Roadway Safety
Identifying Needs and Implementing Countermeasures

Brian E. Chandler
ROADWAY SAFETY
ROADWAY SAFETY: IDENTIFYING NEEDS AND IMPLEMENTING COUNTERMEASURES

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ABSTRACT

This book introduces the basics of safety needs identification, countermeasure selection, and implementation of treatments designed to reduce the number of roadway crashes and resulting injuries and fatalities. It describes the current state of the practice and research regarding finding roadway safety issues, choosing treatments, and implementing their installation. It focuses on crashes occurring at intersections, in work zones, and as the result of a lane departure.

KEYWORDS

Transportation, safety, health, countermeasure, treatment, injury, fatality, intersection, lane departure, work zone, data, analysis, culture, exposure, crash, severity, speed
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PREFACE

Around the world, more than one million people are killed in roadway crashes each year. Safety engineers, behavioral researchers, vehicle manufacturers, and other professionals are working diligently to improve traffic safety. Nonmotorized advocates are improving bicycle and pedestrian experiences as well.

The purpose of this textbook is to equip students with a basic knowledge of roadway safety needs identification, countermeasure selection, and implementation of safety treatments.
ACKNOWLEDGMENTS

Brian E. Chandler wishes to acknowledge the following for their support before and during this project.

Dr. Bryan Katz served as collection editor of the publication and provided editorial reviews with an eye on students.

Mr. James Ellison provided in-depth technical and editorial review of each chapter.
CHAPTER 1

INTRODUCTION

On September 11, 2001, nearly 3,000 people were killed in New York City, Washington, DC, and outside of Shanksville, PA, in the worst terrorist attack in U.S. history.\(^1\) It was a senseless act of violence. On September 12, 2001, approximately 115 people were killed in acts of impatience, imprudence, distraction, and neglect at dozens of roadway locations around the country. On September 13, 115 more were killed, and another 115 each day for the rest of the year. By the end of 2001 more than 42,000 people died in roadway crashes in the United States. Each was a senseless act of violence, and preventable.

Around the world the toll is even greater. More than 1 million people die each year worldwide on the road—ranking in the Top 10 causes of death by the World Health Organization.\(^2\) One reason traffic crashes are not “on the radar” like some other health issues is the complexity of the problem. It requires solutions from engineers, public policy makers, law enforcement personnel, advocates, and ultimately each road user.

These deaths are more than numbers. They are mothers and fathers, daughters and sons, teachers and students, coaches and players, bosses and employees, friends and neighbors. The effect of traffic fatalities is widespread and far-reaching, its toll both economic and emotional.

But there is hope.

Over many years, and especially in the last decade, traffic safety professionals have made great strides to improve the safety of roadways, vehicles, and road user competencies. Roadway safety is now considered in the transportation planning process, roads are designed safer, and highway systems are operated to improve safety. All road users, including those not in motor vehicles, are experiencing a safer travel environment.

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The objective of this text is to introduce the basics of safety needs identification, countermeasure selection, and implementation of safety treatments designed to reduce the number of roadway crashes and resulting injuries and fatalities. This book walks through the current state of the practice and research regarding identification of roadway safety issues, selection of countermeasures, and implementation of the selected treatments.

Chapter 2, Identifying Safety Needs, describes the data needed to determine the types and locations of safety issues in a given jurisdiction. These data include crash history, roadway attributes, traffic information, and other risk factors.

Chapter 3, Studying Individual Locations, shows the process of analyzing intersections, segments, and other locations to determine the underlying issues that may be causing crashes.

Chapter 4, Countermeasure Selection, shows the criteria for selecting countermeasures at a given location. These include past success of a treatment in similar circumstances, feasibility of implementation, and engineering judgment.

Crash types vary widely, and this book addresses a subset of those crash types most likely to be affected by infrastructure-based countermeasures. The next three chapters describe the concerns and solutions related to three of the most common crash types in most regions—intersections, lane departure, and
work zones. Chapter 5 includes crashes occurring at stop-controlled and signalized intersections, the differences between them, and the solutions to reduce crashes at each. Chapter 6 introduces an overall approach to lane departure safety and describes specific countermeasures for curves, single-vehicle run-off road, and opposite direction crashes. Chapter 7 includes a description of work zones crashes, their causes, and potential solutions, including different strategies for the different parts of a work zone.

Chapter 8, Countermeasure Implementation, lays out the approaches used by safety experts to address identified needs. It includes spot location solutions to address specific site problems, and systemic, policy-level, and comprehensive approaches that address broader issues.

Chapter 9, Future of Traffic Safety, introduces a broad-based plan of action for eradicating roadway fatalities for good through a combination of problem identification and correction, safety culture changes, and technological advances.
CHAPTER 2

IDENTIFYING SAFETY NEEDS

We’re all trying to get somewhere. Some of us are just having a harder time than others.

—Audra Jenkins

The traffic safety issue is both large and complex. As with any big challenge, the most effective way to begin addressing it is to identify the needs and develop a plan to address those needs one step at a time. Traffic safety issues must be identified, and then addressed.

2.1 UNDERSTANDING THE NEEDS

Reasons for Identifying Safety Needs. Government agencies with responsibilities for roadway operations and maintenance must consider more safety needs than can be addressed with the funding available. To do this, it is important for agencies to identify the needs accurately for efficient use of these limited resources. Spending money at locations (or on types of crashes) that are not a real need limits the ability of agencies to improve safety.

In addition to funding, agencies need people to implement safety projects. In some cases agency staff can install the treatments themselves (e.g., sign installation, changes to traffic signal timing). For other efforts, such as construction projects, public agencies still need inspectors, contract managers, and supervising engineers to ensure the work is completed correctly.

Accurately identifying needs is the first step toward choosing cost-effective countermeasures.

Understanding the Needs. The “why” of traffic crashes is often just as important as the “what.” For example, safety data can show that an intersection is suffering a number of right-angle crashes, but the numbers alone do not tell the entire story. Additional information is needed to understand
why the crashes are occurring. Reasons could include red-light-running at a signalized intersection, poor sight distance at a rural stop-controlled intersection, drivers running a stop sign, or a number of other potential reasons. Telling the story at a location is a good way to understand the problem to be solved.

2.2 DATA NEEDS: IT ALL STARTS WITH DATA

Identifying safety needs starts with data. Think of data as the safety story for a given location, community, or larger jurisdiction (like a county, state, or country). It can help explain why drivers are running off the road at a particular curve, or at which signalized intersections motorists are most likely to run red lights. Analyzing large data sets can help practitioners identify the most common contributing circumstances to all crashes in their region.

Several types of data can be used by safety practitioners and researchers to identify safety issues, prioritize locations, and select countermeasures. There are three common types of data needed for a safety project or program.

1. **Crash history data** can include the number of crashes, severity of any injuries sustained, crash type, contributing circumstances, and the sequence of events.
2. **Roadway data** include functional class, cross-section design of the roadway and roadside, pavement type, and existing traffic control.
3. **Exposure data** include traffic volumes (often measured as average annual daily traffic), segment length, and population.

2.2.1 CRASH HISTORY DATA

Crash data sets are the primary source of knowledge about the traffic environment, human actions that led to the crash, and vehicle performance. To identify needs by using this information, it is important for the data to be timely, accurate, complete, consistent, integrated, and accessible. High-quality information has the potential to improve problem identification, the prioritization of different safety concerns, and performance evaluation of countermeasures.
• **Timeliness.** The time it takes for crash records to be made available after a crash occurs varies widely. Some agencies have electronic systems set up for near-real-time collection of this information, while others do not. The sooner safety analysts can know about an emerging safety need, the sooner they can begin addressing it.

• **Accuracy.** Most safety decisions are based on the identification of safety needs through crash reporting, which means those reports must include accurate information. Due to the complexity of traffic crashes and various requirements of law enforcement officers at the scene, it can be difficult at times to ensure accurate information is collected. To further complicate data collection, law enforcement personnel are rarely at the scene of a crash when it occurs, so they are piecing together the who/what/where/when of the crash after the fact, often with limited and potentially inaccurate information (e.g., witness testimony).

• **Completeness.** Having access to a full report of a crash is valuable to safety practitioners and analysts to help them understand the story of that event.

• **Consistency.** Consistent data within a jurisdiction (like a single city police department) and among multiple jurisdictions (for the sake of state or national crash analyses) are helpful to analyze larger data sets and make comparisons as needed.

• **Integration.** The ability to easily integrate data sets together, including combining crash data with other types (e.g., roadway, exposure), increases the options for analysis, and can lead to better decisions regarding countermeasure selection.

• **Accessibility.** The best data in the world are not useful if the information cannot be used. Access to crash history data are vital to decision making.

The primary sources of crash-related safety data for the local practitioner include local crash reports completed by law enforcement officers, state and local crash databases, national crash repositories, hospital records, and subjective sources like public notifications.

**Standard Crash Reports.** A primary source of information—and the basis of larger crash history databases—is the set of crash reports completed by law enforcement organizations. These represent the most comprehensive form of crash data available. Crash reports are the record of each traffic crash that has occurred on a public roadway, typically completed by a law enforcement officer. The format of the report varies...
from state to state, though most states have a standard reporting form. These forms are typically updated every 8–10 years.

**Defining Reportable Crashes.** States across the country use varying definitions to determine when a crash is deemed “reportable.” This can occur because of the effort required by law enforcement officers to produce crash reports along with their other public safety duties. Most states will report any traffic crash that includes a personal injury, and many have an estimated cost threshold for a property damage only crash to be considered reportable. Cost thresholds have two downsides: First, estimating a dollar value for property damage at the scene is an impossible task for anyone, including law enforcement officers. Second, in most states the dollar value is not updated often, so many have outdated values that effectively make every crash legally reportable.

In some cases, if the vehicle can be driven away from the scene of the crash or no person was harmed, then the crash is not considered reportable. Nonreported crashes are not recorded in a database, so information from these events (e.g., location, contributing circumstances, and crash type) cannot be analyzed for needs identification.

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**MODEL MINIMUM UNIFORM CRASH CRITERIA**

The Model Minimum Uniform Crash Criteria (MMUCC) guideline is a recommended standardized data set for describing motor vehicle crashes and the vehicles, persons, and environment involved. The 110 recommended data elements can be collected at the crash scene, derived from collected data, or obtained from other data sets (e.g., driver history, hospital records, or roadway inventory). MMUCC implementation should help improve the quality of local- and state-level data, which in turn can improve national estimates based on state data sets.

The MMUCC was originally published in 1998 and is regularly updated every 4–5 years in response to emerging highway safety issues and technological advances in data collection and use. For additional information, go to www.mmuc.us.

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Standard reports vary in detail and length, but most include the following information about a crash:

- Date and time
- Crash severity
- Crash type
- Roadway information
- Weather and pavement conditions
- Number and types of vehicles involved
- Drivers’ personal information
- Actions that led to the crash
- Contributing road user behaviors (e.g., alcohol-involved, distracted, unbelted)
- Diagram and narrative description of the crash that may include witness accounts

There are many crash reporting issues that should be considered by practitioners when working with law enforcement officers.

**Location Coding.** The exact location of a crash is sometimes difficult to determine accurately because the location of impact is often not where the vehicles come to rest, and the law enforcement officer on the scene was not present when the crash occurred. Identifying crash locations is sometimes dependent on the level of technology available, the experience of officers, and the care given to accuracy. Typical location data include distance from a known location (e.g., intersection, bridge, or landmark), street address, identified milepost or log point, or Global Positioning System position by latitude and longitude. In some areas landmark-type locations can be long distances apart, making it difficult to use the locations in analysis.

**Defining Crash Types.** Officers within the same geographic area or those in various jurisdictions within a state may define safety terms differently, which can sometimes make it difficult to identify trends. For example, an angle crash is sometimes described as Right Angle, Angle, or T-bone, depending on the officer’s training, background, and habits. Standard terms can be used and defined on the crash report to address this issue, but the free-form sections (e.g., the officer’s narrative) are susceptible to inaccuracies.

**Defining Crash Severity.** Jurisdictions are generally consistent with regard to the definition of a fatal crash; however, even this has some complications:
What if the person died in the hospital 2 days later? Or 20 days later? Or because of something that might not have been related to the crash? What if they had medical issues that caused their death before the traffic crash occurred? What if homicide or suicide was involved? Should these situations be considered traffic fatalities?

As the severity of a crash diminishes, the classifications of personal injury severity can vary around the country. Many jurisdiction use a scale called “KABCO,” where each letter in the acronym stands for a different severity:

- **K**: Killed in the crash. Road user died within 30 days of the event.
- **A**: A-level (severe) injury. Ambulance removes victim from the scene.
- **B**: B-level (minor) injury. An obvious injury occurred but may not require transport.
- **C**: C-level (apparent, possible) injury.
- **O**: Only property damage; no injuries.

The severity level of an injury crash (e.g., severe, minor, apparent) is subjective and often difficult for a law enforcement officer to determine at the scene. In the vast majority of crashes no follow-up with hospital or emergency medical services (EMS) is conducted to revise severity information in the crash report.

**Secondary Effects of Traffic Crashes.** Regardless of the severity of a traffic crash, it is likely to have effects beyond simple property damage. Even when no injuries are reported, people’s bodies are affected by the experience of a collision. There is also an emotional toll that can have lasting impacts. And in every case of a reported crash there are a series of “inconvenience steps” each party must take to deal with the ramifications of the crash—contacting insurance companies, working with automobile repair shops, and so on. So even in the most minor crash, the effects can be long-lasting and impactful on the lives of those involved. Because of this, it is important to determine where, when, how, and why crashes occur to attempt to reduce their numbers in the future.

**State Crash Database.** Crash reports are often centralized in a single, state-maintained repository for analysis and reporting. This database captures the reports from state, county, and municipal law enforcement agencies. It includes information about every reported traffic crash in a jurisdiction, regardless of which law enforcement agency filled out the report. Data accessibility is an important element to safety needs determination, but the methods used
for data compilation and dissemination differ by state. In some cases it can be
difficult for local agencies to access the crash database.

**National Crash Databases.** Due to the wide variety of crash data collec-
tion methods, report forms, and jurisdictions reporting across the country,
there is not an established database of all crashes occurring in the United
States. However, some subsets of the data are available for national
analysis.

The Fatality Analysis Reporting System (FARS), maintained by the
National Highway Traffic Safety Administration (NHTSA) under the
United States Department of Transportation (USDOT), includes data for
every fatal traffic crash on public roads in the United States. FARS was
developed to provide an overall measure of highway safety at the national
level, help identify traffic safety problems, suggest solutions, and provide
an objective basis upon which to evaluate the effectiveness of standards
and highway safety programs. Each state provides specific fatal crash in-
formation in a standard format to FARS. Once collected by the FARS
analysts, the data are recoded to match the FARS forms. FARS data are
used to answer questions regarding the roadway, vehicle, and driver fac-
tors that contribute to traffic crashes.2

The benefit of the FARS database is that it includes information on
every fatal crash. The downside is that this is a relatively limited dataset to
use for needs identification and countermeasure application.

**Medical Services Data.** Other potential sources of information are hospi-
tal and EMS records. EMS data can provide the location and severity of
medical service responses to traffic crashes. Similarly, some hospitals
have data available regarding emergency room visits or other admissions
and discharges connected to traffic crashes. However, due to a number of
federal and state regulations regarding the privacy of medical information
(e.g., the Health Insurance Portability and Accountability Act [HIPAA]),
the accessibility of this data is limited.

The Crash Outcome Data Evaluation System (CODES) attempts to
link crash reports to injury outcome records collected at the scene and en
route by EMS, by hospital personnel after arrival at the emergency de-
partment or admission as an inpatient, and/or on the death certificate.
CODES is designed to foster and cultivate crash-outcome data integration

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2 Adapted from U.S. Department of Transportation, National Highway Transportation Safety
Administration, “Fatality Analysis Reporting System (FARS) Encyclopedia” website.
among safety partners. In some cases the State Department of Health has access to the CODES linkage data and relationships with the State Department of Transportation to make these data accessible.\(^3\)

**Subjective Information.** Sometimes citizens or citizen groups will report unsafe driver behaviors or situations to state and local agencies by telephone or e-mail. In other cases the local newspaper may capture a safety concern based on a high number of crashes or public complaints. The agency typically responds with a field visit and/or return correspondence. Although this information is anecdotal and not based on objective data, public response can sometimes help practitioners identify safety needs that have not been captured by crash history reports or other objective measures.

In addition, a known change to the traffic pattern in a location could trigger a safety needs analysis. Examples include a new school being constructed, a large commercial or tourist traffic generator, additional work zones expected, and so on.

### WHAT ABOUT UNREPORTED CRASHES?

An increasing percentage of crashes (especially those that do not include a personal injury) do not receive a formalized crash report or get logged into a crash database. Reasons include:

- Reduced number of law enforcement employees with increased responsibilities.
- People fear increased insurance premiums.
- People do not want to contact authorities due to their behavioral issues (impaired driver, unbuckled, and so on).

**Maintenance Staff and Law Enforcement.** In addition to citizen requests, other safety partners can provide subjective information based on their time spent on the roads. Roadway maintenance personnel spend a lot of time in the field and often see unsafe road user behaviors and roadway safety concerns before they would show up in a crash history analysis.

Law enforcement officers can also provide information to engineers and analysts about potential unsafe roadway conditions and behavioral

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\(^3\) CODES description and links to additional information are available at www.nhtsa.gov/Data/State+Data+Programs.
issues in the jurisdiction. For example, if officers have written a high number of speeding or aggressive driving citations along a given segment of roadway, this could indicate a need for further study. Issues may include a design speed inconsistent with the posted speed limit, or other visual cues leading to higher speeds. An additional benefit of law enforcement’s knowledge of local roadways is that they spend a significant amount of time on the roads at night and on weekends—more than most government agency employees. This perspective can support unique safety needs that may be more apparent during these times.

2.2.2 ROADWAY DATA

A roadway data element is loosely defined as information related to the roadway or roadside environment. Safety-focused examples include lane width, shoulder width and type, and roadside slope.

MODEL INVENTORY OF ROADWAY ELEMENTS

A complement to the MMUCC, the Model Inventory of Roadway Elements (MIRE) is a list and data dictionary of roadway and traffic data elements identified as those most important to roadway safety. Improving safety-related roadway and traffic data can help practitioners make appropriate decisions on roadway design and operation.

Additional information about MIRE is available at safety.fhwa.dot.gov/rsdp/mire.aspx

Pavement. The age, type, and width of pavement can affect the safety of the roadway and may contribute to the feasibility of some safety treatments. For example, asphalt pavement in poor condition is typically not a good surface for installing pavement markings or milled-in rumble strips. If lane departure crashes were occurring on a corridor with poor pavement condition, signing or vertical delineators may be more useful and cost-effective options.

Shoulders. Shoulder width and type make a big difference in the recovery area available for a motorist who departs the roadway. Many roads in the United States have no shoulder, or may have an earthen shoulder with no gravel or hard surface added. In these cases it can be difficult for a motorist to recover after leaving their lane.
Roadside. The condition of the transportation environment outside the roadway and shoulder can have a significant impact on the severity of crashes when they occur. A clear zone can provide recovery area for motorists, slope flattening can help prevent overturning vehicles, and protecting or relocating fixed objects can prevent severe crashes.

Geometric Design. The geometric layout of a roadway or intersection (e.g., radius of horizontal and vertical curves, general alignment through an environment, design of an interchange, etc.) can have an effect on the design speed, required signing, and overall safety.

**ROAD ASSESSMENT PROGRAMS: iRAP, usRAP**

The International Road Assessment Program (iRAP) and United States Road Assessment Program (usRAP) focus on roadway inspections to identify safety risks. Each organization provides tools and training to help automobile associations, governments, funding agencies, research institutes, and others improve road safety. The usRAP mission includes identification of “major safety shortcomings which can be addressed by practical road improvement measures.”

An important aspect of these programs is their focus on risk without the need for crash history data. The tools developed and used by iRAP and usRAP partners (Star Ratings, Risk Mapping, and Safer Roads Investment Plans) are particularly useful to government agencies and other safety advocacy groups that lack access to adequate crash data for assessing risk. By investigating roadway elements, these safety experts can still make, “data-driven decisions using video logs of roadway features known to be associated with crashes, and investment plans showing cost-effective solutions.”

For additional information, visit www.irap.net and www.usrap.us.

**2.2.3 EXPOSURE DATA**

If a practitioner were to focus only on the raw number and severity of crashes occurring in a jurisdiction or at a specific location, he or she could

---


come to inaccurate conclusions that limit the effectiveness of safety treatments.

