Law enforcement and public education efforts continue to make sure that seat belts are being worn and that drunk driving is eliminated. When it was learned that passenger side airbags could cause death of small adults and children, the use of air bags in certain situations was suspended.

Highway crashes generally have more than one causal factor, as suggested in the Venn diagram of Figure 6.3. Important items pertaining to the design and performance aspects that affect safety are discussed for each area of the diagram. Traffic control markings and devices are usually used to help the driver control the vehicle. Each of these areas is the subject of a section in this chapter, and the highway environment is covered in Chapters 7 and 8.

6.1.3 Highway Safety Improvement Programs

Despite the progress illustrated in Figure 6.2, highway safety remains a primary concern to highway engineers and public officials. For many years, the U.S. federal government has enacted legislation to encourage (and sometimes require) states to adopt programs “to reduce traffic accidents and the resulting deaths, injuries, and property damage” (HSIP, 1981). The Highway Safety Improvement Program (HSIP) was defined in a federal publication in 1979. The HSIP remains in this day a good framework for planning, implementing, and evaluating safety programs and projects. Figure 6.4 shows the basic components that comprise the HSIP, along with the processes that make up each component. In this section, methods commonly used to carry out the processes are introduced and demonstrated.

Planning Component, Process 1: Collect and Maintain Data. If collected properly, crash data can help identify the scope and nature of traffic safety problems in a community. Traffic crash data depend on collisions being reported to law enforcement agencies, so that the events can be documented. Once a crash report is filed out and filed, it becomes the basis for an analysis of that crash and the compilation of summary...
data. The right-hand side of Figure 6.5 is the top section of the back page of a crash report that was filled out at the crash scene by a police officer. These locally created reports eventually become part of a national database. See, for example, the Fatality Analysis Reporting System at www-fars.nhtsa.dot.gov. From these data, the analyst can compute crash rates, look for patterns in the history of crashes at a particular location, propose solutions, and evaluate their expected effectiveness.

THINK ABOUT IT
Have you ever been involved in a traffic collision? If so, did a police officer fill out a crash report? If not, why not?
Planning Component, Process 2: Identify Hazardous Locations and Elements. Although there are more than 6 million crashes each year on U.S. roadways (NHTSA, 1998), a traffic collision is considered a "rare event."

**THINK ABOUT IT**

If you were asked to go to a busy intersection near your residence and wait for the next collision to occur, how long would you have to wait?

To help determine how "dangerous" a roadway section or intersection is, a local agency could refer to the crash reports on file and then determine the total number of crashes at that location. Another way to assess the safety performance of a location is to compute its crash rate. For an intersection, the standard measure is crash rate per million entering vehicles (RMEV). The key "ingredients" are (a) the number of crashes in a given year and (b) the average daily traffic volume (ADT) on all approaches to the intersection.

\[
\text{RMEV} = \frac{\text{crashes/year}}{\text{approach ADT} \times \text{days/year}} \times 10^6
\]  

*(6.1)*

**Example 6.1**

Several intersections in Myshaca had an apparent increase in collisions last year. One such intersection—Fisk at Kesmencse—may need some special attention. It had 13 crashes. The four legs of that intersection had two-way ADT values of 9671, 2893, 9506, and 261 per day last year. Calculate the intersection's crash rate, so that it may be compared with the rates for other similar intersections.
Solution to Example 6.1  Equation 6.1 uses approach ADT, not two-way ADT. That part of a road’s ADT that departs from the intersection must be excluded. A reasonable way to estimate approach ADT is to take half of the two-way ADT. Therefore, the intersection crash rate at Fisk and Kissimmee last year was

\[
\text{RMEV} = \frac{13}{0.5 \times (9671 + 2893 + 9506 + 2611) \times 365} \times 10^6 = \frac{13}{0.5 \times 24,681 \times 365} \times 10^6 = 2,886
\]

THINK ABOUT IT
Why must we exclude the departing ADT from the calculation of RMEV?

