 1990. The 1990 approach ADT's are estimated to be the following: NB 3,540; SB 12,355; EB 7,200; and WB 9,760. What was the 1990 crash rate at this intersection?

6.9 Crash Rates. The intersection of South Street and Earl Avenue had the highest number of accidents (41) in Tippecanoe County in 1991. Its accident rate was 3.730/MEV. What was the total AADT of all four approaches to South and Earl in 1991?

6.10 Roundabouts. The NB, SB, EB, and WB approach AADT at a roundabout in West Virginia are 5,242, 854, 387, and 944, respectively. The number of crashes at the roundabout for the years 1993, 1995, and 1996 were 9, 10, and 9, respectively. What is the crash rate at this roundabout?

Human Factors and Transportation Engineering

6.11 Human Factors in Daily Life. Make a list of items or environments that you have experienced that serve as examples of good or bad design from the perspective of human factors. They do not have to be related to transportation, although transportation examples are preferred.

6.12 Reaction Time Tests. With a good Internet search engine, use the words "reaction time test" to find two different reaction time tests on the Web. Try them. Describe the tests you tried, summarize your results, and comment on the validity of the tests.

6.13 Visual Acuity. The state DOT wants to erect a sign warning drivers of a merge in the road ahead. If the average driver must be able to see the sign from a distance of 400 feet, how tall must the letters be? Use the visual acuity data from Figure 6.18.

6.14 Visual Acuity Test. Print out some letters and numbers onto a sheet of paper, using Arial font, bold, point size 36. Attach the sheet to a wall. Ask someone else to start at the opposite side of the room and move forward until a character can be read. Note the character's height, and the distance to the target. Have the subject continue moving forward until the subject has identified all characters on the target. Which characters were misidentified? Which characters were easiest to see? Compute the unobstructed visual angle for each case. What guidance does this visual acuity experiment offer for the design of traffic signs?

6.15 Safety Device Design. What is the current status of the design and use of airbags in automobiles? Comment on air bags being one of the few safety devices that carry a warning label.

6.16 Human Factors. Based on your study of human factors in this course, respond "True" or "False" to each statement below.

(a) An individual's ability to perform a task may vary over time and depend on working conditions.
(b) Drivers tend to overestimate the speed of very large vehicles, such as locomotives.

6.17 Human Factors at Railroad Grade Crossings. What is it about trains at grade crossings that drivers often misjudge? Why is this a problem?

6.18 Stopping For a Train. You are traveling at 70 mph on a slushy road (friction coefficient = 0.20) when you hear a train whistle. You then see the warning sign that is placed 1000 feet before the gate-protected railroad grade crossing. You know you must try to stop.

(a) How close will you be to the gate when you come to a stop? Your reaction time is 1.5 seconds.
(b) Where will the train be relative to the grade crossing when you come to a stop?

6.19 Racing the Train. A friend is driving along a local road at 55 mph. This friend lates to wait for anything, even the train that he sees heading for the grade crossing ahead. There is no gate at this grade crossing-only a cross-beam sign and a bell. Your friend makes the decision to try to beat the train to the crossing. Although he can only guess at these values, the train is 1000 feet from the crossing and moving at 60 mph when your friend first sees it. At that time, your friend is 800 feet from the crossing.

(a) Assume your friend has a reaction time of 0.6 seconds. How far from the crossing will he be when he begins to accelerate?
(b) Your friend's car can accelerate at the rate of 28 ft/sec/sec, but it has a maximum speed of 85 mph. How fast will it be going when it reaches the crossing?
(c) How much time did your friend take to reach the grade crossing? Did he beat the train?

6.20 Aging Society. What must a transportation planner or engineer take into consideration in a society where an increasing number of people are over 65 years of age?

Vehicle Attributes That Affect Safety

6.21 Stopping on a Downhill Grade. At one point on SR285, there is a 4.9 percent downhill grade. How long will it take to bring a car traveling at 48 mph to a stop on that downhill segment if the driver's reaction time is 2.0 seconds and f = 0.29?

6.22 Traffic Accident. A transportation student is driving on a level road on a cold rainy night and sees a construction sign 520 feet ahead. The student strikes the sign at 35 mph. Further note, the student claims that he was not violating the 55 mph speed limit. Are you investigating the accident and you will testify in court.

(a) What evidence will you seek?
(b) What will you tell the court? (Be specific about reaction times and possible initial speeds.)

Traffic Control Devices

6.23 Traffic Control Devices. Recently, the county highway engineer observed a two-person crew about to install a traffic control devices on the campus of Mythica State University. At the base of the signpost were two signs, both with the message "Two Way Traffic Ahead." One sign had a rectangular shape with black lettering on white background; the other was diamond-shaped with black on yellow. If the crew was making the correct change, which sign would be the correct one to put up?

(a) Diamond-shaped with black on yellow
(b) Rectangular shape with black letters on white background

Briefly explain your answer.

6.24 Traffic Control Devices. A driver on the northbound (NB) approach to a stop sign-controlled intersection sees the sign and supplemental plaque shown below. Drivers on which approach to that intersection will have to stop? Circle the approach directions that comprise your answer.

(a) EB
(b) NB
(c) SB
(d) WB
6.25 Traffic Control Devices. The three SB lanes on Northwestern Avenue (as it enters the "T" intersection with Cherry Lane) are marked as shown in the figure below. (S3 traffic moves from right to left in the figure. Line "C-C" represents the curb; it flares out. Line "D-D" is the stop line at the intersection.)

(a) What color should the solid centerline "A" be?
(b) What color should dashed line "B" be?
(c) What change to dashed line "B" would probably be a good idea?

Highway Design for Safety

SCENARIO

As SR361 approaches Shoridan from the east, it crosses the Mythaca River by means of an old truss bridge (figure 7.1). The bridge takes SR361 not only over the river but also over the road that runs alongside it—fittingly called River Road. Because of new trip patterns and increasing traffic volumes, Shoridan area officials have called for a direct connection between SR361 above and River Road below. At present, the connection must be made by driving to the outskirts of Shoridan and doubling back more than a mile to River Road. The other alternative is to leave SR361 several miles east of the river and use county roads with limited capacity and poor sight distances to reach River Road. The proposed direct connection would involve a significant change in elevation, from the bridge level, down a hillside, to the river valley level. The proposed connector road presents safety problems, in that grades, curves, and speeds will have to be controlled to maintain safe driving conditions. To make the design challenge even more difficult, the hillside to be used for the connector road has already been partially developed. Numerous homes have been built to take advantage of the views of the Mythaca River Valley and Mundich Bay. Any connector road to the valley will have to remove several of the homes. Of course, it would be desirable to remove as few hillside homes as possible. Moreover, there may be environmentally sensitive areas in a preferred right of way that will have to be avoided. In many ways, highway design is a three-dimensional "puzzle" that must be solved by the engineer and supporting staff.