To improve the accuracy of identifying safety needs, normalizing data can benefit the decision-making process. Following are the two most common exposure data elements used for this purpose:

1. **Traffic Volume.** The number of vehicles along a roadway segment or entering an intersection normalizes the data to support more accurate comparisons. For example, if two intersections have the same number of crashes but differing traffic volumes, the location with fewer vehicles (i.e., less exposure) will have a higher crash rate. Crash rate analysis incorporates traffic volume to show that increased exposure leads to increased likelihood of crashes occurring.

2. **Roadway Miles.** Simply comparing two corridors by the number of crashes can be problematic if they are not of the same length. Even if no other data are available, comparing the number of crashes and the length of the road can support more accurate comparisons among roadway segments.

### 2.3 IDENTIFYING SAFETY NEEDS: LOCATIONS

One approach to identifying safety needs is to pinpoint the locations of previous crashes, concluding that past crashes occurring at those locations are likely to continue without intervention. All available information should be used to analyze where crashes have occurred in the past; the types of crashes that occur most frequently; and the severity of the crashes in terms of harm to road users.

The analytical methods range from simple “push pin” maps (physical or computer-based) for identifying clusters of crash sites, to detailed statistical analyses of crash frequency, rate, crash type, roadway features, and other data to determine the most appropriate treatment locations for preventing future crashes.

Once crashes are identified, practitioners can screen the network using a number of approaches, starting with the most basic (a simple count of crashes) and increasing in complexity.

**Crash Frequency and Severity.** One can count the number of crashes using information from local law enforcement crash reports, public notifications, or the state crash database. The end result of this study is a summary of crashes by location, type, and severity that can be sorted to identify trends
and mapped to identify clusters of crashes of a given type. By incorporating crash types and certain road user behaviors (e.g., impairment, distraction), practitioners can identify not only high crash locations, but also those locations that have a high number of fatal and injury crashes, and those that have particular identified contributors.

Once identified, a practitioner can rank intersections, route segments, and other roadway locations by crash frequency, personal injury severity, and/or other criteria (e.g., crash type, contributing circumstances). One outcome could be connecting the location of crashes to potential infrastructure or operational elements like sharp curves, sight distance limitations, or outdated signal timing.

**Crash Averaging.** Studying crash history requires some basic knowledge of statistics, because it can be easy to make inaccurate conclusions based on too little data or confounding factors.

Crash averaging allows the practitioner to analyze multiple years of data for analysis. Due to the randomness of traffic crashes, it is likely that a single year could have a much higher or lower number of crashes than the typical average year. Three to five years of data often provide a strong balance of enough time to develop a solid average (and trending information), but not so much time that conditions at the site have changed significantly.

A rolling average takes additional years of data to provide a more “flattened” look of past data to identify changes over time, but not be distracted by a 1- or 2-year spike or dip. Table 2.1 shows a basic rolling crash average at a given location.

**Crash Rates.** Crash rates can be used to compare the relative safety of multiple locations with similar but nonidentical attributes. The combination of crash frequency and vehicle exposure (traffic volume, roadway length, or regional population) provides information needed to calculate a crash rate. Traditional crash rates are expressed as "crashes per Million Entering Vehicles (MEV)" for intersection locations and as "crashes per 100 Million Vehicle Miles Traveled (VMT)" for roadway segments.

The benefit of crash rate analysis is that it can provide a more level playing field when comparing a number of locations within a jurisdiction. By normalizing the data, a high number of crashes is not the only criterion used to make decisions on safety treatments.
Table 2.1. Rolling crash average example

<table>
<thead>
<tr>
<th>Year</th>
<th>Crashes</th>
<th>5-year period</th>
<th>Rolling 5-year average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>20</td>
<td>2007–2011</td>
<td>19.8</td>
</tr>
<tr>
<td>2012</td>
<td>18</td>
<td>2008–2012</td>
<td>20.4</td>
</tr>
<tr>
<td>2013</td>
<td>36</td>
<td>2009–2013</td>
<td>21.4</td>
</tr>
<tr>
<td>2014</td>
<td>25</td>
<td>2010–2014</td>
<td>22.2</td>
</tr>
<tr>
<td>2015</td>
<td>42</td>
<td>2011–2015</td>
<td>28.2</td>
</tr>
</tbody>
</table>

**Segment Rate Calculation**

The crash rate for a road segment is calculated as:

\[
R = \frac{C \times 100,000,000}{V \times 365 \times N \times L}
\]

where \( R \) is the crash rate for the road segment expressed as crashes per 100 million VMT; \( C \) the total number of crashes in the study period; \( V \) the number of vehicles per day (both directions); \( N \) the number of years of data; and \( L \) the length of the roadway segment in miles.

If a segment of road was being assessed with the following values:
- \( C = 10 \) crashes over the past 5 years on this segment,
- \( N = 5 \) years of data,
- \( V = 2,000 \) vehicles per day,
- \( L = 25 \) miles,
then the resulting segment crash rate,

\[ R = \frac{10 \times 100,000,000}{2,000 \times 365 \times 5 \times 25} = 10.96 \text{ crashes per 100 million VMT} \]

**Intersection Rate Calculation**

The most common equation used to calculate a crash rate at an intersection is as follows:

\[ R = \frac{C \times 1,000,000}{365 \times N \times V} \]

where \( R \) is the crash rate for the intersection expressed as crashes per MEV; \( C \) the total number of intersection crashes in the study period; \( N \) the number of years of data; and \( V \) the number of vehicles entering the intersection daily from all directions.

If an intersection were being assessed with the following data:

- \( C = 52 \) total crashes over the past 5 years,
- \( N = 5 \) years of data,
- \( V = 9,000 \) entering vehicles per day,

then the resulting intersection crash rate,

\[ R = \frac{52 \times 1,000,000}{365 \times 5 \times 9,000} = 3.17 \text{ crashes per MEV}. \]

**Limitations of Crash Rates.** It is important to understand the limitations of crash rate calculations. On a segment shorter than 1 mile, the formula will be divided by a number less than 1, which effectively multiplies the effect of a single crash. Also, urban crash rates and rural crash rates tend to be much different due to prevailing speed of vehicles, roadway alignment, and some human behaviors. Similarly, crash rates on Interstate highways are typically much lower than narrow, two-lane roadways due to roadway design differences.

For these reasons, it is important that when using crash rates, analysts should only compare locations that are somewhat similar in terms of traffic volume, length, urban/rural location, and roadway type.

**Advanced Analysis.** A number of resources, including the *Highway Safety Manual*, provide information about statistically rigorous crash history
analyses and methods, including the use of safety performance functions that incorporate some of the same data elements discussed in this book (e.g., traffic volume, number of lanes, lane width, roadway alignment, traffic control type) to identify an expected number of crashes per year for a given intersection or segment. That information can be compared to the actual crash history to determine if a location is operating as safely as expected.

**Identifying Potential for Crashes without Crash History.** Although much of the safety analysis focuses on examining a jurisdiction's crash history to identify locations for treatment, it is also important to find intersections and segments that show potential for future crashes. The reality is that we cannot stop crashes that occurred in the past, but we can attempt to prevent crashes from occurring in the future. This can be accomplished as follows:

1. Determine which roadway- or traffic-related issues are most likely to contribute to safety concerns.
   a. Geometric elements, lane/shoulder configuration, roadside design elements.
   b. Location types: work zones, school zones, curves, rural expressway intersections.
   c. Traffic volume and patterns.
2. Identify intersections and segments with these roadway or traffic features. Even though some roadways with these attributes have yet to experience a high number of crashes, the roadway or traffic attributes may point to a potential for future safety problems. This provides safety experts an opportunity to prevent traffic crashes before they occur.

**Limitations to Location-based Analysis.** The potential inaccuracies of location-based crash reports must be considered during analysis. For example, a non-intersection location may be coded as “one-half mile south of Main Street” in a database, but in reality that was a rough estimate made by the reporting officer or a citizen. Analysts should not assume high precision from this type of location identifier. Additionally, sometimes the report may simply have errors related to the direction of vehicle travel, indication of the North arrow on the diagram, or the indication of traffic control devices (e.g., traffic signal, two-way stop, all-way stop, and so on) at an intersection.
In addition, previous crashes at particular locations do not guarantee that future crashes will occur at the same place. However, a history of crashes is an indicator of future risk, as the crash history indicates a potential opportunity for infrastructure improvement, increased law enforcement efforts, or education/marketing efforts to improve safety.
Like Sherlock Holmes, the role of the traffic safety professional is to use evidence to solve the mysteries of crashes occurring on the roadway. Also like Mr. Holmes, engineers and analysts have many tools, insights, and strategies at hand to help in their traffic safety investigations.

3.1 CRASH REPORT

As discussed in Chapter 2, each time a law enforcement officer responds to a crash event, he or she completes a crash report form to help “tell the story” of the incident.

The crash report includes the following types of information:

- **Crash-level** data elements provide information about the crash as a whole. Examples include date, time, weather conditions, and roadway surface conditions.
- **Vehicle-level** data elements include characteristics of the motor vehicles involved in the crash, the events that occurred with each vehicle, and the results. Examples include vehicle body type, direction of travel, vehicle actions, and most harmful event.
- **Person-level** data elements describe the characteristics of persons involved in a crash, the actions each person takes, and the resulting personal injury consequences of the crash event.
3.1.1 CRASH-LEVEL DATA ELEMENTS

Identification Number. Each crash has an identifier (typically a number) that is unique to that event. This allows all other data related to the crash to be tied together, and it allows aggregation of data without “double-counting.” In the Wyoming example illustrated in Figure 3.1, the state uses “Case No.” in the top-right of the report form to indicate each as a unique case.¹

Figure 3.1. Wyoming crash form, page 1, 2007

Date and Time. Understanding the date and time of the crash may provide analysts information about the circumstances. Combining this information for multiple crashes may help identify problematic time(s) of day or day(s) of the week at this location.

Crash Location. In most cases crash report data are populated in a database that is searchable by location. When a safety professional needs information about an individual intersection, curve, segment, or other specific location, he or she can search the database for information at that location. Crash reports will typically contain the county, city, and one or more of the following attributes:

Latitude/Longitude Coordinates. Identifying the latitude/longitude of a crash ties that incident to a specific place on the earth, regardless of future changes to roadway alignments, log miles, and so on. This method facilitates multilayer mapping of other safety-related information that also uses latitude/longitude coordinates.

Linear Referencing System. A linear referencing system (LRS) starts with a linear representation of the roadway (typically measured in log miles by county or log miles by state). Then the crash event is tied to the roadway at a particular point (log mile) as its reference. An advantage of the LRS is that all data can be located on the map by specifying a single point on that line (versus the two points needed with latitude and longitude).

Identifying the location accurately is not as easy as it may seem. First of all, the law enforcement officer completing the crash report is almost never at the scene of the crash when it occurs. Therefore, he or she is “piecing together” the story of the incident based on physical evidence at the scene (e.g., current placement of vehicles, skid marks, details of vehicles and other property damage), accounts from those involved whose version of the event may not be entirely accurate, and accounts from witnesses near the scene.

In addition, the term “location” is not always easily identifiable. For example, a vehicle that runs off the road in “the middle of nowhere” is sometimes difficult to locate accurately on a map. Further, the tools used to identify location (either with latitude/longitude or LRS) can be used incorrectly. For example, Global Positioning System (GPS) devices in law enforcement vehicles must be activated to provide accurate latitude/longitude information. In one example, analysts discovered a high number
of crashes at a particular location, sharing it with safety engineers as a concern. Upon investigation it was discovered that the location in question was the law enforcement officer’s driveway. The system had not started in the morning, and the automated system had pasted the leftover GPS data into the crash form.

For interchanges and intersections, it can be important to know exactly where within the junction a crash occurred. In some cases, interchanges and intersections are fairly complex, so locating a crash inside that junction requires additional effort. For complex interchanges there will be a vertical component (e.g., two or more ramps running over/under each other), which results in the same latitude/longitude and more than one location.

**Harmful Events.** The crash report will identify those events that were the first and/or most harmful to vehicles or persons involved.

*First Harmful Event.* This element is the first action to cause damage to a vehicle or injury to a person. Examples include overturn, collision with a motor vehicle or person, or collision with a fixed object (e.g., traffic sign support, bridge rail, or tree).

*Most Harmful Event.* This is the action that caused the most vehicle damage or personal injury.

**Environmental Conditions.** These elements explain the conditions of the environment surrounding the crash event.

*Weather Conditions.* Identifying the weather conditions can help determine if certain crash types occur under certain weather. Examples include clear, rain, snow, fog, and wind.

*Road Surface Condition.* This element identifies the surface of the roadway itself at the time of the crash. Examples include dry, wet, ice, and debris. A high number of crashes in wet conditions could indicate poor pavement friction.

*Light Condition.* This element shows the type of light and its level at the time of the crash. Examples include daylight, dark-lit, and dark-not-lit.

### 3.1.2 VEHICLE-LEVEL DATA ELEMENTS

These elements provide specific attributes for each vehicle in the crash. In some cases, there can be multiple vehicle records in a single crash report.
**Motor Vehicle Make, Model, and Body Type.** Identifying a specific vehicle by make and model can help an analyst visualize the crash, and the aggregation of this information can identify trends. General information about the vehicle body type (e.g., passenger car, tractor trailer, motorcycle, school bus) can be important to understand the actions leading to the crash. Some vehicles may have special safety needs.

**Speed Limit.** Though it may seem more natural for this element to fit in the Crash Elements, it must be included here. Multiple vehicles may be traveling on intersecting roadways with differing speed limits, or the vehicle body types may necessitate different speed limits. For example, on some freeways large trucks have a special speed limit—say, 60 mph—while passenger cars have a posted speed limit of 65 or 70 mph.

**Roadway Information.** Similar to speed limit, roadway data are often included in the crash report by vehicle. Examples include number of lanes, road alignment (straight or curve), grade, and the type(s) of traffic control devices for that vehicle.

**Sequence of Events.** This element shows what action(s) the vehicle took prior to and during the crash event. Examples include changed lanes, turned left, ran off roadway, crossed median, collided with pedestrian, collided with utility pole, and overturned. The crash report will include a number of events (usually three to eight) per vehicle.

### 3.1.3 PERSON-LEVEL DATA ELEMENTS

Person-level elements provide information about each individual involved in the crash, whether they were a motor vehicle driver or passenger, pedestrian, or otherwise involved. Note that in many cases personal information is held proprietary by the jurisdiction and is not available to the public. Agencies must take care to protect the identity and personal information of citizens involved in traffic crashes.

**Identifying Information.** The crash report will include each person’s name, date of birth, and gender, which can be aggregated to develop trends, including young driver-related and older driver-related crashes. For motor vehicle drivers and passengers the seating position in the vehicle may also be included.
Injury Status. The personal injury status of each person involved (using the KABCO scale discussed previously) helps show the overall impact of this crash on the people involved, separate from damage to vehicles and other property.

Behavioral Issues and Condition. For each person involved, the crash report will include information to answer the following questions related to driver decisions that typically occur before the trip begins.

Restraint Use. Was the person buckled in a seat belt (if in a motor vehicle) or wearing a proper helmet (if riding a motorcycle or bicycle)?

Impairment. Was the person under the influence of alcohol or other drugs? Was blood alcohol content information collected at the scene or at another location, how was it collected, and what were the results?

Fatigue. Was a driver drowsy at the wheel or asleep prior to the crash?

Driver Decisions and Actions. These elements are related to the choices the road user makes prior to and during the crash.

Speeding. Likely data element fields include Too Fast for Conditions and/or Exceeding the Posted Speed Limit.

Contributing Actions. These are actions occurring on scene that may have contributed to the crash. They may or may not be motor-vehicle-moving violations. Examples include failure to yield, following too close, and improper passing.

3.1.4 TELLING THE STORY: CRASH NARRATIVE AND DIAGRAM

As the officer’s crash report is considered a story and the safety analyst’s role is an investigator, some of the most important information learned about a crash is qualitative. The event narrative—including the officer’s observations, driver and passenger statements, and witness accounts—literally “tells a story” of the crash. Additionally, the crash diagram is the “picture that tells a thousand words” of the incident.
Crash Narrative. An officer has the opportunity with the narrative section of the report to provide a detailed account of the crash event, and to add pertinent information that may not be easily added in the other sections of the report. Common elements of the crash narrative include the following:

Environmental Elements. These may include whether the crash was in a work zone or other atypical environment, whether workers were present in the work zone, and so on. There may have been another incident (traffic crash, stalled vehicle, other road-related issue) that occurred previously and contributed to this crash.

Statements from Involved Parties. The narrative can include descriptive statements by drivers, passengers, other road users, and witnesses to the crash. In some cases a driver may state what he or she saw, or the reason for their error on the roadway. Examples may include statements like “The sun was in my eyes” or “I looked down at the radio, and then hit the car in front of me.”

Overall Story of the Event. The officer will often provide an overall story of what occurred in the crash through the narrative, with supporting evidence (e.g., physical, testimonial from involved parties). This is sometimes not feasible to collect through the typical check-box setup of other report sections, so the narrative helps bring it all together.
Crash Diagram. This section of a crash report allows law enforcement officers on the scene to describe the details of the crash event.

Geometry. This is the layout of the roadway, intersection, and nearby environment, complete with any pertinent geometric issues. These could include grade, roadway geometric design, and traffic control devices.

Vehicle Placement. Information includes a visual representation of the number of vehicles and the specific location of each vehicle involved, providing easy-to-understand information about exactly where the crash took place, and the location and position of each vehicle at the time of the crash.

Vehicle Action. The diagram includes a graphic version of the action of each vehicle to show its movement at one or more points in time during the crash event. For example, Vehicle 1 may be shown avoiding Vehicle 2 that stopped in the roadway, then losing control and running off the road, and then colliding with a tree.

3.2 CRASH HISTORY DIAGRAM

The first section of this chapter focused on the crash data collected on scene to develop a crash report for a single crash. This section describes the compilation of multiple crash reports to develop a crash history diagram.

To identify crash patterns at a single location, safety professionals can combine the basic information from individual crash reports to develop a crash diagram (Figure 3.3). Elements typically added to the diagram for each crash include:

- Crash type (e.g., head-on, angle, rear-end)
- Date
- Time of day with special emphasis on day/night

Laying out multiple crashes in a single diagram can help an analyst identify patterns related to the elements listed above. Examples may include:

- A high number of a certain crash type
- A high percentage of crashes occurring at night
- Most crashes occurring on a single intersection approach
Figure 3.3. Crash history diagram example
(Image Credit: FHWA Road Safety Audit Toolkit for Federal Land Management Agencies and Tribal Governments, FHWA-FLH-10-0011)
Once practitioners identify safety needs through the study of individual crash reports and multi-incident crash diagrams, they can begin connecting those crash types and locations to potential solutions.

4.1 CRITERIA FOR SELECTING COUNTERMEASURES

Safety countermeasures can be deemed applicable by the following criteria:

- Data-supported, established success
- Local success
- Engineering judgment
- Feasibility of implementation (cost, political/public acceptance)

4.1.1 DATA-SUPPORTED, ESTABLISHED SUCCESS

Some safety countermeasures have been rigorously researched over time in multiple environments, and researchers have published results to provide practitioners solid evidence of the treatment’s value. These values are sometimes defined as crash reduction factors (CRFs) or crash modification factors (CMFs).
Crash Reduction Factor. Historically, safety practitioners used a CRF to calculate the percent reduction of crashes expected to occur after a treatment was introduced at a site. For example, an advanced curve warning sign installed before a curve with a history of crashes may be expected to reduce those crashes by 20 percent. A location with 30 crashes in a “before treatment” study period could be expected to have those reduced by 6 crashes (20 percent of 30), resulting in 24 crashes in an “after treatment” study period of the same duration.

The advantage of the CRF is that it can be easily understood by nonresearchers: transportation partners within an agency, decision makers in management roles, elected officials, and the general public.

Crash Modification Factor. The CMF term was introduced in the mid-2000s and popularized in preparation for the Highway Safety Manual in 2010. A CMF is essentially the mathematical inverse of the CRF, calculated as $CMF = 1 - CRF$. CMFs tend to be used more often during research studies for the following reasons:

- The CMF is a multiplicative factor, so multiple treatments can be mathematically combined more easily than multiple CRFs.
- CMFs allow for much easier application of a condition that could increase crashes by using a CMF greater than 1.0. For example, reducing the width of shoulders on a roadway may have a CMF of 1.10 (depending on how much the shoulder width is reduced). This equates to an expected 10 percent increase in crashes.