If a roadway section is not “near” (usually defined as within 100 feet of) an intersection, a crash rate per hundred million vehicle miles (RHMVM) is computed.

\[
\text{RHMVM} = \frac{\text{crashes/year}}{\text{ADT} \times \text{days/year} \times \text{miles in section}} \times 10^8 \quad (6.2)
\]

Example 6.2
A new state highway safety program offers funds to improve local roads with RHMVM values greater than 100. A 6.1-mile section of Tyler Road in Myths County had six crashes last year. The two-way ADT was 755 vehicles per day. Does Tyler Road qualify for the state program?

Solution to Example 6.2  Unlike the intersection crash rate, the roadway section crash rate uses the two-way ADT.

\[
\text{RHMVM} = \frac{6 \text{ crashes}}{755 \text{ vpd} \times 365 \text{ days} \times 6.1 \text{ miles}} \times 10^8 = 356.9
\]

Tyler Road had an average of only one crash per mile last year, but the corresponding crash rate was high enough to qualify for state funds.

THINK ABOUT IT
Why does RHMVM use two-way ADT?

Does the crash rate found in Example 6.1 "prove" that Fisk and Kissimmee is a dangerous intersection? Did the state set its RHMVM threshold for funding local roads at the right level? A common way to answer either question is to consider a
representative sample of intersections or roadways and then determine whether the crash history of any particular location is "extreme." A critical rate analysis begins by identifying locations with similar characteristics (geometries, ADT, traffic control). Crash rates for the comparison group of sites are calculated by using several years of data and either Equation 6.1 or 6.2, as appropriate.

**THINK ABOUT IT**

Why are several years of data preferable to using just last year's data when computing RMEV or RIHM/M?

The mean crash rate \( \bar{x} \) and sample standard deviation \( \sigma_x \) for the comparison group is calculated. Any rate greater than \( C \) in Equation 6.3 below can be considered to be "extremely high."

\[
C = \bar{x} + (Z * \sigma_x)
\]  

(6.3)

Because of the variability of the data being analyzed, a confidence level needs to be specified. Most often, a 95 percent confidence level is chosen. The Z value that corresponds to a 95 percent confidence level is 1.96.

**Example 6.3**

The intersection of Wyckliffe Boulevard and Kolfax Avenue has had 9.35 collisions per million entering vehicles (MEV) during the last 3 years. The crash rate for rear-end collisions is 5.7 per MEV. Eight other intersections in Mythaca have characteristics similar to Wyckliffe and Kolfax. Their crash rates for the last 3 years are summarized in Table 6.1. Does Wyckliffe and Kolfax have an unusually high crash rate for total collisions?

<table>
<thead>
<tr>
<th>TABLE 6.1</th>
<th>Critical Rate Analysis for Example 6.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison Site</td>
<td>Total Collisions Rate</td>
</tr>
<tr>
<td>1</td>
<td>7.89</td>
</tr>
<tr>
<td>2</td>
<td>9.24</td>
</tr>
<tr>
<td>3</td>
<td>7.09</td>
</tr>
<tr>
<td>4</td>
<td>6.67</td>
</tr>
<tr>
<td>5</td>
<td>7.20</td>
</tr>
<tr>
<td>6</td>
<td>7.95</td>
</tr>
<tr>
<td>7</td>
<td>9.94</td>
</tr>
<tr>
<td>8</td>
<td>6.68</td>
</tr>
<tr>
<td>Mean, 3</td>
<td>7.58</td>
</tr>
<tr>
<td>Sample standard deviation, ( \sigma )</td>
<td>1.329</td>
</tr>
</tbody>
</table>
Solution to Example 6.3  The mean crash rate \( \bar{x} \) for the comparison group is 8.08 crashes per MEV. The sample standard deviation \( \sigma_s = 1.129 \) is computed by using

\[
\sigma_s = \sqrt{\frac{\sum (RMEV_i - \bar{x})^2}{n - 1}},
\]