However, CMFs are more difficult to explain to nontechnical stakeholders. In the example above, the 20 percent reduction is easily understood by most, while a 0.80 modification of crashes—though accurate—can be confusing.

The Federal Highway Administration has developed a clearinghouse to collect and continuously update research on the quantified benefit of safety treatments. The CMF Clearinghouse offers this repository of CMFs and additional related resources to transportation practitioners. It is available at www.cmfclearinghouse.org (Figure 4.1).
4.1.2 LOCAL SUCCESS

In some cases, a state or local agency will implement a countermeasure and then rely on their local experience to choose whether to use it again in the future. Results have the advantage of being local. Some are less comfortable with research studies of treatments from elsewhere, and they prefer the comfort of knowing something worked in their geographic area. The disadvantage is that the results are often not as rigorous due to a relatively small sample size. They are typically basic before/after studies (sometimes referred as “naive studies”) that do not take as many research-related factors into account. Transportation professionals must weigh these pros and cons if they use local data for decision making.

4.1.3 ENGINEERING JUDGMENT

Regardless of previous local experience or rigorous, statistically sound safety data analysis, each location is different and requires some understanding of its unique attributes. Engineers and other safety professionals must exercise judgment to determine the best safety solution to a given problem.

In many cases, there will be small nuances about installing countermeasures that can enhance or reduce their effectiveness. For example, chevron alignment signs should be installed at certain spacing around a curve, and this spacing varies based on the degree of curvature (i.e., its “sharpness”) and the associated advisory speed for traversing the curve. Once that spacing is laid out on paper and the practitioner goes to the site, he or she may discover that a driveway is located at the exact location one of the chevrons should be. Since it is not feasible to move a driveway for sign placement purposes, judgment must be used to determine the best course of action. In this case it could be shifting all signs to keep the desired spacing, or just moving one or two to a different location to accommodate the existing driveway.

4.1.4 FEASIBILITY OF IMPLEMENTATION

On publicly accessible roadways, which most are, there are many perspectives to consider before installing a treatment. Sometimes what may be considered a perfect solution by safety engineers is simply not feasible for the public, elected leaders, nearby business owners, or other transportation stakeholders. Collaboration is an important aspect of transportation work.
Every transportation project costs money, and due to resource limitations, when one project is selected many others are not. Therefore, cost must be a factor when determining which countermeasures to apply at a given location, and more broadly across the transportation system.

Public acceptance is key to any transportation project. Transportation issues affect everyone, so citizens have opinions about how their system should be designed and operated. Safety is a particularly heightened subject due to the emotional aspects of traffic crashes (especially those involving injuries and fatalities). Bringing the public into the process as soon as possible—even during initial analysis and review of potential countermeasures—can help them understand the decision-making process, site limitations, budget realities, and any potential undesirable effects of certain treatments.

For example, one countermeasure to reduce high-speed angle crashes on expressways is a median U-turn intersection. This design requires a motorist who would normally drive straight across an expressway to make a new series of movements: Turn right, make U-turn, and then turn right again. This takes longer and requires some opposite-direction travel, which is not always understood or accepted by the public. It is important to discuss the safety value of this treatment with the public and be clear about the cost (e.g., additional travel time).

4.2 COUNTERMEASURES

The following chapters are loosely organized around a few elements of traffic crashes—location, crash type, and road user type. Each includes an introduction of the topic and a list of safety countermeasures. Each countermeasure is organized as described in this example from Chapter 6.

**EXAMPLE COUNTERMEASURE**

*Lighting.* Adding overhead lighting can provide a safety benefit by improving visibility of the roadway—especially in curves. Seeing the roadway is an important factor in navigating its geometry. The public tends to support overhead lighting installations due to these benefits, and also for general perceived public security benefits of having more of their community lit at night. When installing lighting, the following should be considered.
**Power Source.** Lighting requires electric power, and depending on the location of need, feasibility can be affected by the distance between the necessary lighting and the nearest power source.

**Electricity Costs.** One downside of lighting is the ongoing cost associated with its use. When considering this treatment, practitioners must calculate the utility cost. In recent years this has become a less significant financial issue with the introduction of high-efficiency street lights.

**Lighting Pole Location.** Utility pole installation introduces a new fixed object to the roadside, so care must be taken regarding placement. For example, it is important to install signing on the inside of the curve instead of the outside. Adding a light pole to the outside of the curve increases the chances that it could be hit by an errant vehicle.

Following are the upcoming chapters.

**Chapter 5—Intersections.** One of the most likely locations for a traffic crash is at the point where different directions of travel cross. This occurs most often at intersections. This chapter will focus on countermeasures to address safety problems at signalized and unsignalized (e.g., stop-controlled or yield-controlled) intersections.

**Chapter 6—Lane Departure.** More than half of fatalities in the United States are the result of lane departure crashes. Specific crash subtypes include run-off-road, overturn, head-on, and cross-median crashes. Systemic countermeasures can be particularly cost-effective for lane departure crashes, including signing, rumble strips, and pavement marking.

**Chapter 7—Work Zones.** The introduction of a work zone (construction, maintenance, utility, or other), by its very nature, violates road user expectations. The closure of lanes and installation of new road layouts and traffic control can make it difficult for motorists and other road users to navigate the area. Along with those traveling through the work zone, workers are particularly vulnerable. Countermeasures include signing, pavement marking, delineation, and crash cushions.

The final chapters, **Chapter 8—Implementation of Countermeasures**, and **Chapter 9—Conclusion/Future of Traffic Safety**, discuss approaches to implementation, safety management, and other cross-cutting issues related to emerging needs in roadway safety.
INTERSECTIONS

Excitement is a crossroad which runs in all directions. No man lacks personality; he just never connected with you at the intersection.

—Criss Jami, Kilosophy

Intersecting roadways are, by their very nature, potential points of conflict. Road users are changing direction and/or interacting with others who do. Even drivers traveling cross-country will, from time to time, drive through intersections. They range for relatively simple, four-leg, two-way-stop-controlled intersections to wild conglomerations of pavement, signals, signs, and stripes. Users can range from traditional motor vehicles to every type of road user (pedestrians, bicyclists, horse-and-buggy, trucks, buses, emergency vehicles, semi-trailers, and over-sized loads).

More than 26 percent of all fatal traffic crashes in the United States occur at intersections.¹ Safety at intersections is a complicated proposition. No two intersections are exactly alike, so choosing countermeasures for one will not necessarily guarantee effectiveness for another. Transportation professionals must take care to understand the nuances of the intersection they are studying.

Most intersection crashes involve more than one vehicle, meaning multiple contributing circumstances from multiple drivers affect the outcome. The rules around right-of-way (i.e., “who gets to go first”) at intersections can be complex, too. At a signal-controlled intersection, a motorist in a left-turn lane can sometimes freely turn left (via protected left-turn movement with a green arrow), other times can turn left only if no other traffic is approaching from the opposite direction (via permissive movement with a green ball or flashing yellow arrow [FYA]), and sometimes must stop and wait, even if there are no other road users nearby (red signal indication).

And these are just the legal movements. In some cases this same left-turning
driver could still end up in a traffic crash at no fault of his or her own if
someone else makes a mistake. Intersections are the most collaborative loca-
tion on the roadway system, and a single-user error can affect multiple oth-
ers. Users navigate in cooperation with each other and the jurisdiction that
designs and operates the roadway.

Countermeasures at intersections are numerous and range in complexity.
Some of the most useful are quite basic—signs to warn of the intersection’s
presence, pavement marking to help drivers navigate through the intersec-
tion, and the most iconic of all traffic signs—STOP.

More complex safety treatments include traffic signals, innovative de-
signs, additional signing and pavement markings, and new ways of defining
intersections (e.g., roundabouts, continuous flow intersections, and so on).
The following sections are organized by intersection control—uncontrolled,
unsignalized (including stop-controlled), and signalized. Intersection traffic
control is very important to safety practitioners as they determine the most
appropriate countermeasures to address safety needs.

5.1 UNCONTROLLED INTERSECTIONS

The most basic intersection is one with no traffic control—no Stop signs,
Yield signs, signalization, or any other devices to provide right-of-way infor-
mation to approaching road users. In this case much of the burden is placed on
drivers and other road users to navigate the intersection safely. Uncontrolled
intersections are most commonly found in two low-traffic-volume situations:
rural areas with very long sight distance or neighborhoods with low intersec-
tion approach speeds. In the first case, approaching vehicles can easily see
each other and yield the right-of-way as required. In the second, low speeds
allow each intersection to act as an “all-way-yield” where each driver looks
out for others, then proceeds once the intersection is clear.

Problems at uncontrolled intersections occur when sight distance
becomes limited, speeds increase, or traffic volumes increase to the point
that taking turns without official traffic control becomes problematic. The
following countermeasures can support safety at these locations.

5.1.1 SIGHT DISTANCE IMPROVEMENTS

Intersection sight distance is defined as the distance a motorist can see an
approaching vehicle, typically from a perpendicular leg of the intersection.
For uncontrolled intersections this is a dynamic distance, ever-changing as vehicles approach. Motorists see each other across the *sight distance triangle*, a shape created by placing a point at the driver’s eye, the object that driver is attempting to see (in this case, an approaching vehicle from the right or left), and the potential point of conflict if both vehicles were to arrive at the intersection at the same time (i.e., the midpoint of the intersection). See Figure 5.1 for an illustration of this triangle at an uncontrolled intersection.²

![Sight distance triangle for an uncontrolled intersection](image)

Uncontrolled intersections rely heavily on sight distance for safety since the right-of-way is not determined by a sign, but rather first-come, first-served and other rules of the road (e.g., drivers must yield to users on their right). A number of items can obstruct the view of one or more drivers, including utility equipment (e.g., poles, transformers, boxes, and so on), billboards or other signs, buildings, parked cars, or vegetation.

Vegetation includes trees, hedges, bushes, and seasonal crops. In some parts of the country the sight distance may be appropriate for most of the year, but some crops, like corn and wheat, can become a significant sight obstruction in the late summer and autumn. Solutions to sight distance obstructions typically include removing the obstructions from the sight distance triangle. When completed drivers will be able to see approaching vehicles on the opposing approaches, and therefore make better decisions about entering the intersection safely.

5.1.2 ADD TRAFFIC CONTROL

One of the most effective ways to address crashes occurring at uncontrolled intersections is to add devices to control the right-of-way. Most commonly this is a conversion to a two-way stop-controlled intersection. To determine which direction should receive the STOP signs, transportation professionals should consider two main criteria: traffic volume and sight distance. Counting the number of vehicles entering the intersection determines which direction should be considered the “mainline road” and which should be considered the “side street.” Based on volume the STOP signs should be placed so that side street motorists stop and then yield to mainline traffic before proceeding.

Another criterion must be considered to address safety at this new two-way stop-controlled intersection. Sight distance continues to play a role. Motorists at the STOP sign must have sufficient intersection sight distance to see approaching vehicles from their position at the STOP sign. If sight distance varies greatly among the approaches, practitioners should consider placing STOP signs on the legs with the better sight distance, since those road users will have the burden of ensuring they are not causing a conflict at the intersection.

Care must also be taken related to how the addition of a STOP sign at the study location could affect driver expectations at adjacent uncontrolled intersections. In an area with many uncontrolled intersections, installing STOP signs at only one location could violate driver expectations or cause confusion at other intersections nearby.

5.2 TWO-WAY STOP-CONTROLLED INTERSECTIONS

A common intersection includes four legs, two that are controlled by STOP signs and two with no control. Another common arrangement is a
three-legged “T” intersection with the STOP sign for one direction (the vertical line of the T, called the “stem”).

Safety problems arise at stop-controlled intersections for the following reasons:

1. Side street motorists run the STOP sign (either on purpose or inadvertently) and collide with mainline vehicles or run into the end of the roadway, which could be a rock bluff or ditch.
2. Side street motorists stop, and then pull out in front of mainline vehicles.
3. Mainline motorists are unable to react to a mistake made by side street motorists, resulting in a collision.

Solutions to crashes at two-way stop-controlled intersections usually fall under one of these categories:

1. Additional conspicuity of the stop condition through enhanced STOP signs and other methods.
2. Warning of an upcoming stop condition with signing, pavement marking, rumble strips, or technological solutions.
3. Traffic calming to reduce speeds of all entering vehicles.

In most cases practitioners should start with the most basic and low-cost treatments to address stop-controlled intersections with safety needs. In many cases a small, low-cost countermeasure can have a significant effect allowing safety experts to reserve funding for a higher number of low-cost treatments and saving higher-priced countermeasures for those sites that do not respond to less-expensive solutions.

5.2.1 STOP CONDITION CONSPICUITY

It is very important for road users to see and have ample time and space to react to a stop condition at a two-way Stop-controlled intersection. The following treatments can help improve the conspicuity of the intersection for approaching motorists.

STOP Sign Replacement. As one of the most important signs on the roadway, it is concerning that there are thousands of nearly unreadable STOP signs on the roadway due to age. The life of a typical highway sign is approximately 10 years barring specific weather damage, vandalism, or
impact with vehicles. In some environments, however, and depending on the direction the sign faces, it could lose its retroreflective properties more quickly.

**Vegetation Removal Near Signs.** Foliage can grow such that it blocks the STOP sign and otherwise makes it difficult for motorists to identify the upcoming intersection. Trimming trees and other vegetation can help motorists see the STOP sign with plenty of time to respond.

**Increased STOP Sign Size.** The standard size of a STOP sign is 30 to 36 inches, depending on roadway. By increasing the size of the sign, its target value increases, which increases the opportunity it will be seen by approaching motorists. STOP sign sizes of 36, 48, and 60 inches have been used by state and local agencies for this purpose.

**STOP Sign Full Post Retroreflective Strip.** To increase target value of the STOP sign, practitioners can install a narrow red retroreflective strip to the sign post (see Figure 5.2). This adds more square inches of red material to the sign installation, and it also visually “ties” the STOP sign to the ground, which can be especially useful in dark conditions when the post would typically not be visible.

*Figure 5.2. Full post retroreflective strip STOP sign enhancement*
**STOP Sign Flashing Beacon.** The addition of a red flashing beacon to the top of the STOP sign, or light-emitting diode (LED) lights around the outer border, can increase the sign’s conspicuity. This can be a static flasher (i.e., flashing on-and-off constantly); it could be activated by every approaching vehicle; or it could be activated only by vehicles approaching at a certain speed or greater.

**Supplementary STOP Signs.** In some cases the standard placement of the STOP sign may be in a location that is difficult for approaching motorists to see, or it could be blocked by vegetation or other items. Placing a second supplementary STOP sign provides another opportunity for road users to see it.

The ideal location for this second STOP sign is in the middle of the stop approach. In some cases agencies are able to add a relatively small (e.g., 6 ft wide) raised or painted splitter island at the side-street intersection approach to install the STOP sign at this location. The curb of this island and associated pavement markings show the motorist that he or she is entering an intersection. This installation is feasible only if sufficient pavement width were available for the installation, and if the additional sign did not disrupt turning movements from mainline vehicles—especially large trucks.

If a median splitter island is not feasible, then placing the supplementary STOP sign on the far left of the approach can still provide conspicuity benefits.

**Stop Bar Placement.** In some cases the position of the STOP sign can make it difficult for a motorist on the side street to achieve optimal sight distance. Adding a stop bar (typically a 12-inch white pavement marking that stretches across the width of the approaching lane) can help with vehicle placement and sight distance optimization. Additionally, a stop bar can add conspicuity to the intersection if the STOP sign is not easily seen.

In addition to the stop bar, the word “STOP” can be added to the pavement just before the stop bar to provide motorists additional information.

**Approach Pavement Markings.** For side street and mainline approaches, edgeline and centerline pavement marking in advance of the intersection can provide vehicle placement guidance to entering motorists. On the mainline, a gap in the pavement marking is required to indicate the presence of an intersecting roadway.
**Double-Arrow Warning Sign.** At three-leg intersections the stem of the T is normally the stop-controlled leg, and opposite the stem is an ideal location for additional signing for increased conspicuity. Installing a double-arrow warning sign at this location provides more information to approaching vehicles of (1) the stop condition and (2) the end of the roadway. The double-arrow warning sign can be enhanced further with barricades or flashing beacons to make it even more conspicuous.

**Vegetation Removal for Sight Distance.** Vegetation can cause problems in the sight distance triangle. Ensuring these areas near the intersection are clear improves visibility for approaching road users, and also “opens up” the intersection so it can be easily recognizable as such.

**Lighting.** If signs and pavement markings are nonexistent, worn due to age, or covered by snow or vegetation, the intersection could be difficult for approaching motorists to identify at night. This can be of particular concern in rural areas with less ambient light.

Adding overhead lighting to an intersection can provide a significant benefit to its conspicuity in dark conditions. An added benefit is that the light poles make the intersection easy to identify in the daytime too. Studies have shown reduction in both day and night crashes after the installation of lighting.

Access to a power source is sometimes a concern, especially in rural areas that may not be near a convenient power drop. Considerations must include ongoing power costs of lighting, though with current and emerging technologies for street lights it is less expensive now than in the past.

### 5.2.2 ADVANCED WARNING

Providing both mainline and side-street motorists advance warning of an upcoming intersection can help raise their awareness before they reach it.

**Intersection Warning Signs.** For mainline road users, the Intersection Warning sign informs them of potential conflicts with side street motorists. The two most common are the CROSS ROAD sign and SIDE ROAD sign. Even though the mainline drivers do not have responsibility to stop at the intersection, this information may help with awareness as they approach. The signs can also help reduce the probability of rear-end crashes by alerting approaching drivers that someone ahead may be slowing to
turn. The distance from the sign to the intersection is determined by sight distance and prevailing speed.

Providing a second, left-mounted intersection warning sign is a low-cost way to improve conspicuity of this sign and give extra warning of the upcoming intersection. Practitioners typically place the supplemental left-mounted sign even with its right-mounted partner.

### FLUORESCENT YELLOW SIGN SHEETING

In the past few years some agencies have used fluorescent yellow sign sheeting to provide an enhanced warning sign to road users. In some conditions a standard yellow sign—especially after many years of use—can blend in with the natural environment. A fluorescent yellow sign stands out from the background colors, even during autumn when leaf colors are more likely to blend with signing.

**Street Name Plaques.** Adding the name of the upcoming side street to the Intersection Ahead sign provides help to road users with wayfinding, and also can help mainline drivers make turning movement decisions that give following motorists plenty of time to react. The driver can signal ahead of time, and in the case of left- or right-turn lanes they can get into those lanes—and out of the mainline traffic—sooner. This reduces the conflicts that can occur on the mainline as motorists sometimes make last-second decisions to turn.

**Stop Ahead Signs.** For side-street motorists approaching the intersection, a STOP AHEAD sign can provide the information necessary to prepare for an upcoming stop-controlled intersection. Historically this sign was recommended primarily for sight distance-restricted conditions (e.g., the STOP sign was hidden over a hill or around a curve). More recently it has been promoted as a valuable supplement regardless of sight distance. As with some other signs, the STOP AHEAD sign can be mounted both right and left to provide additional opportunity for road users to see it, or it can be oversized to increase its conspicuity.

**Warning Sign Post Retroreflector.** To increase target value of any intersection-related warning sign, practitioners can install a narrow yellow retroreflective strip to the sign post. This adds more square inches of yellow material to the sign installation, and it also ties the warning sign to the ground, which is especially helpful in dark conditions when the post would typically not be seen.
Warning Sign Flashing Beacon. The addition of a yellow flashing beacon to the top of advanced warning signs can increase conspicuity of the sign. This can be a static flasher (i.e., flashing on-and-off all the time), or it could be activated by approaching vehicles.

Stop Ahead Pavement Marking. As a supplement to the Stop Ahead sign, agencies can install the words STOP AHEAD on the pavement near the same location as the sign for additional emphasis. Pavement marking legends and symbols (i.e., “horizontal signing”) are only a supplement to standard signing due to two major limitations.

1. Pavement markings are not viewable during inclement weather. They are difficult to see during wet pavement conditions, and totally unreadable if the pavement is covered by ice or snow.
2. Pavement markings must be maintained regularly due to wear and tear, which occur quickly because of their location in the roadway lane. They may not be visible after even a few months after installation and before reapplication.

Transverse Rumble Strips. Transverse rumble strips add auditory and tactile warnings to the visual components of signs and pavement markings. They are placed within the travel lane. Practitioners can install transverse rumble strips in a number of ways:

- Grind strips into the pavement—typically less than ½ inch deep—using specialized equipment.
- Install a mounted rubberized surface on the top of the pavement. This is typically used only in regions that do not experience snowfall and associated roadway plowing.

Transverse rumble strips make noise with every vehicle, so practitioners must take care regarding placement so that nearby residences and business are not adversely affected. This treatment is most often installed in rural areas not in proximity to residential or commercial properties.

Advanced Warning Systems. Beyond the static warning signs and pavement markings, advanced warning systems combine vehicle detection and speed detection technologies to warn motorists of real-time potential conflicts. The warning may be provided by a beacon on the signs, LED lights around the sign borders, an overhead beacon at the intersection, or larger supplementary message signs.
Mainline Motorist. Detection of side-street vehicles can alert mainline motorists of a potential conflict ahead, especially if sight distance restrictions are an issue or the intersection has high-speed approaches.

Side-Street Motorist. Detection of the presence and speed of mainline vehicles can help road users on the side street make better decisions about entering the intersection. Speed detectors on the side street can alert motorists approaching a STOP sign that their speed may be too fast to stop comfortably. These flashers—triggered by a vehicle approach speed determined by an engineer—can be placed on the STOP sign, overhead, or both.

5.2.3 TRAFFIC CALMING

Lane Narrowing. By narrowing the approach lane for mainline motorists, practitioners can encourage reduced speeds through the intersection. For the side street, narrowing the lanes can provide room for a splitter island for a second, left-mounted STOP sign, and it can make the intersection more conspicuous.

In-lane Pavement Marking. A number of in-lane peripheral treatments have been tried on roadways to reduce motor vehicle speeds. Examples include bars across the lane that vary in depth and spacing, chevron-shaped pavement markings in the lane, and painted blocks placed on the edge of the lane (in the drivers’ peripheral vision) at different spacings. Most are designed to produce an illusion of acceleration to encourage speed reduction entering an intersection.

5.2.4 GEOMETRIC DESIGN

Skewed Intersections. The ideal alignment of the intersection of two roadways is 90 degrees, and motor vehicles are designed to help drivers see left and right at this angle. Any skew away from 90 can create a sight distance concern for motorists. Some parts of the vehicle can block sight distance (especially the pillars between the windshield and front doors), as can passengers in the front seat.

Eliminating or reducing the skew angle can provide safety benefits at an intersection by improving sight lines. Practitioners can improve the skew angle in a number of ways.
• **Realignment.** Changing the configuration of the intersection geometry is the most effective way to improve a skew problem, but also the most expensive.

• **Pavement Marking and Channelization.** In some cases a full realignment may not be necessary, as the problem can be addressed by improving vehicle positioning. At some skewed intersections there is extra pavement available. By creatively placing pavement markings and channelization (e.g., delineators or mountable curb), a practitioner can provide drivers a better location to position their vehicle for improved sight distance at a skewed intersection.

**Bypass Lanes at T-Intersections.** At T-intersections the “top” of the T provides an opportunity for through traffic to bypass left-turning motorists, traveling through the intersection without stopping. The result is similar to a left-turn pocket, though the design differs slightly, looking more like a “through lane bypass” on the right. The result is a potential reduction in the number of stopped vehicles awaiting a gap to turn left, which can reduce the number of rear-end crashes at the intersection.

5.2.5 **PAVEMENT TREATMENTS**

**Pavement Marking.** Pavement marking can be used on the side street approach to inform motorists that an intersection is upcoming. For the mainline drivers, a centerline double-yellow approaching the intersection disallows passing in advance of the intersection, which can reduce conflicts in the vicinity.

At signalized intersections, pavement marking can also include lane use control markings (i.e., in-lane arrow markings), stop bars, and painted splitter islands to separate different turning movements.

**Pavement Friction Treatments.** The friction of the pavement makes a big difference in its ability to work with a vehicle’s tires to stop the vehicle appropriately. Basic physics shows that reduced pavement friction can increase the time it takes a vehicle to stop once a driver applies the brakes.

Reduced friction at intersections is often caused by one of the following:

1. Pavement deterioration over time, reducing the friction of the roadway.
2. Rutting in the wheel paths because most motorists drive in the same part of the lane. When these paths become worn down, they create a small trough that can collect water and contribute to motorists losing control.

Water on the road reduces its friction so if dry pavement friction is relatively low or rutting has occurred, then these issues combined with wet weather can potentially lead to crashes.

Low-cost countermeasures to address wet pavement crashes include treatments to increase the friction of intersection approaches or fix wheel path rutting. Friction improvements can be made in the following manner:

1. **Overlays** of the roadway include adding a new surface (typically asphalt) on top of the current pavement to increase friction, fill ruts, and provide a smoother driving surface.
2. **Grooving** is sometimes considered on concrete pavement. Cutting small grooves longitudinally or laterally into the pavement surface provides better avenues for water to run off the roadway.
3. **Grinding** is sometimes conducted on concrete roads. It is normally just a “roughing up” of the surface to combat any friction-reducing polishing of the aggregate.
4. **High Friction Surface Treatment** (HFST) is a longer-lasting countermeasure that provides a higher friction value. A HFST product consists of an aggregate, a resin, and a binder. The aggregate is ideally a highly angular type of rock. The resin is epoxy or something similar. This treatment is more expensive than the others, but at intersections with a history of wet crashes it is likely to address the problem. Depending on the approach speeds, sight distance, and expected queue lengths, the length of a HFST installation at an intersection can vary.

5.2.6 **TRAFFIC SIGNAL TO ADDRESS UNSIGNALIZED INTERSECTION CRASHES**

Traffic signals can provide a significant safety benefit at an intersection. Research has shown that, under the right conditions, the installation of traffic signals can reduce the number and severity of crashes. However, inappropriately located or designed traffic signals can have a negative effect on traffic safety, so practitioners must take care in their placement, design, and operation.
A specific crash type that a traffic signal can often address successfully is a right-angle crash. By providing right-of-way control for conflicting movements, a traffic signal minimizes the decisions a road user must make at the intersection. Instead of requiring a driver to choose a gap in oncoming traffic, the traffic signal stops the conflicting motor vehicles and requires all users to take turns.

The MUTCD includes warrants and additional guidance for the installation of traffic signals based on traffic volume, crash history, and other criteria. These warrants are introduced in Section 5.4, Signalized Intersections.

5.3 EXPRESSWAY INTERSECTIONS

Expressways are defined as multilane divided highway facilities (usually four lanes—two in each direction) that include at-grade intersections. They are found in rural and urban areas. Rural expressways, in particular, can have very high mainline speeds—up to 70 miles per hour. These freeway-level speeds coupled with side street intersections result in a number of potential high-speed conflict points. Since many expressways tend to have high traffic volume, navigating the intersections to enter or exit the expressway can be problematic, and when crashes occur they often result in severe injuries and fatalities.

The conflict points are numerous. Vehicles crossing an expressway must watch for four lanes of traffic, coming from two directions, and traveling at high speeds. In some cases the median between the two directions is quite narrow, so side street motorists will attempt to cross all the four lanes and the median in a single movement.

Mainline traffic on expressways can have safety conflicts, too, especially related to turning movements at intersections. For example, a motorist wanting to turn left must first slow down, usually before a left-turn pocket is available, as high-speed traffic follows behind. Then the motorist must enter the (sometimes narrow) median to prepare to cross opposing traffic. The vehicle is sometimes situated awkwardly—not quite perpendicular, yet not parallel either—which can cause sight distance issues for the driver.

Recently safety experts have developed solutions to address expressway intersection crashes. Many are those introduced in the previous section on two-way stop-controlled intersections, with some modifications required to accommodate high-speed motorists, including increased sign sizes and modified placement. Additional solutions include those described in the following sections.
5.3.1 TURN LANE DESIGN

Right-turn Lanes. Motorists on high-speed expressways, when needing to turn right onto a side street, can benefit from a right-turn lane or pocket. This lane gets the right-turning motorists out of the mainline traffic, allowing them to slow and make their turn without causing a conflict with following vehicles.

In some situations this right-turn lane or pocket can be added to an existing cross section of expressway without adding pavement. If an expressway has a full-depth shoulder (i.e., the shoulder pavement is designed to handle traffic) then pavement markings alone can be used to create a right-turn lane.

Left-turn Lanes. For reasons similar to right-turn lanes, a left-turn lane/pocket on the mainline roadway provides a safer place for left-turn motorists to decelerate before making their turning movement.

Offset Left-turn Lanes. The difficulty with making a left turn on an expressway (from the mainline to the side street) is that a motorist can sometimes have difficulty seeing approaching vehicles. Similar to skewed intersections, the design of most expressway medians can create a situation where some parts of the vehicle or a front seat passenger blocks sight distance. Due to the speed of approaching vehicles (in some cases 70 mph or greater), excellent sight distance is imperative.

An offset left-turn lane at an expressway intersection provides the motorist with a better view of oncoming vehicles by putting them in the windshield view instead of the side window. By facing oncoming traffic, drivers can make a better gap judgment decision, reducing the opportunity for left-turn crashes (Figure 5.3).
5.3.2 ALTERNATIVE DESIGNS, ACCESS CONTROL

Median U-Turns. The crash type most likely to produce a fatality or serious injury at an expressway intersection is an angle crash. The purpose of the median U-turn treatment is to swap out this crash type for others that are typically less severe: weaving and rear-end crashes (Figure 5.4).

Figure 5.4. Median U-turn expressway intersection allowing right-in, right-out, and left-in movements

Median U-turns restrict access at the expressway intersection to either right-in-right-out only or right-in-right-out-left-in only. In both cases the through and left-turn movements from the side street are disallowed. Instead, motorists make a right turn onto the mainline, and then at another location downstream they make a U-turn to head back the “correct direction” toward their destination. If their initial desire was to drive straight on the side street, then their new movement is a right turn. If they initially wanted to make a left, then they simply continue on the mainline after the U-turn.

Possible conflict points include merging onto the mainline after the right turn, merging to the left lane to make the U-turn, and merging a third time onto the expressway again. However, the injury potential of these merging crashes is much less severe than an angle crash at the same location.

Care should be taken to provide adequate space between the main intersection and the U-turns, yet the distance must be perceived as reasonable by drivers since they are initially driving in a different direction than their intended destination.
5.3.3 GRADE SEPARATION

For some expressway intersections, one of the most effective options may be a grade-separated interchange. However, given the construction cost (10 to 100 times that of some of the treatments listed so far in this chapter), right-of-way needs, time needed for construction, environmental issues with a large project, and other constraints, grade separation is often not a feasible option.

That said, this book provides information about interchange safety and issues to consider in Section 5.6, Interchanges.

5.4 SIGNALIZED INTERSECTIONS

A traffic signal is designed to efficiently distribute right-of-way to conflicting movements at an intersection. Signalization can also help enhance mobility of some movements, such as a platoon of through traffic traveling along a major arterial. Because a traffic signal has two objectives—safety and mobility—there are situations where these conflict. It is important to know how each can affect the other to operate the safest signalized intersections possible and address road users’ mobility needs (Figure 5.5).
Intersections under traffic signal control have a unique set of needs. They are usually experiencing higher volumes of traffic than unsignalized intersections, and they are more likely to have a variety of road users, including motor vehicles, pedestrians, bicyclists, and users with special needs (e.g., children, older pedestrians, disabled pedestrians).

Additional information about the basics of traffic signal control can be found through a number of sources, including the Federal Highway Administration’s *Signalized Intersections Informational Guide*, most recently updated in 2013.

There are two types of crashes most likely to result in a severe injury or fatality at signalized intersections.

1. **Angle Crashes.** These typically occur due to a driver running a red light. Due to the speeds and angle of impact in this type of crash, results can be severe.

2. **Left-turn Crashes.** Left turns are the most complex aspect of signalized intersections, and how they are handled geometrically and with signal phasing directly affects safety and operations. Since these crashes include vehicles traveling in opposite directions, the results often involve personal injury.

The treatments at signalized intersections range in cost based on the identified problem and known countermeasures.

### 5.4.1 TRAFFIC SIGNAL WARRANTS

The MUTCD provides guidance to determine the feasibility of signal installation at a given intersection in Chapter 4C, *Traffic Control Signal Needs Studies*. These are commonly referred to by practitioners as “signal warrants.” The MUTCD recommends the following eight warrants be considered, which address traffic volume, safety needs, and other special situations (e.g., school crossings, coordinated systems):

1. Eight-hour vehicular volume
2. Four-hour vehicular volume
3. Peak hour
4. Pedestrian volume
5. School crossing
6. Coordinated signal system
7. Crash experience
8. Roadway network
Warrant 7, crash experience, is “intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal.” The MUTCD provides a number of safety-related criteria that, if met through an engineering study, deem the warrant satisfied.

- Other safety alternatives have been attempted, observed, and enforced, but crash frequency has not decreased.
- Five or more reported crashes per year that could be addressed by installation of a traffic signal.
- Motor vehicle or pedestrian traffic volumes meeting certain levels, with the assumption that increased exposure at the intersection could lead to crashes.

The most important concept regarding signal warrants is that meeting the criteria for a warrant does not mean a signal is required at that location. In every case the MUTCD states, “A traffic control signal should not be installed unless an engineering study indicates that installing a traffic control signal will improve the overall safety and/or operation of the intersection.”

### 5.4.2 TRAFFIC SIGNAL CONSPICUITY

The first basic need at a traffic signal is for it to be seen by approaching road users, especially motorists (due to their relatively high approach speeds). The following treatments can be used to make it easier for users to identify a signalized intersection ahead.

**Signal Head Placement.** The best location for a traffic signal head (the multi-light device that houses the red–yellow–green indications) is aligned with the motorist’s lane. One reason is that this puts the signal head in the driver’s cone of vision—a conical shape with an approximately 20-degree angle from the driver’s eye. Users can focus most directly in this cone, so placing the most important information here helps increase their ability to see it and make safe decisions at the intersection.

In some cases the signal heads are placed on the side of the road. This is especially common in older downtown areas, and is sometimes chosen for aesthetic reasons or due to budget limitations. Moving these signal heads (or adding more) to an overhead mast arm or span wire increases the signal’s conspicuity.

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Sometimes a signalized intersection has limited sight distance, making it difficult for an approaching motorist to see it due to obstructions or roadway alignment—like a horizontal curve or a hill. Practitioners can add supplemental signal heads at various locations to provide additional information to the motorists. Far left and far right installations can help for horizontal curves. Very high placement of an additional signal head can help drivers cresting a hill in advance of the signal. If the signal is behind an obstruction (like a bridge), then adding a supplemental head on the near-side of the obstruction can help.

**Number of Signal Heads.** A traffic signal should provide one signal head for each lane of travel, with a minimum of two signal installations. The minimum provides redundancy in case of a bulb burn-out or obstruction (by trees or large vehicles), which is especially important when the signal indication is red. Installing a signal head for each lane provides lane use guidance to the driver, and helps them know exactly what movements are allowed from that lane.

**Signal Head Size.** The standard size of a single traffic signal indication (the actual “light” part) is a 12-inch diameter. Most major roads in the United States meet this standard, though the previously used 8-inch indications are still in place decades after their installation in some jurisdictions. Studies have shown that drivers see large signal heads more easily.

**Signal Head Backplates.** A signal head backplate is a rectangular border that surrounds the signal. It provides a number of benefits.

1. The backplate helps identify the signal head as such, versus just a few circular lights hanging in the sky.
2. Sun glare can be a problem at certain times of day, especially for east-facing and west-facing traffic signal approaches. A backplate helps block the sun, so road users can better see the traffic signal indications.
3. Retroreflective backplates are backplates with borders delineated with retroreflective tape (Figure 5.6). At night this additional retroreflective border identifies the traffic signal by showing a rectangular shape with the indications inside. It also provides information about which indication is lit—even for those with poor vision or color vision deficiencies—by identifying placement. A signal lit at the top of the head is known by motorists as red—stop—regardless of whether they can actually identify the color as red.
Advanced Warning Signs. As discussed above, some signalized intersection locations can be difficult to identify by approaching motorists (especially those traveling at relatively high speeds) due to horizontal curves or vertical hills blocking their view of the intersection. A SIGNAL AHEAD warning sign can tell motorists that they are approaching a traffic signal.

If a single warning sign does not seem to provide enough information to drivers, practitioners can enhance the warning in a number of ways:

1. **Doubled-up signs**, either on both sides of the road at the same lateral location or multiple times longitudinally on the approach, can increase the chance that a motorist will see the sign and be warned of the signal ahead.

2. **Oversized signs** increased from the standard 36-inch size can add to the sign’s target value and increase the chance it is seen.

3. **Fluorescent yellow** sign sheeting is brighter than standard yellow sheeting. It can help the sign “pop out” from the background more effectively. Fluorescent yellow is especially beneficial during autumn months in some jurisdictions (where background trees are red, orange, and yellow) and during overcast conditions.

4. **Flashers** can be added to the top of the warning signs to grab motorists’ attention. A single flashing light can have some effect. Other
applications include two lights flashing alternately (i.e., in a “wig-wag” sequence). Combining the doubled-up signs with flashers can allow a practitioner to “wig-wag” on either side of the roadway.

5.4.3 WAYFINDING AND LANE PLACEMENT

Advance Cross Street Name Signs. Adding the name of an upcoming cross street on an advanced sign provides information to motorists before they get to the intersection. Knowing what direction they wish to navigate beforehand, road users can enter the appropriate lane early, avoiding potential merging conflicts near the intersection that can occur when drivers make late lane-change decisions.

Historically these advance street names have been signed in two different ways:

1. **Warning Sign Plaques.** In this case the street name is added as a black-on-yellow (i.e., black letters on a yellow background) plaque under the advance warning sign.

2. **Directional Sign.** At some locations the advance street name sign is a directional, white-on-green sign. One advantage of this sign type is that it is more flexible in placement. Warning signs are required to be placed within a prescribed range of distances from the intersection due to sight distance and other criteria, but practitioners can exercise preference in the location of directional signs.

Lane-use Control Signs. Lane-use control signs can be added to an overhead signal installation and/or prior to the signal to provide information to the motorist about the appropriate lane for each maneuver. Examples include “Left Turn Only Lane” or “Through Lane.” The information can be conveyed through words or symbols. It is especially helpful to provide this information to drivers when there are restrictions or combination lanes.

5.4.4 SIGNAL TIMING

One of the most cost-effective means of improving the safety and operation of a signalized intersection is to modify the signal timing. Each traffic signal includes a controller that acts as its “brain” or “computer,” collecting information from detectors at the signal, directing the signal indications to provide right-of-way for each movement, and constantly monitoring any conflicts that might be caused by errors in the signal’s operation.
There are many details regarding signal timing available in the existing literature, including the Federal Highway Administration’s *Traffic Signal Timing Manual.*

**Clearance Interval.** The clearance intervals at signalized intersections are those time periods when no movement has a green/go indication. It includes the yellow change period and red clearance period. The recommended practice for calculating the clearance interval is as follows:

\[
CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V}
\]

where \(CP\) is the change period (seconds), \(t\) the perception–reaction time of the motorist (seconds), \(V\) the speed of the approaching vehicle (ft/s), \(a\) the deceleration rate of the vehicle (ft/s\(^2\)), \(W\) the width of the intersection, curb to curb (ft), \(L\) the length of vehicle (ft), and \(g\) the percent grade of the intersection approach (positive for upgrade, negative for downgrade).

From a safety perspective the clearance interval timing serves these purposes:

1. **Reduce Red Light Running and Rear-end Crashes.** Timing of the yellow change period provides information to help approaching motorists determine whether to stop or go during the clearance interval. It should be timed in such a way to protect motorists who are in or near the dilemma zone.

2. **Clear the Intersection.** Appropriate clearance intervals clear the intersection of road users before the change in right-of-way to the next directional movement (a conflicting vehicle or pedestrian phase) receives a green/go indication.

Modification to clearance intervals is a useful system-wide practice due to its low cost and high benefit to safety and traffic operations. It can also be a spot location solution to address the following identified crash types:

- Angle or left-turn crashes due to red light running
- Angle or left-turn crashes due to vehicles failing to clear the intersection
- Rear-end crashes on the through approaches

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Yellow Change Period. The purpose of the yellow light is to warn drivers of an upcoming change in right-of-way assignment. In most cases the yellow change period is approximately 3 to 6 seconds. Very large or very small intersections can push these limits, as can relatively high or low approach speeds.