where \( n \) is the number of comparison group members. The denominator uses "\( n - 1 \)," because the comparison group is treated as a sample of "all" intersections like those in the comparison group. Using Equation 6.3 with \( Z = 1.96 \), \( C = \bar{x} + (Z \times \sigma_s) = 8.08 + (1.96 \times 1.129) = 8.08 + 2.21 = 10.29 \). Although Wyckliffe and Kolfax has a crash rate higher than all but one of the intersections in the comparison group, its crash rate does not exceed the critical rate set by Equation 6.3. Therefore, it does not qualify as a hazardous intersection based on total collisions.

Planning Component, Process 3: Conduct Engineering Studies. The HSIP (FHWA, 1981) listed 24 types of studies that could be used to provide information needed to determine safety deficiencies at locations that had been identified in the previous process as hazardous. The best single method for our purposes is the collision diagram (see Figure 6.6). The diagrams drawn as part of each crash report (see the right-hand side of Figure 6.5) for a given intersection are transferred to a single graphic representation of that location. In Figure 6.6, 15 crashes for the year 1975 are depicted with arrows. Except for the events involving northbound vehicles, each collision's arrow is labeled with a date and time. Some also have conditions ("nud," snow, wet) noted. Also important is the symbol that represents the type of collision: rear-end, head-on, sideswipe, out of control, left turn, right angle. It is often possible to detect a pattern in the collisions shown in the diagram. If so, specific countermeasures can be proposed for evaluation. Common categories by which trends are classified are:

- **Type of collision**
- **Severity.** Fatal, personal injury, or property damage only
- **Contributing circumstances.** DUI, reckless driving, equipment failure, and so on
- **Environmental conditions.** Weather, roadway surface, lighting conditions
- **Time of day.** Daylight, night, dawn, dusk

If any of this information is not present on the collision diagram, the original crash report should be checked. After one or more recurring characteristics have been identified, a list of possible causes can be developed. If, for example, left-turn head-on collisions are prevalent, possible causes are (U.S. DOT 1981, p. 101):

- Restricted sight distance
- Yellow phase too short
- Absence of separate left turn phase
- Approach speeds too high.

For each of these possible causes, one or more countermeasures can be proposed. For a summary of the procedure in concise form, see Table 6.2.
### TABLE 6.2 Sample Accident Pattern Table

<table>
<thead>
<tr>
<th>Accident Pattern</th>
<th>Probable Cause</th>
<th>General Countermeasure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-angle collisions at an unsignalized intersection</td>
<td>Restricted sight distance</td>
<td>Remove sight obstructions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Restrict parking near corners.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install stop signs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install warning signs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install/improve street lighting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduce speed limit on approaches.</td>
</tr>
<tr>
<td></td>
<td>Large total intersection volume</td>
<td>Install signals.</td>
</tr>
<tr>
<td></td>
<td>High approach speed</td>
<td>Install yield signs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channelize intersection.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install signals.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reroute through traffic.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduce speed limit on approaches.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install rumble strips.</td>
</tr>
</tbody>
</table>


### Planning Component, Process 4: Establish Project Priorities.

After countermeasures have been proposed, they must be evaluated. The basic evaluation procedure is to estimate the effectiveness of a particular countermeasure and then compare that estimate against the countermeasure’s cost. Estimating a countermeasure’s effectiveness is not easy. A common method is to determine by how much the crash rate will be reduced and then convert that reduction into a benefit in economic terms. There are two serious problems with this method.

1. It is far from certain how effective a certain countermeasure will be. If, in Table 6.2, “install stop signs” is chosen as the countermeasure, by how much will “right-angle collisions at an unsignalized intersection” be reduced? Numerous attempts have been made to develop crash reduction factors for this purpose (Creasey and Agent, 1985; Ermer et al., 1992).

2. It is difficult to translate any given estimated reduction in crashes into benefits. How much is a human life worth, if its loss because of a traffic collision can be avoided? How much is a personal injury worth? How much should be spent to prevent each property damage only crash from happening?