All Red Clearance. As shown in the formula above, the All Red Clearance time is calculated as the time it takes an approaching driver at the prevailing speed to proceed through the intersection if he or she entered (i.e., crossed the stop bar) at the very end of the yellow change period. This is the width of the intersection plus the length of the vehicle, divided by the vehicle speed.

In some jurisdictions engineers have chosen to add more All Red Clearance time to each phase to provide an additional buffer for intersection clearance, and to reduce the potential for conflict when the next phase receives a green indication. The downside of this practice, however, is potential noncompliance if motorists learn of the longer All Red and then choose to use it as part of their clearance.

Dilemma Zone Protection. The Dilemma Zone is that location on the roadway where, at the onset of yellow, a motorist could be confused about whether stopping or proceeding through the intersection is the better decision. Every motorist has experienced the discomfort of “should I stop or should I go?” That is the dilemma zone.

The traffic signal controller, in conjunction with a series of detectors (induction loops, video, radar, and so on), can minimize the occurrence of dilemma zone issues by determining where vehicles are and changing from green to yellow when no vehicles are in the dilemma zone.

Coordination. Coordinating a heavily traveled movement can reduce the number of red lights each motorist sees as they travel from one end to the other. Theoretically, reducing the number of red lights experienced per trip can equate to a reduced number of red light running violations.

Remove Flashing Operations. Motorists can become frustrated if they must wait for a green light in very low traffic volume situations (often at night or very early morning). One way engineers have addressed this is to provide overnight flash operation. However, research has identified overnight flash as a safety concern.

1. The traffic signal may have been put in place partially due to sight distance issues. Reverting it back to a “de facto stop controlled-
intersection” during dark conditions reintroduces this potential problem.

2. Using Red Flash on the side street and Yellow Flash on the main-line roadway is particularly concerning due to driver expectation. In most cases seeing a flashing red light at a signal (e.g., when an error occurs) is to be treated as an All Way Stop. If a motorist on the side street assumes conflicting vehicles also have a flashing red, then they may proceed into the intersection, causing a collision.

With the advent of actuated traffic signals, it is recommended to keep the signal in Red-Yellow-Green at all times, using the detectors and signal timing to provide convenience to motorists in low-volume conditions.

5.4.5 LEFT TURNS

Left turns are the most important movement at any signalized intersection. The needs of each left turn directly affect the number of phases, cycle length, and timing of each traffic signal. Left turns are also one of the most problematic safety issues at a signal. If a left-turning motorist makes a mistake by pulling out in front of an oncoming vehicle, the result of the crash can be severe due to the physics involved—two vehicles moving in opposite direction and colliding head-on or nearly head-on.

The following treatments can reduce the opportunity for left-turn crashes at signalized intersections.

**Left-turn Protected Only.** Some signal phasing plans allow for permissive left turns, typically indicated by a green ball or flashing yellow arrow. In this case a left-turning driver must yield to oncoming traffic before proceeding through the intersection. At a location where a high number of left-turn crashes have been identified, converting the left-turn control from permissive or permissive-protected\(^5\) to protected-only can reduce the number of left-turn crashes significantly.

Beyond crash history, the following criteria should be considered for using protected left turns at signals:

- Left turners must cross three or more lanes of opposing traffic.

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\(^5\) In permissive-protected operations, there is a permissive left-turn phase (as described in the text) and a separate protected left turn phase, indicated by a green arrow, that provides left turners right-of-way with no conflicts.
Opposing traffic is high speed (e.g., some consider 45 mph and higher too fast to allow permissive left turns).

- High opposing traffic volume. In this case it is unlikely that the permissive phase could be used often, anyway, because motorists would have a difficult time finding a gap. Removing the permissive phase has little effect on mobility and provides a safety benefit.

There are two significant drawbacks to protected-only left turns that practitioners must consider before installation.

1. **Mobility Reduction.** If the permissive left-turn phase was used regularly by motorists at an intersection, and then it is taken away, it is likely that the protected left phase will need to be extended to accommodate the left-turning volume. This affects the operation of the entire traffic signal, which could increase traffic delay for all motorists. It will undoubtedly increase delay for left turners who previously used the permissive phase.

2. **Noncompliance.** If a protected-only left-turn phase is added at an intersection that motorists consider unwarranted it can cause frustrations and potential noncompliance. Left-turning motorists waiting at the protected left turn, but seeing no conflicting traffic, may choose to run the red light because they are convinced it is a safe (if illegal) maneuver.

**Modified Permissive Left Indications.** In some cases converting protected-permissive left-turn phasing to protected-only is not feasible due to operational needs. In this situation a different permissive left-turn indication (i.e., something other than a green ball) can provide better information to the left-turning traffic. For example, studies have shown the flashing yellow arrow indication to have higher driver recognition than the traditional green ball indicating a permissive left-turn movement. It is important to note, however, that a permissive left turn—regardless of the indication style—is still generally not as safe as a protected-only left-turn phase.

**5.4.6 RED LIGHT RUNNING COUNTERMEASURES**

**Conspicuity and Signal Timing.** As discussed above, improvements to conspicuity of the traffic signal and appropriate signal timing (especially clearance intervals) can make a big impact on signalized intersection safety.
Automated Red Light Enforcement. One strategy to deter red light running violations is to install automated enforcement systems. A basic red light enforcement setup (Figure 5.7) follows this process:

1. Cameras take photos of any vehicle entering the intersection after their indication has turned red. Some jurisdictions take a photo of only the back of the vehicle with a focus on the license plate. Others also take a windshield view for the purpose of identifying the driver. Additionally, some systems have added video clips to make violation identification easier.

2. Photos (and/or video) are communicated from the camera system to a centralized review location (usually a city police department).

3. A law enforcement officer reviews the footage to confirm the following.
   - A violation has occurred.
The vehicle and its license plate number are easily identified (e.g., the photo is in focus so the plate is legible, the camera is not obstructed by ice or snow, and the flash was used at night to get clear information).

If driver identification is required from a windshield view, that information is confirmed.

4. Citation is sent by mail to the registered owner of the vehicle. The citation includes photos of the red light running violation, and in some jurisdictions a link to a video online.

5. The registered owner chooses to pay the fine or appear in court.

As mentioned above, jurisdictions may legally define red light running captured by an automated system as a nonmoving violation (which ties the violation to the vehicle) or a moving violation (tied to the driver).

- **Nonmoving violation.** In this case the citation issued by the automated enforcement system is tied directly to the vehicle, not the driver (similar to a parking ticket). No “points” are added to a driving record. The penalty is simply a fine. In this case only the vehicle’s owner is responsible for the violation. If the owner was not the driver at the time, he or she is allowed to seek restitution from the known violator (again, similar to a parking ticket).

- **Moving violation.** Other jurisdictions consider red light running violations, when captured by an automated system, the same as an officer-identified violation. In this case identifying the driver of the vehicle is necessary, which is conducted using a windshield camera. The violation can affect the violator’s driving record.

**Red Signal Indicator Lights.** In some cases fully automated enforcement may not be a feasible option due to cost, legislation limitations, or public perception. One limitation law enforcement officers have is that they must see the violation (including seeing the red signal indication) with their own eyes to write a red light running citation. If they are following a vehicle that runs a red light, then sometimes the officer must also run the red light (potentially putting the officer and other road users in danger) to pull over the driver and issue a citation.

Indicator lights (sometimes called “rat lights”) are placed underneath the traffic signal head, and the light is omnidirectional—meaning it can be seen from anywhere in proximity to the signal. It is directly wired to the red indication on the traffic signal. This light allows officers to set up on the far side of the traffic signal to identify motorists running a red light,
and then pull them over from a safe location downstream of the traffic signal without entering the intersection themselves.

### 5.4.7 PEDESTRIANS AT INTERSECTIONS

Motor vehicles are not the only users of unsignalized and signalized intersections. Pedestrians also navigate these locations, and when they do they are vulnerable to conflicts with motor vehicles. When a pedestrian is struck by a motor vehicle, even at relatively low speeds, personal injuries are almost certain.

For pedestrians to safely cross the roadway at intersections, they need to be easily seen by motor vehicles, and in some cases they need to be given the right-of-way. Following are pedestrian safety treatments and additional discussion of their pros and cons.

**Conspicuous Crosswalks.** Agencies have attempted a number of designs at crosswalks to make them visible to approaching motor vehicles. By identifying the crosswalks as places where pedestrians have the right-of-way, and making those crosswalks easy to see, pedestrian safety can be improved.

Longitudinal crosswalk markings have better visibility to approaching drivers than the historically-used two transverse crosswalk lines, especially for higher-speed approaches and midblock crosswalks with no traffic control devices present. Some communities have tried creative patterns within their crosswalks to make them more noticeable. (Figure 5.8).

![Figure 5.8. Crosswalk treatment in Portland, Oregon](image)
Pedestrian Signals: Confusion Regarding Indications. The MUTCD provides the following definitions for pedestrian signal indications (Figure 5.9):

- A steady WALKING PERSON (symbolizing WALK) signal indication means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles.

![Pedestrian Signal Push Button](image)

**Figure 5.9.** Push button for pedestrian signal

- A flashing UPRAISED HAND (symbolizing DON’T WALK) signal indication means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady WALKING PERSON (symbolizing WALK) signal indication shall proceed out of the traveled way.

- A steady UPRAISED HAND (symbolizing DON’T WALK) signal indication means that a pedestrian shall not enter the roadway in the direction of the signal indication.
These indications, though used for years, are still misunderstood by many pedestrians. The messages can be described as follows:

- **WALK** = Walk (ok, we’re fine so far).
- **FLASHING DON’T WALK** = Continue walking (wait, what?) if you are already in the crosswalk.
- **STEADY DON’T WALK** = If you are in the crosswalk, keep walking because motorists are getting a green light within a couple seconds (if they have not already). If on the curb, wait for the WALK signal.

Once traffic engineers identified that pedestrians did not understand these instructions, they designed a sign to teach pedestrians what to do, in detail, when they see certain indications. But since the sign is not much clearer than the confusing signal indications it attempts to explain, the problem remains. Fortunately, engineers and pedestrian advocates have developed some additional tools and strategies to increase safety for pedestrians.

**Countdown Signal Heads.** By adding a countdown number to the pedestrian traffic signal, pedestrians crossing the street at a signalized intersection receive additional information about how much time they have left to cross. According to the MUTCD, the countdown should be displayed only during the FLASHING DON’T WALK time period (which is also called the “pedestrian clearance interval”), though some agencies have chosen to display the countdown during all phases.

**Addressing Right-turn Conflicts with Signal Phasing.** One concern with pedestrian crossings is the vehicle in the parallel through/right-turn lane. For example, if a northbound motor vehicle receives a green ball indication to travel through the intersection or turn right and a northbound pedestrian receives a WALK signal to cross, the motor vehicle should yield to the pedestrians in the crosswalk. This can be confusing for motorists, who are taught that a green light gives them the ability to “just go” without yielding to others. Additionally, adjacent pedestrians are often in the right-turner’s blind spot, increasing the opportunity for conflict. To address this situation, practitioners can modify phasing in one or more of these ways.

- **Leading pedestrian phase.** By giving pedestrians a WALK indication a few seconds before parallel motorists receive a green, the pedestrians can move out of the driver’s blind spot and into the middle of the crosswalk, making it easier for motorists to see them.
•  **Lagging pedestrian phase.** Giving motor vehicles a green indication first shows pedestrians that they (the pedestrians) need to be aware of potential conflicts with right-turning vehicles.
•  **Exclusive pedestrian phase.** If pedestrian volumes and/or safety concerns are high enough to warrant, then practitioners can stop all vehicle traffic for an exclusive pedestrian phase. In some cases this phase can even allow diagonal pedestrian crossing at the intersection.

**Disallow Permissive Left Turn.** Left-turning motorists are focused on two things—conflicting traffic headed toward them and the traffic signal potentially turning yellow. Once they see a gap in oncoming traffic, their primary objective is getting through the intersection as soon as possible to avoid a head-on collision. Adding a responsibility to also check the crosswalk for pedestrians can result in conflicts in the crosswalk. Making this left turn “protected only” (and therefore disallowing left-turners and adjacent pedestrians from getting a green/WALK indication at the same time) can reduce pedestrian/vehicle conflicts.

### 5.5 ALTERNATIVE INTERSECTION SOLUTIONS

Along with the basic intersections discussed above and the ways to improve their safety, practitioners have designed alternative intersection solutions to improve both safety and operations.

### 5.5.1 MODERN ROUNDABOUT

A modern roundabout is a circular intersection where vehicles enter under yield control (i.e., the rotating traffic in the circle has the right-of-way) making a right turn only. Vehicles exit the roundabout by turning right at the motorist’s desired departure (Figure 5.10).
Figure 5.10. Vehicle entering a roundabout

Channelization of intersection approaches, deflection around the center island, and appropriate signing and pavement marking provide a low-risk environment for navigating roundabouts.

Roundabouts can provide significant safety improvements to an intersection, with fatality and serious injury crash reductions of more than 90 percent. The reasons roundabouts operate so safely include the following:

- **Reduced speeds.** Motor vehicles navigating a roundabout do so at approximately 15–20 mph. Crashes that occur at this speed are unlikely to cause personal injury. Comparatively, signalized intersections can have speeds through the intersection at 60 mph or higher, and unsignalized intersections in rural areas have speeds higher than that, approaching 80 mph in some jurisdictions.

- **Conflict types.** The types of conflicts most common at roundabouts are sideswipe and rear-end crashes. Sideswipe crashes (with vehicles impacting at “flat angles” traveling in the same general direction) are unlikely to be severe. Similarly, rear-end crashes at the slower roundabout speeds are typically property-damage-only incidents.

5.5.2 **OTHER INTERSECTIONS**

Beyond roundabouts, practitioners have designed and operated a number of innovative intersection designs in recent years. Details about these
alternatives and more are available through FHWA’s *Alternative Intersections/Interchanges: An Informational Report*.\(^6\)

**Displaced Left-turn Intersection.** The displaced left-turn intersection, also referred to as a “continuous flow intersection,” moves the left turns to a location in advance of the main intersection, taking that traffic to the other side of the opposing roadway.

**Quadrant Roadway.** A quadrant roadway intersection adds a “connector” in one of the intersection quadrants to handle what would typically be left-turn movements. By doing so, the main intersection is converted to a basic two-phase signal with no left turns allowed.

**Protected Intersection.** A protected intersection extends protected bicycle lanes into the intersection to support safe movement of nonmotorized users. It includes a corner refuge island, forward stop bar, setback crossing, and special bicycle signal phasing to complement the standard signal.\(^7\)

### 5.6 INTERCHANGES

From a safety perspective, interchanges are essentially a series of intersections and segments (including curves), both of which are addressed separately in this text.

#### 5.6.1 APPLICABLE INTERSECTION AND ROADWAY DEPARTURE TREATMENTS

The following treatments have been identified as particularly useful to address interchange safety needs:

- Curve treatments at ramps
  - Signing, including actuated signs
  - Pavement marking
  - High-friction surface treatments

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\(^7\) Additional information is available at www.protectedintersection.com.
Signalized intersection treatments
- Increased conspicuity
- Signal timing
- Countermeasures to prevent wrong-way drivers, as many wrong-way crashes occur due to a mistake made at an interchange.

5.6.2 ADDITIONAL LOW-COST TREATMENTS

Beyond those treatments discussed in other chapters, the following countermeasures can provide additional safety benefits to road users traveling through interchanges.

In-pavement Signing. On applicable ramps—often at complex freeway-to-freeway interchanges, in-lane signing on the pavement can provide additional navigational information to motorists.

Location Markers within the Interchange. Location markers indicate the location on the roadway for easy identification in case of emergency. At an interchange this can become complex, especially on long freeway-to-freeway ramps, so the markers can benefit emergency responders.

5.6.3 ALTERNATIVE INTERCHANGE DESIGNS

Engineers are researching and implementing new, alternative interchange designs to improve traffic safety and operations, including the following.

Single Point Urban Interchange (SPUI). At a SPUI all major movements occur at a single point above or below the interchange underpass or overpass. The design allows for a single traffic signal to control all movements. Issues to consider are the very large size of the structure, traffic signal clearance interval needs, and maintenance of the roadway assets.

Diverging Diamond Interchange (DDI). Also called a “Double Crossover Diamond Interchange,” the DDI is designed to accommodate left-turning movements at a signalized interchange without additional left-turn bays and complex signal timing. The result is the design illustrated in Figure 5.11. An interesting feature of a DDI is that some motorists drive on the left side of the road to make through and left-turn movements.

The DDI requires careful design of pavement markings and signing to ensure drivers safely navigate the interchange.
Figure 5.11. Diverging diamond interchange configuration
(source: FHWA-HRT-09-060)
Hey, hey, something’s different in the world today.  
They changed my traffic signs to a brighter yellow.  
—Jason Mraz, Curbside Prophet

Running off the road or departing a vehicle’s correct lane is the most common way to suffer a severe injury or fatality in a traffic crash. More than half of all traffic fatalities in the United States occur when a vehicle departs its intended lane.¹ Lane departure crashes often result in the following harmful events:

- Overturn
- Collision with a fixed object (e.g., tree, utility pole, ditch, bridge, embankment)
- Opposite-direction crashes caused by crossing the centerline or median, or by driving the wrong way

Another aspect of lane departure crashes that makes them challenging to research is location identification. As described in the previous chapter, intersection crashes occur at one of a finite number of junctions, but lane departure crashes can occur anywhere—there are an infinite number of points along the roadway that a motorist can depart the lane. Therefore, increasing the safety of the roadway must sometimes occur with long-line countermeasures intended to make the entire corridor safer, rather than choosing individual points on the road to treat.

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6.1 OVERALL APPROACH TO LANE DEPARTURE SAFETY

Because lane departure crashes are so common and have such severe outcomes, practitioners have spent a great deal of time and effort researching and testing treatments for this crash type. To reduce the number and severity of lane departure crashes, traffic safety experts focus on a hierarchy of three objectives:

1. **OBJECTIVE A: Keep vehicles in their appropriate lane.** Theoretically speaking, if a road user does not depart their lane, they cannot have a lane departure crash. Treatments focused on this objective tend to be the most cost effective. However, they also require more of the driver. Examples include signing and pavement marking.

2. **OBJECTIVE B: If a vehicle leaves the lane, provide an opportunity to return to the road safely.** Once a vehicle is no longer in its appropriate lane, there is still a chance to avoid a crash. Providing rumble strips to warn the driver of their departure, shoulders for recovery, and forgiving roadsides give them an opportunity to get back into their lane before a crash occurs.

3. **OBJECTIVE C: Minimize the severity of a lane departure crash if it occurs.** If the first two sets of treatments are not successful and a crash is imminent, the last resort is to reduce the severity of that crash. Breakaway sign supports, guardrail, cable barrier, and attenuators do not prevent crashes from occurring, but they can reduce a potential fatal or serious injury crash to a minor injury or property-damage-only event.

Each treatment listed in this chapter will be denoted with an indication of (A), (B), or (C) to identify its primary lane departure safety objective.

6.2 CURVE TREATMENTS

Due to the difficulty of identifying locations for treating this crash type, analysts search for common attributes of the locations that suffer the highest number of lane departure crashes. One of those is horizontal curves, which tend to experience more crashes than tangent sections.

Curves tend to be a problematic section of the roadway because they require motorists to navigate along a curved section instead of the straight
line of the majority of most roadways. In some cases this curve can be quite sharp, requiring motorists to reduce their speed, and sometimes it is combined with other complications, including the following:

- **Vertical curve.** A horizontal curve may occur at the bottom of a hill, or even in the middle of it, making it more difficult for drivers to judge the sharpness of the curve and reduce speed, if needed.
- **Visual trap.** In some cases, especially in rural areas, horizontal curves can be difficult for drivers to identify because of other roadway and roadside features. Visual traps include tree lines, utility lines, and side streets that continue straight while the roadway curves. These visual elements can trick the driver into thinking they should continue straight.

To increase horizontal curve safety, practitioners can implement a number of different types of treatments, including advance warning devices, in-curve signing, and speed reduction techniques.

### CURVES VERSUS TURNS

In the world of traffic engineering, “curves” and “turns” have different definitions and, in some cases, different requirements. The MUTCD Section 2C.07 defines the terms as follows:

- **Curve:** Ball-bank advisory speed is greater than 30 mph.
- **Turn:** Ball-bank advisory speed is 30 mph or less.