### THINK ABOUT IT

What method would you use, if you were required to estimate the value of a human life and justify it? Answer the question again, this time for a personal injury crash or a property damage only crash.

Table 6.3 shows values published in a NHTSA report (Blincoe, 1994). The “economic costs” result from goods and services that must be purchased or productivity
that is lost as a result of motor vehicle crashes. They do not represent the more intangible consequences of these events to individuals and families, such as pain, suffering, and loss of life. The estimates of "comprehensive costs" (Miller et al., 1991) combine both economic costs and values for "intangible" consequences. The costs someone might be willing to pay to prevent the crash can be much higher than the economic costs of injuries (Blincoe, 1994). Currently, most authors seem to agree that the value of fatal risk reduction lies in the range from $2 million to $5 million per life saved.

If the effectiveness of a particular countermeasure is known, the following equation can be used to determine its benefit.

\[
\text{crashes prevented} = \frac{\text{EC} \times \text{CRF}}{\text{base ADT}} \times \text{forecast ADT} \quad (6.4)
\]

where

- \(\text{EC} =\) expected number of crashes over a specified time (usually a year) if the countermeasure is not implemented and the traffic volume remains the same
- \(\text{CRF} =\) crash reduction factor = percent reduction in crashes if the countermeasure is implemented
- \(\text{base ADT} =\) traffic volume per day before countermeasure is implemented
- \(\text{forecast ADT} =\) traffic volume per day for specified time after countermeasure is implemented

Note that there may have to be a separate CRF for each degree of crash severity. A particular countermeasure might be expected to reduce fatal crashes by 12 percent, personal injury (PI) crashes by 33 percent, and property damage only (PDO) crashes by 24 percent. Or, for each crash prevented, the severity of the prevented crash cost be drawn from a probability distribution (e.g., 41 percent fatal, 40 percent PI, and 19 percent PDO). A further complication is that a countermeasure may not prevent crash but may instead reduce its severity. The basis for the CRF value and the use of Equation 6.4 would have to be adjusted accordingly. In Example 6.4, we use Equation 6.4 in a relatively simple form.
Example 6.4

The Mythaca County Engineer’s staff believes that installing stop signs at a previously uncontrolled intersection will reduce crashes by 26 percent. In the base year (last year), there were 11 right-angle collisions at the intersection, whose approach volume was 3273 vehicles per day. Ten years from now, the approach ADT is forecasted to be 4000 vehicles per day. How many crashes will be prevented 10 years from now, if the stop signs are installed?

Solution to Example 6.4 Using Equation 6.4, the estimate of right-angle crashes prevented

\[
= 11 \times 0.26 \times \frac{4000}{3273} = 3.50 \text{ per year.}
\]

Example 6.4 tells only part of the story. A more complete analysis would include the following:

A. The crashes prevented in the years between the base year and the 10th year.
B. Years beyond the 10th year, if the life of the countermeasure extended that far.
C. An estimate of the cost of the project, spread out over the life of the project.

Let us extend the period of analysis to 15 years. In those 15 years, traffic is expected to increase at the same rate as in the 10-year analysis. Because \((1 + r)^{10} = 4000/3273 = 1.222\), the annual traffic growth rate \((r) = 2.0\) percent. In the absence of any countermeasure, \(CRF = 0.0\) in Equation 6.4 and the number of right-angle crashes will also increase 2.0 percent per year. So, for any year \(k\),

\[
\text{crashes prevented in year } k = \text{CP}(k) = (EC)(1 + r)^k \times CRF \quad (6.5)
\]

During year 1, \(CP(1) = 11 \times (1.02)^1 \times 0.26 = 2.917\) crashes prevented. During year 2, \(CP(2) = 11 \times (1.02)^2 \times 0.26 = 2.975\) crashes prevented. Over a 15-year period, the total number of crashes prevented would be calculated as follows:

\[
\sum_{k=1}^{15} \text{CP}(k) = \sum_{k=1}^{15} EC \times (1 + r)^k \times CRF \quad (6.6)
\]

For \(EC = 11, r = 0.02, n = 15, \text{ and } CRF = 0.26\), a total of 50.45 crashes would be prevented. See the calculations in the "CP(k)" column of spreadsheet Table 6.4.