#### 6.2.1 HOW SHARP IS THE CURVE?

Identifying curve sharpness using the degree of curvature, curve radius, or recommended advisory speed helps practitioners determine the most appropriate treatment. A curve’s sharpness can be determined in the following ways:

- **Design plans.** In some cases the as-built design plans include the radius of the curve, which can be used to calculate degree of curvature and design speed (to be used to select the recommended advisory speed). However, depending on the age of the roadway and the number of pavement overlays, the design plans may not
provide an accurate representation of the real-world curve's attributes, which often change over time.

- **Ball-bank Indicator.** Many traffic engineers will “ball bank” a curve using a basic indicator—a device similar to a carpenter’s level with an air bubble inside liquid—to determine the most appropriate advisory speed. The MUTCD recommends the following ball-bank readings for advisory speeds:
  - 16 degrees of ball bank for speeds of 20 mph or less
  - 14 degrees of ball bank for speeds of 25 to 30 mph
  - 12 degrees of ball bank for speeds of 35 mph and higher

- **Accelerometer.** In recent years researchers and manufacturers have developed easier-to-use and more accurate devices, including accelerometers, to measure side friction factors and assist in determining the most appropriate advisory speed.

Additional information about procedures to determine advisory speed is available through the FHWA’s *Procedures for Setting Advisory Speeds on Curves*.2

### 6.2.2 ADVANCE WARNING

The first step in keeping a driver safe as he or she approaches a curve is to provide advance warning that a curve is ahead. This will warn the driver to pay close attention to speed and lane placement as he or she navigates the next roadway section.

**Advance Warning Signs (A).** Signs are one of the least expensive and most effective ways to warn motorists of an upcoming change in horizontal alignment. According to the 2009 MUTCD (Table 2C-5), warning signs are required on curves where the curve advisory speed is 10 mph less than the speed limit of the roadway.

Installing warning signs in advance of a curve or turn provides information to motorists before they enter the curve, giving them a chance to modify their approach speed as they enter the new horizontal alignment. The MUTCD also provides appropriate placement distances for advance warning signs.

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Warning Sign Enhancements (A). The following additions and enhancements to the basic advance warning signs can make them more beneficial.

- **Advisory speed plaques.** Adding the advisory speed underneath the warning sign provides additional information about the sharpness of the curve and a recommended approach speed for drivers to safely navigate it. The speed added to this sign is determined by the procedures referenced above. MUTCD Table 2C-5 indicates when an advisory speed plaque is required, recommended, or optional.

- **Doubled-up signs.** Drivers do not always see every sign on the road due to occlusion from vehicles ahead of them (especially large trucks) and in-vehicle or outside-vehicle distractions. To address the first issue, practitioners can install a supplemental left-mounted sign to increase the chance the driver will see one of them. For distraction concerns, practitioners can install advance warning signs at two locations in advance of the curve—one further from the curve and one closer.

- **Increased sign size.** Typical warning signs are 36-inch diamonds, but larger sign sizes can be used (48 and 60 inches are the most common for this situation) to make the sign easier for motorists to see.

- **Fluorescent yellow sheeting.** Warning signs are standardized as yellow. However, fluorescent yellow sign sheeting is also allowed, and it provides enhanced conspicuity of the sign, especially in overcast conditions or if the background could make it difficult to see (e.g., a forest of trees, especially in autumn as leaf colors change).

- **Sheeting on post.** Adding retroreflective sheeting to the sign post provides additional “target area” to motorists as they approach the curve, making the sign more likely to be seen.

- **Flashing beacons.** Installing flashing beacons above warning signs can draw attention. The flashers can be passive (i.e., flashing all the time), combined with another to produce a wig-wag effect (e.g., for two advance warning signs on either side of the road), or active flashers tied to an approaching vehicle as follows:
  - **Vehicle detection.** The beacon begins flashing when a vehicle approaches.
- **Speed detection.** The beacon only flashes if the approaching vehicle is traveling at a certain speed (set at a predetermined speed above the posted advisory warning speed).

- **In-sign light-emitting diode (LED) flashers.** An alternative to a flashing beacon is the addition of LED flashers around the frame of the sign. Advantages include potential additional conspicuity and low power draw, making solar power a viable alternative for this treatment.

**Advance Pavement Marking (A).** To supplement advance warning signs, practitioners can also consider messages on the pavement. Because the pavement in front of the driver is in the cone of focused vision, it is sometimes an even better place to provide warning information than the side of the road. The downsides include the following:

- **Maintenance.** Maintaining pavement marking within a lane can be difficult, because the marking gets run over by every vehicle as it passes over. Similarly, snow plows can scrape off the markings.

- **Limited use.** These markings are visible only in dry pavement conditions. Water, snow, and ice make the message effectively invisible to drivers. Unfortunately, in inclement weather it is particularly important for motorists to see warning devices in advance of upcoming changes in horizontal alignment.

Messages vary and can include either text (CURVE AHEAD, SLOW—CURVE, or similar) or a visual representation of the advance warning curve sign. In the latter treatment care must be taken so the advance warning is not confused with a left-turn or right-turn lane marking.

### 6.2.3 IN-CURVE WARNING

Advanced warning devices discussed above have limited usefulness due to their position in advance of the curve. In-curve warning devices, on the other hand, provide road users with important information when they need it most—during curve navigation.
Horizontal Alignment/Advisory Speed Sign (A). The 2009 MUTCD added the option for a supplementary warning sign to be placed at the point of curvature—that point where the roadway is no longer a tangent section and begins its horizontal curvature. This sign can include an advisory speed within the sign itself (rather than a separate plaque installed below the sign).

One-direction Large Arrow (A). The large arrow sign is typically placed in the line of sight of the motorist as he or she enters the curve—approximately in the middle of the curve placed on the outside of the curve.

Chevron Alignment Signs (A). One of the most important safety devices used by safety professionals, chevron alignment signs provide drivers with the shape and sharpness of a curve at multiple points along the way, allowing them to course-correct (by changing speed and/or their position within their lane) as they navigate through the curve. The 2009 MUTCD (Table 2C-5) requires chevrons signs, other alignment delineation, or a one-direction large arrow on curves where the advisory speed is 15 mph less than the posted speed limit. The MUTCD also provides typical spacing of chevron alignment signs in Table 2C-6.

Enhancements to chevron alignment signs can include some of the same concepts as advance warning signs: oversize, fluorescent yellow sheeting, and post sheeting. Additional enhancements include:

- **Stacked chevrons.** For vertical/horizontal alignment combinations, adding some higher-placed chevrons above the standard placement can provide drivers important alignment information that is difficult to see with standard-height signs.

- **Sequential flashing chevrons.** Like the LED flashers mentioned above, practitioners can install chevrons with embedded LEDs. Another available feature is to make the chevrons flash sequentially (similar to “chaser” holiday lights) to increase conspicuity.

Delineator Posts (A). In some cases chevron signs may not be feasible for installation or deemed too costly to install and/or maintain. Plastic or U-channel delineators, including a retroreflective strip or button at the top, can provide similar alignment information around curves in situations where chevrons are not desirable.
**Pavement Marking (A) and Rumble Strips (B).** On-pavement treatments can also provide alignment information to motorists navigating a curve. Standard pavement marking (edgeline and/or centerline) provides a visual cue. Rumble strips provide an audible and tactile warning that a vehicle has crossed the edgeline or centerline.

**Friction Surface Treatments (A).** The friction between a vehicle’s tires and the pavement is vital to keep the vehicle on the road, especially around horizontal curves. Additional information about pavement friction treatments is available in *Section 6.6.1, Wet Pavement Crashes.*

### 6.2.4 SPEED REDUCTION

One important action required to safely navigate a curve is reducing operating speed. In addition to the treatments already discussed, practitioners can consider the following to encourage speed reductions.

**Speed Feedback Signs (A).** Speed feedback signs identify the approach speed of each vehicle and present a message to the driver in response. For this device the feedback may include “Your Speed Is XX mph,” a simpler “SLOW DOWN” warning, or both (Figure 6.1).

**Lane Narrowing (A).** Narrowing the width of a travel lane in advance of a curve can provide “traffic calming,” which has been shown to reduce travel speeds. In some cases professionals install pavement marking to reduce the lane width. In others, practitioners can add rumble strips or vertical delineators to encourage reduced speeds. Another benefit of lane narrowing is that it makes the upcoming curve more conspicuous.

**In-pavement Markings (A).** Researchers have experimented with a number of in-lane pavement marking designs to encourage reduced speeds. They have tried blocks on the sides of the lane, bars across the lane, chevron designs, and other patterns to create an illusion of increased speed with hopes that drivers will reduce their approach speed in response. The MUTCD provides details for Speed Reduction Markings, which are 18” x 12” blocks placed on the sides of the lane.
6.3 SINGLE VEHICLE RUN OFF ROAD

One of the most common types of lane departure crash involves a single vehicle running off the road. Once a vehicle departs the roadway, the roadside area is often not as safe to traverse as the travelway, and the following events can occur:

- Overturn
- Hitting a fixed object
- Overcorrection, resulting in an opposite-direction crash

Addressing this crash type at its genesis—a vehicle departing its lane—means a focus on exactly that: Keeping the vehicle in its lane or helping the driver get the vehicle back in its lane before a crash occurs.

6.3.1 PAVEMENT MARKING

Pavement marking, often called “striping,” consists of two materials, a binder and retroreflective elements.
Binders are made of one of the following materials:

- **Waterborne paint.** Commonly used by highway agencies, paint is the least expensive, but also the least durable product. It typically lasts approximately 1–3 years, but this duration is highly dependent on weather conditions, traffic volume, type of traffic, and type of winter weather maintenance operations.

- **Durable markings.** More expensive and more durable binder materials include epoxy, thermoplastic, adhesive tape, and others. The increased cost is offset by long life—approximately 5–7 years (again, dependent on weather and traffic volume).

Pavement marking also consists of a retroreflective material to ensure that the paint or other marking can be seen by motorists in all light conditions. The reason signs and pavement markings are visible in the dark is retroreflectivity. To explain, first consider a mirror—it is a specular reflector. If you were to bounce light at a certain angle onto a mirror (say, from a headlight of a vehicle), the light would exit away from the light source at the same angle as entry. If you were to replace that mirror with a sphere, the sphere will reflect light directly back to the source—this is retroreflectivity. Most pavement markings use thousands of very tiny, spherical beads to take light from headlights, capture the paint color below (typically white or yellow), and retroreflect that color directly back to the headlight. Since in most vehicles the headlights are relatively close to the driver’s eyes, the driver is able to see the pavement marking. However, there are cases when retroreflectivity does not work as well:

- **Rain events.** When the pavement marking is covered with water (even a very small amount), that layer of water reflects light (similar to the mirror discussed above), sending the light away from the driver’s eye instead of toward it.

- **Removed elements.** Over time the spherical retroreflective elements can be worn away by traffic or scraped off by snow plows. When enough are removed, the paint below will not be visible in dark conditions.

- **Special vehicles.** Some vehicles, including large trucks, buses, and recreational vehicles, have a longer-than-typical distance between the front headlights and the driver’s eyes. Because of this, less light from the pavement marking is retroreflected to the driver. This necessitates higher retroreflectivity to be adequately seen by special vehicle operators.
Pavement Marking—Edgelines (A). Edgeline pavement marking is one of the most cost-effective ways to provide guidance to motorists. Edgelines on the right side of the road (from the driver’s perspective) should be painted white. Edgelines are typically 4 inches wide, though some agencies have used 6-inch and 8-inch markings for certain situations. For example, one state uses an 8-inch pavement marking to separate motor vehicle lanes from protected bicycle lanes.

On a four-lane divided roadway the left edgeline should be painted yellow to indicate that opposite-direction traffic is to the left of that yellow marking. For multiple lanes in one direction, a skip pattern of white stripes (typically a 10-ft stripe with a 30-ft gap between each marking) indicates that same-direction parallel travel is allowed, as illustrated in Figure 6.2.

![Figure 6.2. Divided highway with edgeline Rumble stripes and durable skip markings](image)

Pavement Marking—Centerlines (A). Centerlines provide additional information for motorists to help them stay in the appropriate lane. Centerlines should be yellow in color. The main purpose of centerline pavement marking is to provide sufficient information for navigation and lane placement. In some cases it is also used to identify passing zones (skip pattern) and no passing zones (solid pattern).
CHOOSING EDGELINES, CENTERLINES, OR BOTH

In some situations the width of the roadway may make it difficult to determine the most appropriate pavement marking design to optimize safety. Adding only edgelines may encourage vehicles to be so close to the middle that opposite-direction crash risk increases. But adding only centerline markings could cause vehicles to be too close to the edge of a narrow roadway, increasing the opportunity for run-off-road-right crashes.

Research has provided some guidance, and efforts continue to identify the best combinations for narrow roadway conditions. For example, *Use of Edgeline Markings on Rural Two-Lane Roadways* states, “An edge line, with no centerline, can be placed on a narrow, low volume road without increasing crashes,” including opposite-direction crashes. Additional guidance is available in the MUTCD, Chapter 3B, Pavement and Curb Markings.

6.3.2 RUMBLE STRIPS

Rumble strips are milled or grooved patterns placed on the pavement that provide an audible and tactile warning inside the vehicle to warn the driver that he or she has drifted outside the travel lane. This warning can give motorists time to recover before completely departing their lane.

**Shoulder Rumble Strips (A).** Shoulder rumble strips are typically placed on the paved shoulder, a few inches to the right of the edgeline pavement marking. Rumble strips are particularly effective in preventing those crashes where motorists drift out of their lane due to inattention, fatigue, impairment, or distraction (Figure 6.3).

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Edgeline Rumble Stripes (A). Similar to shoulder rumble strips, edgeline rumble stripes are installed to prevent run-off-road crashes. The difference is that these rumbles are installed in the same location as the edgeline pavement marking. Installers mill the rumble strip first, and then add pavement marking on top of the rumble—this is why it is called a rumble “stripe.” This treatment is often preferred to shoulder application by some practitioners for the following reasons (Figure 6.4).
• **Earlier warning.** Edgeline rumble stripes alert the driver of a potential lane departure sooner than shoulder rumble strips because it is on the edgeline pavement marking. The warning may prevent the motorists from even encroaching on the shoulder.

• **Wet-dark retroreflectivity.** The rumble stripe has two “super power.” The first is the ability to be seen during wet-and-dark conditions. Due to the shape of the rumble stripe (it is milled in a “trough”), pavement marking is added at a number of angles—flat on the top of the roadway (above the rumbles) and flat in the very bottom of the rumbles, but angled up to create a diagonal face within each rumble strip trough. This face maintains retroreflectivity of the stripe below it even if there is water, snow, or ice in the bottom of the rumble strip.

• **Extended pavement marking life.** The pavement marking inside the rumble strip is protected from vehicles driving on it and snow plows scraping the pavement. Therefore, the retroreflectivity of the pavement marking can be maintained longer. This provides two main advantages:
  - **Early spring safety improvement.** End-of-winter pavement marking condition is improved significantly from the situation before rumble stripes were installed. In many cases early-spring (just after winter weather has ended, but before new stripes can be installed due to low temperatures) is a difficult time for visibility. The stripes have been beat up by snow plows for many months, reducing their effectiveness. Rumble stripes can protect some of the pavement marking from this wear-and-tear, which in turn can make these roadways safer during a vital part of the calendar year.
  - **Opportunity to extend time between striping.** Depending on traffic volumes and other conditions (e.g., the aforementioned winter maintenance), the time between striping maintenance varies by route. For example, some locations that typically receive annual pavement marking may be able to go 2 years in between restriping. This is a cost savings to the agency and a safety benefit by limiting worker exposure, and an increase in driver convenience by reducing the number of maintenance work zones.
6.3.3 SHOULDERS (B)

If a motorist is unable to stay within his or her lane, the next line of defense is a roadway shoulder. Shoulders come in a variety of width and types. Widths typically range from minimal (less than 1 ft) to 12 ft. Shoulder types include the following:

- **Earth.** A dirt-and-grass shoulder provides a potentially recoverable area to the motorist, and though it can be improved with additional materials, it is a much better situation than an immediate dropoff, embankment, rock face, or other unforgiving roadside.

- **Gravel.** Adding gravel makes the shoulder more traversable, increasing the opportunity for a motorist to re-enter the travelway before a crash occurs. It can also reduce the possibility of overcorrection to the other side of the road. Gravel shoulders require regular maintenance to ensure the material is in place and an edge dropoff has not formed at the edge of the travelway.

- **Paved.** Paving shoulders with asphalt or concrete provides space for a vehicle to re-enter the roadway safely. It also provides space for a shoulder rumble strip and for other modes of travel (e.g., bicyclists, farm equipment operators, and so on).

6.3.4 SAFETY EDGE\textsubscript{SM} (B)

One major pavement concern is the potential for a vertical dropoff at the roadway or shoulder edge—wherever the pavement ends and another surface (earth, gravel) begins. Edge dropoffs develop over time as compacted aggregate or soil begins to fall away, or as vehicles drop into that aggregate or soil and cause rutting. If a motorist drifts off the roadway due to inattention, drowsiness, weather conditions, impairment, or distraction, one or both tires can leave the roadway. When a driver tries to correct back to the road, the tires can experience scrubbing to the point that the momentum of the vehicle can suddenly release it into the road. This sudden entry back to pavement often causes out-of-control movements, including entering the opposing lane or running off the left side of the road.

The Safety Edge\textsubscript{SM} changes the vertical edge dropoff to a diagonal transition (typically 30 degrees measured from the horizontal) that allows for motorists to safely recover. It can be placed at either the edge of the travelway (if there is no shoulder) or at the edge of shoulder. Aggregate or
earth is still compacted all the way to the edge of the travelway or shoulder. The Safety EdgeSM only comes into play once the dropoff recurs.

The Safety EdgeSM is a very low-cost treatment, and agencies often include it as part of their standard design for all new overlay projects. By adding a “shoe” to standard pavement equipment, a contractor can provide a safer, angled edge at virtually the same cost of material as a vertical edge, and the equipment can be reused for future projects.

6.3.5 CLEAR ZONE (B)

Providing a clear zone for lane departure events increases the opportunity for a motorist to either re-enter the roadway safely, or at least avoids a crash event. See Section 6.7, Clear Zones, for additional information and details about clear zone policies and treatments.

6.4 OPPOSITE-DIRECTION CRASHES

Opposite-direction crashes include head-on, opposing-direction-sideswipe, cross-median, and wrong-way-driver crashes. Due to the physics involved in these incidents—two vehicles traveling in opposite directions at speed—the potential for fatalities and serious injuries is high. Fortunately, this crash type is successfully treated with systemic solutions, many of which are low-cost.

6.4.1 CENTERLINE PAVEMENT MARKING (A)

Centerline pavement markings can keep drivers from crossing into opposing traffic lanes by providing a visual indication of the separation between lanes.

6.4.2 NO PASSING ZONES (A)

On undivided, two-lane roadways, not all sections have the required sight distance for safe passing/overtaking maneuvers. Practitioners provide different pavement markings for drivers to help them make a safe passing decision.
- **Skip/intermittent yellow.** Passing is allowed. Passing maneuvers are fairly complex and require judgment by the driver to know their speed, the speed of the vehicle they are overtaking, and the gap in the opposing lane they are entering.
- **Solid yellow.** Passing is prohibited. No passing zones are used when sight distance is not sufficient for a motorist to make a passing maneuver, or when other conditions create a potentially unsafe condition (e.g., nearby intersection).
  - Along with pavement marking, a triangular “pennant” sign is allowed for extra emphasis (see Figure 6.5).

![No passing zone pennant](image)

**Figure 6.5.** No passing zone pennant

6.4.3 *RAISED PAVEMENT MARKERS (A)*

To provide additional visual information to drivers, practitioners can install raised pavement markers (RPMs) along the centerline that include a retroreflective element. They are placed at various intervals, but usually between 40 and 100 ft between each reflector. For instance, agencies install RPMs between every-other “skip” in a skip pattern; this is an 80-feet pattern. RPMs provide particular value in wet pavement conditions (especially at night) when the pavement marking is more difficult to see. In some cases the reflectors are simply placed on the pavement. In others (especially in states with snow maintenance activities) agencies choose to recess the RPMs below the surface of the roadway to protect them from snow plows and traffic.
6.4.4 CENTERLINE RUMBLE STRIPS (B)

Even with centerline pavement marking, sometimes drivers are inattentive, distracted, drowsy, or impaired, and as such do not see the roadway striping. If a motorist begins to encroach to their left into the opposing lane(s), a centerline rumble strip (a milled or grooved pattern placed on the pavement) can provide an audible and tactile warning inside the vehicle to warn the driver that he or she has drifted outside the travel lane. This warning can give motorists time to recover before fully entering the opposing lane of travel and potentially causing a crash.

Centerline rumble strips are almost always actually rumble stripes, as the milled-in rumble is painted over with centerline pavement marking. A rumble stripe has two distinct advantages over a rumble strip (i.e., a rumble without pavement marking on top of the pattern):

- **Wet-Dark retroreflectivity.** Due to the shape of the rumble stripe (it is milled in a “trough”), pavement marking is added at a number of angles—flat on the top of the roadway (above the rumbles) and in the very bottom of the rumbles, but angled to create a diagonal face within each rumble. This face maintains retroreflectivity of the stripe below it even if there is water in the bottom of the rumble strip.

- **Extended pavement marking life.** The pavement marking inside the rumble strip is protected from vehicles driving it and snowplows scraping the pavement. Therefore, on some routes the retroreflectivity of the pavement marking is maintained longer.

6.4.5 MEDIAN BARRIERS (C)

In situations where recovery is not possible and a vehicle will likely be entering the opposing lane(s), adding a physical barrier is the “last resort” to reduce the severity of a crash. An important note about median barriers (and any other treatments in the “Objective C” category) is that they do not prevent crashes. In fact, adding a barrier treatment between opposite directions of traffic on divided or undivided highways will almost always increase the total number of crashes on that roadway. Median barriers have a significant role to play to reduce the severity of opposite-direction crashes. Basically, the median barrier replaces a potential head-on (or similar) crash with a less severe fixed object crash. Severity is reduced for the following reasons:
1. **Single vehicle.** When a potential multiple-vehicle event is replaced by a single vehicle crash, the chance of severe outcomes (e.g., fatalities, serious injuries) is reduced because only one vehicle is involved.

2. **Angle of crash.** A head-on crash has the worst angle—180 degrees—with vehicles traveling directly toward each other. A median barrier crash often happens at a very flat angle, reducing the potential severity.

3. **Forgiving roadside hardware.** Roadside hardware (e.g., cable barrier, guardrail, concrete barrier, and so on) is purposely designed to minimize the damage to vehicle occupants when struck.

**Median Access.** One concern raised with barriers is the reduction of median access for motorists, maintenance crews, and emergency services (e.g., police, fire, ambulance, and so on). If police officers are used to “hopping the median” as needed to change directions on a freeway, the presence of a barrier requires a change to their practices. Similarly, some median barrier installations reduce the number of emergency turnarounds, so it is important for roadway agencies to coordinate with emergency services to discuss mutually agreeable accommodations. Some states have developed policies, such as requiring a turnaround opportunity every 2 miles.

Median barriers are made from a number of materials and designs based on need. Following are some of the most common:

**Concrete Barrier.** Concrete barrier is often used in narrower medians and in urban areas to redirect motorists back into their appropriate travel lane. Though the initial cost is relatively high compared to other median treatments, maintenance is minimal due to the solid nature of concrete. Because the material is rigid, designers have developed a shape for this barrier that mitigates damage to vehicles and occupants when struck.

**Double-sided Guardrail.** Guardrail, like concrete barrier, is designed to redirect vehicles. It is less rigid than concrete, making it more forgiving when impacted. This attribute also leads to some maintenance costs and effort after an impact. Additional information about longitudinal guardrail is provided in Section 6.7, Clear Zones.

**Cable Barrier.** Cable barrier is a comparatively new form of median treatment, popularized in the early 2000s for its low price and success in reducing cross-median crashes. Cable barrier is made up of multiple
strands of cable (usually 3 or 4) held up by a series of small posts. When a vehicle impacts the cable barrier, the barrier “catches” the vehicle, keeping it from crossing the median. As a relatively new device, research continues on the following aspects of cable.

- **Cable barrier design.** The number, vertical placement, and weave pattern of cables; spacing and cross-section design of posts; anchor hardware; and materials used for all parts of the cable barrier have been studied and modified over the years to ensure optimal design (Figure 6.6).

- **Tension.** Cables can be low tension or high tension, each having advantages and disadvantages. Low-tension cables are easier to install but must be replaced immediately after a hit. High-tension cables are more complex to install, but when an impact occurs the cables can remain effective even if a few posts were damaged or knocked out of the ground.

- **Lateral placement.** Installations since the 1990s include median cable barrier at nearly every lateral location within the median. Care must be taken to minimize the opportunity for vehicles to go over or under the cable, and the placement of the cable plays a significant role. Placement directly in the center was popular early on, but when water pools in that location it can cause the posts to fall out more easily. Placement near the edge of pavement is effective for catching vehicles, but it also increases nuisance hits and driver discomfort. In addition to divided highways, in some situations placing cable in narrow, undivided roadway medians can provide a safety benefit. With these installations, care must be taken to consider the lateral deflection of the cable, as vehicles can enter opposing lanes for a short period of time immediately after striking the cable.

- **Maintenance.** Though the initial installation of cable barrier is much less costly than either concrete or guardrail, ongoing maintenance is more expensive and requires staff time or a maintenance contract. A knocked-down cable barrier does not provide median protection to prevent opposite-direction crashes, so maintaining the treatment is important.
6.5 WRONG-WAY DIRECTION CRASHES

Wrong-way drivers can contribute to head-on crashes. Though the frequency of this crash type is relatively low, it has a high chance of causing severe personal injury outcomes.

Addressing the problem is difficult, especially at freeway and expressway interchange entrances. It is not easy to identify problem locations for treatment due to the low frequency of wrong-way movement crashes. Also, it is often unclear why the driver entered the freeway/expressway in the wrong direction.

6.5.1 SIGNING AND PAVEMENT MARKING

Practitioners can address wrong-way drivers and associated crashes with the following treatments.

Figure 6.6. Anchor for three-strand, low-tension cable barrier
Signing (A). To minimize the chance of wrong-way motorists, practitioners can install appropriate standard signing. Devices include Wrong Way, One Way, and Do Not Enter signs. Enhancements include oversized signs, installing on both sides of the roadway, and installing at multiple locations.

Pavement Marking (A). Standard pavement marking provides the first clue to motorists of the correct direction of travel (i.e., white pavement marking to the right of the motorist, and yellow marking to the left). Large arrows pointing in the correct direction of travel in the middle of the ramp provide supplemental information to discourage wrong-way travel.

Raised Pavement Markers (A). RPMs have been installed at ramps and other locations where wrong-way driving problems may exist. By installing red-colored lenses on the back side of the RPMs, practitioners can provide a color at pavement level to supplement WRONG WAY and DO NOT ENTER signs.

6.5.2 ACTIVE WARNING (B)

Agencies have installed active warning devices that detect wrong-way drivers. As a motorist begins driving the wrong way down a ramp (or other segment of roadway), the system can flash beacons affixed to signs, turn on LED signs with messages, and even sound horns or other devices to get the attention of the wrong-way motorist.

6.6 WEATHER AND LIGHTING CONDITIONS

6.6.1 WET PAVEMENT CRASHES

When the pavement is wet, crashes are more likely to occur due to the decreased friction between the vehicle tires and pavement surface. If friction is already low due to age of pavement or other degradation, wet conditions can exacerbate the problem. Another concern is rutting of the pavement, which can allow water to pool, resulting in hydroplaning. Treatments include the following:

Grooved Pavement (A). Grooving a concrete pavement surface allows water to more easily run off the roadway, reducing ponding, therefore also reducing opportunities to hydroplane.
Superelevation (A). By increasing the superelevation of a curve (think of a “banked” race car track), vehicles are more likely to stay connected to the roadway at higher speeds. The advantage is that vehicles traveling at high speeds will be less likely to run off the road. The downside is that speeds around the curve can increase.

Surface Friction Treatments (A). Friction is what keeps a vehicle’s tires connected to the roadway itself. On curves in particular, forces act on the vehicle to push it off the roadway. Unfortunately, curves are also highly likely to suffer from reduced friction because the turning movement of vehicles causes additional wear on the pavement. There are a number of different ways to increase pavement friction, including the following.

Resurfacing (A). On asphalt surfaces a new layer of asphalt can provide increased friction. Thickness of this surface varies, including some very thin overlays often called “microsurfaces.” In the case of a microsurface, the main objective is increasing friction. Durability of these resurfacing projects is moderate.

Grinding (A). Concrete surfaces tend to “polish” over time, so grinding the very top level (typically just a fraction of an inch) exposes the higher-friction next layer of concrete.

SUPERELEVATION OR PAVEMENT FRICTION IMPROVEMENT?

Before increasing superelevation around a curve with a history of crashes, practitioners should consider improving pavement friction instead. A roadway that has a high superelevation can also have high speeds, which is undesirable around curves. By leaving a flat (or even reverse superellipse) curve in its current geometry, but greatly improving its pavement friction, two important safety-related effects can occur, creating a “win-win” situation.

1. The friction will keep the tires connected to the pavement—just like superelevation would, but using a different tactic.
2. The “poor” superelevation will make driving the curve at higher speeds uncomfortable to the driver (i.e., they will still feel the same forces of the flat or reverse supercurve), which can help keep speeds down.
High-Friction Surface Treatments (A). For a more durable, long-lasting product with higher friction values, newer high-friction surface treatments (HFSTs) have emerged in recent years to help motorists maintain control on the roadway. A HFST includes a high-quality aggregate (often calcite-bauxite, but products vary by region) and an epoxy binder.

The initial cost of HFST is higher than other friction treatments, but the treatment often lasts as long as the underlying pavement, maintaining very high friction levels during its life, providing a competitive life-cycle cost and long-lasting safety benefit.

6.6.2 DARK CONDITIONS

Dark conditions can increase the likelihood of crashes due to decreased visibility of the roadway, traffic control devices, fixed objects, and potential in-roadway hazards (e.g., animals, other vehicles, and so on).

Lighting (A). Adding overhead lighting can improve safety by increasing visibility of the roadway. Seeing the roadway is an important factor in navigating its geometry. The public tends to support overhead lighting installations due to these benefits, and also for general perceived public security of having more of their community lit at night. When installing lighting, the following should be considered:

- **Power source.** Lighting requires electric power, and depending on the location of need, feasibility can be affected by the distance from the necessary lighting and the nearest power source.
- **Electricity costs.** One downside of lighting is the ongoing cost associated with its use. When considering this treatment, practitioners must calculate the utility cost. In recent years this has become a less significant financial issue with the introduction of high-efficiency street lights.
- **Lighting pole location.** Utility pole installation introduces a new fixed object to the roadside, so care must be taken regarding placement. For example, it is important to install signing on the inside of the curve instead of the outside. Adding a light pole to the outside of the curve increases the chances that it could be hit by an errant vehicle.
Pavement Marking (A). As discussed in previous sections, basic retroreflective pavement marking (edgelines and centerlines) provides navigation information to road users. This is especially true at night when other indicators may not be as visible.

6.7 CLEAR ZONE

A clear zone is a traversable, unobstructed roadside area that allows a driver to stop or regain control after departing the roadway. Clear zones help support recovery and minimize the severity of crashes. The AASHTO Roadside Design Guide defines a clear zone as the total area that borders the roadside, starting at the edge of the traveled way (i.e., the lane used for travel). The guide includes desired minimum widths of clear zone based on traffic volume, operating speed, and geometric conditions of the roadside.4

Two programs, iRAP and usRAP, address roadside risk including clear zone as part of their analyses. See Chapter 2—Identify Safety Needs, for additional information about these roadway assessment programs.

Treatments to improve the clear zone at a given location include flattening slopes along the roadside, removing or moving fixed objects, and otherwise providing recovery areas for errant vehicles.

6.7.1 FLATTEN SLOPES (B)

To make the roadside more traversable or recoverable, practitioners can reshape the side slope to make it less steep. Overturns and fixed object hits can be reduced with this strategy.

6.7.2 FIXED OBJECT STRATEGIES

Some of the most common contributors to severe lane departure crashes are fixed objects. Examples include natural objects (e.g., trees, shrubs, ditches, rock walls, and so on) and man-made devices (e.g., utility poles, mail boxes, bridge abutments, and so on).

Fixed objects on any roadway should be addressed in the following hierarchy, as described in the *Roadside Design Guide*:

1. Remove the object.
2. Redesign the object so it can be safely traversed.
3. Relocate the object to a location to reduce its likelihood of being struck.
4. Make the object breakaway to reduce the severity of a crash.
5. Install attenuation devices to shield the obstacle and/or redirect an errant vehicle.
6. Install an object marker to warn motorists of its location.

**Roadside Trees (C).** Trees are the most struck fixed object along the roadway, accounting for more than 4,000 traffic fatalities annually.\(^5\) The most difficult issue with tree crashes is not the treatment—it is not difficult to physically remove a tree from the roadside. However, tree removal is generally unpopular among citizens due to aesthetic and environmental benefits. Balancing other needs of a community requires discussion with all parties involved, including community leaders, elected officials, property owners, and the general public.

In some cases, removing specific “trees of concern” (e.g., trees very close to the roadway, trees with a history of severe crashes, or single trees standing alone in an otherwise clear roadside) can provide significant benefit and be more publicly acceptable. In all cases, agencies should take great care in discussing the safety need and hearing the public concerns before removing trees.

If a problematic tree cannot be removed, other options include shielding the tree with guardrail or a similar device, or delineating the tree with an object marker. Preventing vehicles from departing the roadway in the first place can also help, so installing other lane departure treatments—rumble strips, signing, pavement marking, high friction surfaces—can reduce tree crashes.

**Utility Poles (C).** Utility poles are the second most hit fixed object. Utility companies are often granted an easement at the back of the agency’s right-of-way for installation of utilities. In some cases this right-of-way is not very wide, so utility poles were installed relatively close to the roadway.

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Most utility poles are not breakaway, so when a vehicle impacts a pole the results can be severe. Treatments for utility pole crashes are similar to trees—ideally the poles should be removed (replaced by underground utilities) or moved further from the roadway. However, the cost of utility pole relocation is high and typically outside the budget of most transportation agencies. In this case, shielding or delineation can provide some benefit, along with other typical lane departure treatments (e.g., pavement marking, rumble strips, signing, and friction improvement) to keep vehicles from departing the roadway.

There have been cases where nontraditional partners have been helpful with utility pole crashes. For example, in some neighborhoods or business communities, property owners have shared the cost to move utilities underground for aesthetic purposes (and potential property value increases), which also improved roadway safety.

**Object Markers (A).** Some fixed objects located along the side of the road—including drain pipes and other items—can be delineated with object markers to make them more easily seen by motorists. This is sometimes used in cases where a fixed object cannot be moved or made to break away, as in the trees and utility poles discussed above. The MUTCD provides guidance on the color and style of object markers (also called “lateral clearance” markers in some jurisdictions).

**Breakaway Sign Posts (C).** Signs installed by agencies along the roadway can act as fixed objects or projectiles when struck. Adding breakaway features to sign posts increases the likelihood that they will break away—sending the sign and post safely above the vehicle instead of entering through the windshield or windows. According to FHWA, the criteria for breakaway supports focus on two things: how much the sign changes the vehicle’s velocity, and the height of the remaining sign (i.e., the “stub”) after vehicle impact. Posts are considered “breakaway” if they slow the vehicle by no more than 15.4 ft per second and leave a stub shorter than 4 inches.6

Breakaway devices can be unidirectional or omnidirectional, depending on the most likely type of impact. For examples, signs installed near an intersection should be omnidirectional to account for potential hits from any angle. In some situations (e.g., signs installed behind guardrail or in other locations where they are unlikely to be hit) breakaway devices may not be required.

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6 Additional information is available on the FHWA sign supports website at http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/breakaway/signsupports.cfm
Roadside Hardware (C). To shield fixed objects or other severe crash risks (e.g., a steep dropoff), practitioners can install roadside hardware. The details of design and installation of roadside hardware are complex and ever-changing. The latest information is available in the AASHTO Roadside Design Guide and the FHWA Roadside Hardware Policy and Guidance website. There are two major types of hardware, each serving a different purpose.

**Longitudinal Barriers.** Longitudinal barriers are installed along the roadside to protect errant vehicles from a hazard on the other side of the barrier. Examples include concrete barriers, guardrail, and bridge rails, including the guardrail shown in Figure 6.7.

![Figure 6.7 Longitudinal guardrail with end treatment](image)

**Impact Attenuators.** An impact attenuator is placed immediately in front of a fixed object (e.g., bridge pier, high-mast pole). It is designed to reduce the impact to passengers inside a motor vehicle. Examples include sand barrels, water-filled barrels, and more advanced attenuators with specially designed, energy-absorbing modules.

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Without continual growth and progress, such words as improvement, achievement, and success have not meaning.

—Benjamin Franklin

Roadways do not last forever and must be maintained, replaced, and improved over time. Similarly, other utility systems (water, wastewater, electricity, and so on) require maintenance and improvement. These activities—maintenance, construction, and utility work—must sometimes take place on or near the roadway, affecting road users.

When an agency sets up (or allows another entity to set up) a work zone, they have immediately violated road user expectations. The corridor previously had a known geometry (e.g., number and width of lanes, curvature, and so on), traffic control devices (e.g., signing, pavement marking), and an expected traffic flow for that time of day. A work zone violates one or more of these by reducing the number and width of the lanes, adding horizontal curves to the travelway (to take motorists around a work area), and installing new signs with unexpected messages (Road Work Ahead; Right Lane Closed; Detour). Due to these changes, it is the responsibility of the roadway agency and its partners to take special care of road users and workers in work zones. This chapter describes the types of crashes, methods to identify concerns, and countermeasures (both street-level and policy-level) to improve work zone safety.

7.1 WHO ARE INVOLVED IN WORK ZONE CRASHES?

Work zones can cause safety concerns for two distinct populations—road users and workers. Road users are navigating a new situation, and workers are placed in a vulnerable position on the road near moving vehicles.
7.1.1 ROAD USERS IN WORK ZONES

As described above, work zones can violate driver expectations—especially those drivers who are very familiar with the section of road, having driven it many times. Commuters and other local drivers, in particular, develop an expectation to the point that they do not use traffic signs and other wayfinding devices to navigate the area. The following additional issues can increase the concern:

- **Daily changes.** Work zone traffic control can change day-to-day, so a road user cannot expect yesterday’s situation to remain, even in the same work zone. There may be a new roadway alignment, detour, number of lanes, and level of congestion.
- **Inaccurate messages.** Due to the complications of the work zone, sometimes traffic control is not entirely accurate. There are situations where the road user follows the signs and markings correctly, but they must still remain alert to navigate the work zone safely.

**DRIVER EXPECTATION**

If you were to be asked to describe a trip from your house to your grandparents’ in another city, including the name of every street, could you? In many cases we tend to forget navigation details like street names, in lieu of other information. You would have no concern driving to your destination, and even recognize the sign names when you saw them, but it is likely you use landmarks (or even muscle memory) to make the trip.

The margin of error for motorists is lower in a work zone than other segments of road, as sometimes lanes and shoulders are narrower, road-sides may be populated with workers or equipment, and there is a greater opportunity for surprise (e.g., a construction vehicle entering the roadway from a random location, or a worker walking across the road). When a crash does occur in a work zone, the limitations of the lane configuration leads to an increased opportunity for secondary crashes upstream.

**Special Users.** Beyond traditional work zone road users—motor vehicles—the following work zone users may have special needs not typically identified by agencies as they design temporary traffic control:

- Pedestrians, including those with disabilities
- Bicyclists
- Motorcyclists
7.1.2 ROAD WORKERS

Workers have many duties, only one of which is to ensure the safety of themselves and road users. They are required to complete maintenance or construction tasks, which is the purpose of the work zone to begin with. Workers must balance the needs of the project with the needs of traffic control. This is handled in some cases by having some workers focused only on keeping the work zone safe. Flaggers, for example, are typically stationed at the beginning of a one-lane-alternating work zone to handle opposite directions of traffic, encourage slow speeds, and alert their coworkers of any concerning driver movements.

Another concern is proximity to motor vehicles, especially in high-speed situations. It is common for workers to be very close to the driving lane while completing their work, putting them at risk of an errant driver.

7.2 IDENTIFYING WORK ZONE SAFETY ISSUES

Studying work zone safety is different than other types of safety analysis because of its temporary nature. Identifying individual work zone’s safety concerns is often not particularly useful, because by the time an analyst can determine where the crashes are occurring, what they are, and how they could be addressed, the work has been completed and the work zone no longer exists. Even when data are collected for a larger study, the relative number of work zone crashes is low due to their transient nature, limiting the ability of safety analysts to develop statistics-based conclusions.