The spreadsheet in Table 6.4 has also been used to estimate the benefit of the crashes prevented. If one half of 1 percent of the crashes at the intersection are fatal and the “comprehensive cost” of a fatal crash in Table 6.3 is used, the corresponding value of the countermeasure in the first year is

\[
\text{Fatal benefit} = 2.917 \text{ crashes prevented} \times 0.005 \text{ fatal} \times \$2,854,500/\text{fatal crash} = \$41,636
\]
In this case, the benefits of the proposed countermeasure far exceed the costs. Often, the analysis is not so clear-cut. Some analyses are very sensitive to the choice of the value of human life, the CRF, and so on. An analyst must be clear in stating higher assumptions and may find sensitivity analyses helpful. Even when such crucial values can be agreed on, there are usually more projects proposed than can be funded in a given budget cycle. For that reason, a system for ranking competing projects must be adopted. Chapter 5 covered ways to rank alternatives.

Implementation Component: Schedule and Implement Safety Improvement Projects. The scheduling of projects is more of a management and budgeting activity, but the proper implementation of the projects depends on good design and construction practices.

Evaluation Component: Determine the Effect of Highway Safety Improvements. Notice that a feedback loop exists on the left side of Figure 6.4. The loop begins at the evaluation component of the HSP. By monitoring the performance of the implemented projects, the agency can ensure that maximum benefits are derived from the projects and the agency can collect information to help make future decisions regarding highway safety improvement projects.

6.1.4 Traffic Conflict Analysis

Although there are too many collisions, they are still rare events at any given location. However, some locations have the potential to be dangerous or to be more dangerous than they already are. To assess the potential for actual collisions, a procedure has been developed to collect data on traffic conditions that are conducive to dangerous interactions between vehicles. This procedure is the traffic conflict technique.

As originally defined by Perkins and Harris (1996), a traffic conflict was any evasive action taken by a driver to avoid a collision. Classic cases are (a) sudden application of the brake to avoid "rear-ending" a vehicle in front that has slowed to turn and (b) sudden swerving to avoid a rear-end collision. During the 1970s and 1980s, the definition was expanded and refined to include time-distance and severity elements. "A traffic conflict occurs when two or more road users approach the same point in time and space, and at least one road user takes successful evasive action to avoid a collision within a predefined minimum time to collision" (Hamilton Associates, 1996).

Figure 6.7 provides a structure for traffic conflict analysis. An "Existing Hazard" is any potential interaction between vehicles. Whether it meets the definition of a traffic conflict depends on the subsequent events indicated in the figure. "Normal interaction between road users generally does not result in a traffic conflict. A precautionary measure to avoid a perceived dangerous situation is also not a conflict. A conflict only occurs when evasive action that is not part of normal driving is taken to avoid a real hazard" (Hamilton Associates, 1996, p. 5). Observers conducting a traffic conflict study must be able to say "yes" to each question along the left-hand side of Figure 6.7. In addition, the observer is expected to assess the severity of each observed traffic conflict, according to the criteria list below.

1. Time to collision (TTC). Using estimated (or measured) approach speed and distance to the potential point of collision, an approximate TTC value can be computed. The severity score for each TTC value is given in Table 6.5.

Now that the benefits side of the analysis has been completed, the cost estimates for the countermeasure must be made. If it costs $85 to install each of four stop signs and an average of $15 per year to maintain or replace each sign, the present worth of the i = 3.0 percent) of the cost to implement the stop sign countermeasure for 15 years is

\[
P(W) = A \left( \frac{(1+i)^n - 1}{(1+i)^n} \right) = \left( 4 \times $85.00 \right) + \left( 4 \times $15.00 \right) \left( \frac{(1 + 0.03)^{15} - 1}{0.03(1 + 0.03)^{15}} \right) = \$1056.28.
\]

A similar calculation is done for the proportion of crashes that are expected to be personal injury (PI) and property damage only (PDO), year by year for all 15 years.

The estimate of total benefits from the proposed countermeasure over the next 15 years is $5,424,260.

**THINK ABOUT IT**

Do the relative values of the total benefits in Table 6.4 for each crash type seem reasonable to you?
In this case, the benefits of the proposed countermeasure far exceed the costs. Often, the analysis is not so clear-cut. Some analyses are very sensitive to the choice of the value of human life, the CRF, and so on. An analyst must be clear in stating his/her assumptions and may find sensitivity analyses helpful. Even when such crucial values can be agreed on, there are usually more projects proposed than can be funded in a given budget cycle. For that reason, a system for ranking competing projects must be adopted. Chapter 5 covered ways to rank alternatives.

**Implementation Component: Schedule and Implement Safety Improvement Projects.** The scheduling of projects is more of a management and budgeting activity, but the proper implementation of the projects depends on good design and construction practices.

**Evaluation Component: Determine the Effect of Highway Safety Improvements.** Notice that a feedback loop exists on the left side of Figure 6.4. The loop begins at the evaluation component of the HISP. By monitoring the performance of the implemented projects, the agency can ensure that maximum benefits are derived from the projects and the agency can collect information to help make future decisions regarding highway safety improvement projects.

### Table 6.4

<table>
<thead>
<tr>
<th>Year</th>
<th>(1+i)^n</th>
<th>Predicted Value</th>
<th>Benefit at year n</th>
<th>Present worth of the interest</th>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02 Traffic growth rate</td>
<td>$2835,500</td>
<td>15 years of project life</td>
<td>0.20 CRF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.005 Total</td>
<td>$875,199</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.190 PI</td>
<td>$712,299</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.000 PDI</td>
<td>$41,440</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A similar calculation is done for the proportion of crashes that are expected to be personal injury (PI) and property damage only (PDO), year by year for all 15 years. The estimate of total benefits from the proposed countermeasure over the next 15 years is $5,424,260.

**THINK ABOUT IT**

Do the relative values of the total benefits in Table 6.4 for each crash type seem reasonable to you?

Now that the benefits side of the analysis has been completed, the cost estimate for the countermeasure must be made. If it costs $85 to install each of the stop signs and an average of $15 per year to maintain or replace each sign, the present worth (of a = 3.0 percent) of the cost to implement the stop sign countermeasure for 15 years is:

\[
P_{WC} = P_0 + A \left\{ \frac{(1 + i)^n - 1}{i} \right\} = (4 \times 85.00 + 15 \times 1056.28) \nonumber
\]

\[
P_{WC} = 340.00 + 60.00 \times 1.938 = 1056.28. \nonumber
\]
6.3 Vehicle Attributes That Affect Safety


6.4 TCDs

[55] Institute of Transportation Engineers (ITE), Introduction to Signs and Markings, Skides and Narative Notes, 4 September 1974.


EXERCISES FOR CHAPTER 6: SAFETY ON THE HIGHWAY

6.1 Crash Rate on Roadway Section. As it passes through a fast-growing part of Mythaca, a 0.79-mile section of Gifford Street has begun to experience a much higher crash rate than in previous years. Over the past 3 years, there have been 14, 13, and 15 crashes on this section of Gifford Street. The two-way ADT on this section of Gifford is 16,474 vehicles per day. What is the annual crash rate per 1,000 vehicles per roadway mile? (Round to one decimal place)

6.2 Crash Rate at Intersection. As Gifford approaches downtown Mythaca, it crosses Gregory Avenue at a signalized intersection. The four approach volumes per day of this intersection are 28,648, 23,856, 12,150, and 10,174. The crash totals for the last 3 years are 91, 96, and 87. What is the annual crash rate for this intersection?

6.3 Accident Rates. The intersection of one-way (EB) South Street and one-way (NB) 4th Street in Lafayette had the fourth highest accident rate (3.229 per MEV) in Tippecanoe County in 1994. If there were 31 accidents and the ADT on South Street was 16,100 in 1994, what was the ADT on 4th Street?

6.4 An intersection "Hazardous?" Concerned about the crash rate at Gifford and Gregory, the Mythaca County Police department has found 10 other intersections in the region that have the same characteristics as Gifford and Gregory. The crash rates at these "control sites" over the past 3 years are 2.83, 3.19, 2.37, 2.59, 1.61, 3.13, 3.68, 2.23, 3.88, and 2.80. (a) What are the mean and standard deviation for the control sites? (b) Use the critical rate method to determine whether Gifford and Gregory qualifies as a hazardous intersection. Use the 95 percent confidence level, which means Z = 1.96.

6.5 Traffic Crashes: A True Story. At about 5 PM on a sunny Saturday (27 July 1996), the driver of a small vehicle traveling west on US52 (Sagamore Parkway in West Lafayette) was waiting to turn left onto Blackhawk Lane. For some reason, the driver realized that an EB pickup truck was approaching the intersection in the left lane at high speed. The pickup truck's brakes were applied, but the small car was hit in the right front fender by the front of the pickup truck. The intersection has four approaches, and Sagamore Parkway has a raised median. There were no injuries. (a) Draw the collision diagram (main box only) for this crash. (b) To begin an analysis of this crash, propose what you think are the two most likely "probable causes" of this crash. Explain if necessary.

6.6 Highway Deaths. Between 1982 and 1994, highway fatalities decreased from about 50,000 to about 40,000. One element was a contributing factor in 50 percent of fatal crashes in 1982. But this percentage went down to less than 40 percent in 1994. What was this "element" and why did its percentage decrease?

6.7 Crash Analysis. Which of the three causes below is most often responsible for highway crashes?

- Mechanical failure of vehicle
- "Failure" of guardrail or roadway
- Human (operator) error

Name two new technological developments that may help to reduce this cause of crashes.
6.9 Crash Rates. The number of crashes at the intersection of US 22 and SR 26 increased from 39 in 1980 to 43 in 1990. The 1990 approach AADT is estimated to be the following: NB 13,540; SB 12,535; EB 7200; and WB 9760. 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, EB, and WB approach AADT at a roundabout in West Virginia are 52,854, 38,377, and 944, respectively. The number of crashes at the roundabout for the years 1994, 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, its 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 subtended 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.
- An individual’s ability to perform a task may vary over time and depend on working conditions.
- 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 train grades 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.
- How close will you be to the gate when you come to a stop? Your reaction time is 1.5 seconds.
- 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 touts to wait for anytime, even the train that he sees heading for the grade crossing ahead. There is no gate at this grade crossing—only a cross buck 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 40 mph when your friend first sees it. At that time, your friend is 800 feet from the crossing.
- Assume your friend has a reaction time of 0.6 seconds. How far from the crossing will he be when he begins to accelerate?
- Your friend’s car can accelerate at the rate of 28 ft/sec², but it has a maximum speed of 85 mph. How fast will it be going when it reaches the crossing?
- 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 SR 835, there is a 4.9 percent downhill grade. How long will it take to bring a car traveling at 80 mph to a stop on this downhill segment if the driver’s reaction time is 2.0 seconds and $f = 0.297$?

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 more, the student claims that he was not violating the 55 mph speed limit. You are investigating the accident and you will testify in court.
- What evidence will you seek?
- 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 Mythaca 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 letters 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?
- Diamond-shaped with black on yellow
- 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 approaches to this intersection will have to stop? Circle the approach directions that comprise your answer.
- EB
- NB
- SB
- WB