These issues can be addressed in two ways: First, it is possible to identify some work zone safety issues in real time and address them immediately. Second, addressing work zone safety can focus on programmatic and policy-level improvements, rather than on fixing individual locations.

For additional information regarding work zone safety data, see FHWA’s Work Zone Safety Data Collection and Analysis Guide.1

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7.2.1 SAFETY-RELATED DATA

Crash data are useful to practitioners to identify work zone safety concerns, helping them learn about the causes of each crash and apply necessary modifications to the current work zone (if it is still active), as well as future, similar work zones. Some of the more common work zone-related data elements include:

- Involved parties (motorists, workers, nonmotorist road users)
- Location within the work zone
- Traffic control and layout
- Queue length
- Type of work zone (construction, maintenance, utility)
- Type of work operation (moving, stationary)
- Worker presence
- Law enforcement presence

Practitioners also use other types of data to support safety analyses:

**Exposure Data.** It can be useful to calculate work zone crash rates. Data include average daily traffic or hourly traffic counts, but due to the difficulty of collecting traffic volumes in work zones, this analysis is often conducted afterwards.

**Mobility and Queue Data.** Excessive delays can cause queuing in a work zone, and if the queues are excessive they can contribute to rear-end crashes. Unlike rear-end crashes at intersections which tend to be low-speed and rarely cause injuries, rear-end crashes at the back of a work zone queue can be severe due to speed differential. In this case a motorist could be traveling at a high rate of speed and then be surprised by an unexpected queue up ahead (especially if that queue extended beyond the first work zone signs).

**Speed Data.** Speed has been identified in more than 25 percent of all fatal crashes that occur in work zones. Speeding can combine with other road user behaviors (e.g., distraction, inattention) and the geometric features in a work zone to increase crash risk.

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7.2.1.1 Data Collection and Analysis

Data for work zone safety are collected either in real time or after the fact. Each approach has its advantages and disadvantages.

Real-time Data Collection. Collecting data in real time provides information that can be used to improve safety at the current work zone—data like crash counts by day (with associated details) and speed and traffic volume data. The disadvantages of real-time data are that accuracy may be reduced to ensure timeliness, and the high volume of data may be difficult to analyze quickly if programs and processes were not set up to make the data usable.

After-the-fact Data Collection. Over time analysts can collect a larger sample of safety data, either from a single work zone or multiple projects, and then combine data sets to identify potential issues. The downside of using information after the fact is that it is rarely useful for the work zone at which it was collected. Additionally, any missing or erroneous data are difficult to correct after the work zone is no longer operating.

7.2.1.2 Challenges to Work Zone Data Collection and Analysis

When dealing with work zones, there are three main parties involved: agency staff, law enforcement, and contractors.

- **Highway agencies** often do not have the resources desired for real-time data collection, and they will not always have staff on site.
- **Law enforcement agencies** have many responsibilities when supporting safety in a work zone, especially if a crash occurs. They must clear the scene as soon as possible to reduce the chance of secondary crashes, which are more likely in work zones due to pre-existing limitations. Also, most state crash reports do not have data elements for details in work zone-related crashes, so officers collect only basic information. Additional elements that would be useful for future analysis include temporary traffic control setup and presence of workers at the time of the crash.
• Contractors and utility companies have a primary yet complex focus—getting the job done quickly for maximum profit while keeping their employees safe and reducing liability. Adding extra data collection to a project can be perceived as extra work with no upside and a potential for increased liability if the data could harm the company.

Addressing These Challenges. Highway and law enforcement agencies, contractors, and utility companies have worked together to address the challenges above with innovative solutions. Following are a few of the many examples:

Visits to Law Enforcement Agencies. Highway agencies can visit the local police department, sheriff’s office, or state enforcement troop location to collect reports of the most recent crashes in a work zone. The agency and contractor can use these reports to identify any issues that can be addressed immediately with modified temporary traffic control or other measures.

Technology Solutions for Real-time Data Collection. A number of devices are available to collect real-time speed and queue information. Some of these devices are portable and can be deployed quickly in a work zone. By identifying reduced speeds—especially unexpected reductions—agencies can respond quickly with additional traffic control or law enforcement presence. The data may also indicate an incident, helping law enforcement and emergency medical staff respond quickly.3

Improving Crash Report Forms. The latest version of the Model Minimum Uniform Crash Criteria includes additional information about crashes occurring in work zones, including the following:

- Workers present? (Yes/No)
- Type of work zone (lane closure; moving work; and so on)
- Location of crash (advance of work zone; transition area; work area; and so on)
- Law enforcement present? (Yes/No)

States are encouraged to adopt these data elements, adding them to their own crash reports forms the next time they conduct an update.

7.3 WORK ZONE SAFETY ISSUES AND SOLUTIONS

According to the MUTCD, Part 6, “The needs and control of all road users...through a temporary traffic control zone shall be an essential part of highway construction, utility work, maintenance operations, and the management of traffic incidents.”

This section will “take a trip” through a typical construction work zone to identify some of the most common safety issues and concerns, and describe some common solutions. In the case of maintenance and utility work zones there may be some differences, but most of the same principles apply regardless of work zone type.

This book provides basic, plain-language discussions of work zone traffic control devices and issues. For a full, engineering-focused overview of temporary traffic control complete with typical applications and associated details (e.g., sign sizes, placement, and so on), see the MUTCD.

7.3.1 GENERAL STRATEGIES

7.3.1.1 Public Communication

Before road users encounter a work zone, agencies have an opportunity to inform them about current and upcoming changes to the roadway or possible delays. This is especially important for major lane closures and road closures, or for any work zone that is expected to cause major transportation delays. Agencies often communicate to their citizens with the following tools:

- **Traditional media.** Agencies submit press releases that may be picked up by local newspapers, radio stations, and television affiliates. Local news programs can let people know of upcoming work zones in the area. The more specific this information is regarding location and time of closures the better.

- **Emerging methods.** Starting in the 1990s agencies began providing updates on construction projects through websites and e-mail. For example, some state departments of transportation (DOTs) now have maps of current lane closures and upcoming closures or other work zone impacts. Social media applications
can also play a role, as agencies can push information to users via tools they already check regularly. Additionally, crowd sourcing applications on smartphones and other devices allow road users to provide immediate feedback about their experience to other users, who can use that information to make informed routing decisions (including the choice to avoid a work zone with significant delays).

7.3.1.2 Work Zone Reviews and Audits

Due to the limited information available from crash reports in work zones, improving work zone safety has focused largely on proactively reviewing and observing work zones during operation. Practitioners conduct various types of work zone reviews.

- **Work zone report card**—In recent years agencies have requested basic review support from nontechnical staff and the general public. A basic, one-page review sheet can include a short set of questions designed for any road user. Sometimes it will also include the option for the reviewer to give the work zone an overall letter grade. Its purpose is to provide work zone experts with a high number of reviews, knowing the reviews are subjective and nontechnical. Questions may include the following:
  - Did you have enough advance warning of this work zone?
  - Were the signs easy to understand?
  - Did you feel comfortable driving at the posted work zone speed limit?
  - Overall, how would you rate this work zone?

- **Work zone inspection**—A work zone inspection is a review of temporary traffic control devices and strategies in an active work zone, conducted by the road owner’s technical staff. It often includes a detailed work zone inspection sheet for documenting any deficiencies or concerns. It is focused on objective items: placement of signs and other devices, presence and operation of flagging operations, matching traffic control design to the real-world installation.
• **Road safety audit**—A Work Zone Road Safety Audit (RSA) is a formal safety performance evaluation that can be conducted at any stage of a planned or existing work zone. The makeup of the RSA team is different than other reviews. It is independent of the road owner and multidisciplinary, which provides an unbiased review of the work zone by a broad team with experience from multiple viewpoints. The process is formalized into eight steps, including a formal presentation by the RSA team to the road owner to discuss findings and recommendations. A full description and tools to conduct Work Zone RSAs can be found in FHWA’s *Work Zone Road Safety Audit Guidelines and Prompt Lists*.

### 7.3.2 APPROACHING A WORK ZONE

The first step in work zone safety is providing notification that a work zone exists and may impact the road users’ navigation. As discussed above, driver expectation is a key factor in traffic safety in general, and with work zones in particular. Providing proper warning of an upcoming change in traffic pattern, roadside activities, or other issues is helpful to motorists.

#### 7.3.2.1 ROAD WORK AHEAD Signing

One of the first signs in most temporary traffic control plans is ROAD WORK AHEAD in black letters on an orange background. This basic message conveys to the driver, “Hey, something different is occurring ahead and you should be more aware than usual. Put down your cell phone, turn down the radio a bit, and pay close attention because you cannot navigate this stretch of road in exactly the same way you did yesterday.” The color orange is reserved only for work zones to help them stand out. In recent years fluorescent orange has become the standard in many states for its extra visibility (similar to the fluorescent yellow signs discussed in previous chapters).

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This sign can be supplemented with improvements, enhancements, or additional devices, including:

- Flags, flashing beacons, or other enhancements to make the ROAD WORK AHEAD sign more likely to be seen.
- The sign itself can be oversized. The typical sign for this purpose is a 36-inch diamond. Signs 48 or 60 inches wide have been used in some situations.
- Practitioners can double-up the signs, installing one on each side of the road. They could also put a second set a little further down the road, but still well in advance of the work zone. This gives the driver two chances to see the warning, in case he or she misses the first sign.
- Temporary transverse rumble strips—raised a couple inches from the pavement—provide a tactile and auditory indication to the motorist to look up and pay attention. These can be coupled with the ROAD WORK AHEAD sign to draw attention to it and the upcoming work zone.

7.3.2.2 Queueing

In some work zone traffic control setups (e.g., reduction in the number of lanes, narrowed lanes, curved alignment, or active work occurring) the capacity of the roadway will be reduced, which can lead to queueing. A queue, defined for traffic purposes, is basically a “backup”—a line of vehicles either at a standstill or slow moving. A queue can cause a number of safety concerns in advance of the work zone:

- If the queue is in a single lane but another lane is open, some motorists may choose to “jump the line,” causing conflicts at a later point in the work zone, general annoyance from road users waiting in line, and potentially road rage.
- If the queue backs up to a limited-sight-distance location (e.g., just around a corner or over the crest of a hill), then approaching motorists will be forced to stop very quickly. This can lead to rear-end crashes, which can result in serious injuries or fatalities due to the high speed of approaching vehicles.
- The queue can back up behind the first work zone sign—ROAD WORK AHEAD. In this case the motorist has no warning that a work zone is coming. His or her first information is the queuing traffic, and without prewarning this can lead to rear-end crashes.
The following treatments can help motorists be aware of upcoming work zones before they approach a potential queue, reducing the risk of back-of-queue crashes.

Queue Detection. Identifying the back of the queue can help work zone experts mitigate safety problems by applying one or more of the treatments listed in this section. This can occur manually—a work zone inspector can check the queue at regular intervals to ensure it is not at a poor-sight-distance location or beyond the first set of work zone signs. There are also devices available to identify the back of queue by constantly measuring the speed of vehicles at certain points in advance of the work zone. They provide a speed profile at these points, and if speed reaches a certain lower threshold, the device can automatically contact the responsible work zone traffic control manager.

Changeable Message Sign (CMS). An agency can install a CMS further in advance of the work zone (sometimes multiple miles) to provide early warning of an upcoming change. Some state agencies and turnpike authorities have existing message signs permanently installed along the road—especially on freeways and high-volume expressways. These signs can be used, too, if their installation location is within an appropriate proximity of the work zone.

Placing Extra Signs. An agency can bring an extra set of signs to the job and either keep them in a vehicle, install but cover the signs, or place them face-down along the side of the roadway. If the queue approaches the original set of ROAD WORK AHEAD signs, then workers can install/reveal these signs, so road users are aware of the upcoming queue.

Vehicle at Back-of-Queue. In some cases, if the queue length varies greatly during the course of a day, placing a maintenance or law enforcement vehicle equipped with warning lights in advance of the back-of-queue can alert approaching motorists. This has the additional advantage of being easily movable, as the worker or officer can simply drive forward or back, along the shoulder, to stay an appropriate distance upstream of the queue.

7.3.3 MERGE AREA

In many work zones the actual work must be done on the existing roadway, which requires a reduction in the number of lanes through the work zone. When a lane is closed, practitioners must set up temporary traffic
control to identify which lane is being dropped and when motorists should merge into the other lane(s). This reduction in the number of lanes requires traffic to merge into the remaining lane(s), which can lead to the following safety concerns:

- Vehicles in a single lane will back up further than in multiple lanes, leading to potential queuing concerns discussed above.
- Lane changes increase the probability of sideswipe crashes. If motorists are surprised by the need to merge, they can make erratic lane change movements in an attempt to follow the signs.
- When merging occurs over a relatively long segment of roadway some motorists may choose to “jump the line” by merging further downstream than others.

Practitioners can use the following methods and devices to help keep the merge areas safe approaching a work zone.

7.3.3.1 Channelizers and Tapers

Proper placement of cones, channelizers, drums, and barrels for various tapers provides motorists the opportunity to safely merge. Practitioners use different type of channelizers, drums, or barrels based on need and cost.

The taper is the diagonal placement of channelizers to help motorists merge their vehicle into a different lane. The main types of tapers are as follows:

- **Merging taper:** Drivers merge into a “common road space” that may be occupied by other motorists.
- **Shifting taper:** Motorists are shifted laterally on the roadway.
- **Shoulder taper:** Work is done on the shoulder, but motorists stay in their normal travel lane. This shift is designed to protect the workers behind the taper.
- **One-lane, two-way taper:** In this case a portion of the road is used alternately by traffic in each direction.
- **Downstream taper:** Used to show motorists they have navigated the work zone and can merge back into the original lane, if desired.
MUTCD Section 6C.08 provides guidance for the appropriate taper length in work zones. Taper length (L) should be determined using the criteria shown in the following two tables (MUTCD Tables 6C-3 and 6C-4).

First, calculate L using one of the formulas given below based on the operating speed.

<table>
<thead>
<tr>
<th>Speed (S)</th>
<th>Taper Length (L) in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mph or less</td>
<td>( L = \frac{WS^2}{60} )</td>
</tr>
<tr>
<td>45 mph or more</td>
<td>( L = WS )</td>
</tr>
</tbody>
</table>

where \( L \) is the taper length in feet; \( W \) the width of offset in feet; and \( S \) the posted speed limit, the off-peak 85th-percentile speed before starting the work, or the anticipated operating speed in mph.

Second, identify the taper length based on the type of taper.

<table>
<thead>
<tr>
<th>Type of taper</th>
<th>Taper length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merging taper</td>
<td>At least ( L )</td>
</tr>
<tr>
<td>Shifting taper</td>
<td>At least 0.5 ( L )</td>
</tr>
<tr>
<td>Shoulder taper</td>
<td>At least 0.33 ( L )</td>
</tr>
<tr>
<td>One-lane, two-way traffic taper</td>
<td>50 ft minimum, 100 ft maximum</td>
</tr>
<tr>
<td>Downstream taper</td>
<td>100 ft per lane</td>
</tr>
</tbody>
</table>

### 7.3.3.2 Early, Late, and Dynamic Merge

Merging vehicles can cause safety concerns depending on approach speed, traffic volume, and the space available. The merge movement is handled differently based on some of these issues.

**Early Merge.** The standard, historic merge concept, Early Merge uses signing to encourage vehicles to merge into the open lane early, then continue single file for a distance in advance of the lane closure. Advantages include lack of conflicts at the merge point in most cases. However, the following concerns can arise:
• **Line cutting.** In an Early Merge, aggressive drivers can “jump the line” by speeding to the front and then cutting in near the end. Other drivers see this as an unfair situation, leading to potential additional aggressive movements.

• **Lane straddling and side-by-side.** To combat the line-cutting problem, some motorists will take matters into their own hands, straddling the line. Large trucks have a habit of driving side-by-side in both lanes to ensure no other vehicles cut.

• **Queueing.** If congestion occurs at the merge point and backs traffic up, the single file line of cars can create a queue (see *Queueing* in this chapter). Further, this queue problem occurs while a “perfectly good traffic lane” is unused adjacent to the queued vehicles.

**Late Merge.** In this case signs encourage motorists to continue in both lanes all the way to the merge point (e.g., USE BOTH LANES TO MERGE POINT), and then simply take turns entering the work zone at that point. Advantages include addressing the line cutting and queuing concerns of Early Merge, especially in cases where large trucks are a significant portion of the vehicles involved. Disadvantages can be seen during low-volume, high-speed conditions. It can be less clear for motorists to determine who has the right-of-way in the “take your turn” location at the merge point. Conflicts can occur, and if they occur at high speeds severe crashes may result.

**Dynamic Merge.** The Dynamic Merge system attempts to use both Early Merge and Late Merge at the times they are most effective. Detectors can determine the traffic volume, approach speed, and potential congestion issues. Based on these factors, the Dynamic Merge system will provide a message to the motorists via CMS to either merge early or merge late. Agencies have seen benefits of Dynamic Merge to improve safety and traffic flow. The downside is cost. While Early Merge and Late Merge setups can be done with standard, static signs and no detection, the Dynamic Merge system requires more expensive signing, detectors to maintain situational awareness of the work zone approach, and either programmed algorithms or work zone experts to decide when the system should switch between early and late merge.

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7.3.4 WORK AREA

In the work area, road users are most likely to come in contact with road workers, equipment, materials and changed roadway conditions (e.g., surface changes, edge dropoff, and so on). Additionally, this is the area work is being conducted so workers are most vulnerable to being hit by errant vehicles.

7.3.4.1 Work Zone Speed Limits

Work zone speed limits are an important tool to keep road users and workers safe. For road users, the reduced speed helps them navigate ever-changing conditions of the temporary traffic control situation. For workers, slower traffic reduces the risk of crashes.

However, speed limits must be set appropriately, following these parameters as recommended in guidance from the MUTCD in Part 6C.01, Temporary Traffic Control Plans.

- Reduced speed limits should only be used where restrictive features or other conditions requiring a reduced speed are present.
- In most cases, speed limits should not be reduced by more than 10 mph.
  - If more reduction is required due to the features of the work zone, care must be taken to provide additional warning to motorists of the reduced speed.
- Large reductions in the posted speed limit (e.g., 30 mph below the non–work zone speed limit) can lead to increased speed variance among motorists, which increases the potential for crashes.

7.3.4.2 Road Users

In the work area road users are exposed to shifting roadway geometry; workers, their vehicles and equipment; and changing conditions on the roadway (e.g., edge dropoff, uneven lanes).

Edge Dropoff. Due to the nature of construction and maintenance efforts, often work must occur over multiple days, weeks, and months, which requires an “unfinished” project on the roadway. One of the ramifications of this is edge dropoff, a vertical drop at the edge of pavement or shoulder.
Depending on the height of the drop and surrounding conditions, a motorist dropping off the edge could overcorrect into oncoming traffic, run off the road, or overturn. Work zone experts can address edge dropoff with the following treatments:

- Policies related to the allowable depth of the edge dropoff and lateral offset from the travelway by time of day, and whether active work is taking place. These standards tend to vary based on operating speed, traffic volume, and type of roadway (e.g., neighborhood street, urban arterial, freeway, and so on).
- Signing warning of the edge dropoff.
- Safety EdgeSM treatment, which is an angled edge (approximately 30 degrees) that helps an errant vehicle recover.
- Channelization identifying the dropoff for road users.
- Positive protection (e.g., concrete or plastic barriers) separating users from the dropoff.

**Ingress/Egress.** Along with road users, workers also have vehicles in and around the work zone, and they often need to move those vehicles to and from specific locations to complete the work. For example, trucks may deliver concrete to a work zone throughout the day, and they must have a place to enter and exit the work zone while keeping workers and road users safe.

- **Access points.** Some ingress/egress points are safer than others due to sight distance, proximity to traffic, and so on. Work zone practitioners should choose access locations that help the workers complete their work while also protecting equipment operators and road users.
- **Signing.** Advanced warning signs (e.g., TRUCKS ENTERING AND EXITING ROADWAY AHEAD) can provide road users the proper warning to look out for work zone vehicles at access points.

### 7.3.4.3 Work Zone Personnel

The most vulnerable people in a work zone are the workers themselves. Whether on the travelway, shoulder, off the shoulder, or well off the road, workers are often working on foot. Further, most workers are primarily tasked with getting a job done efficiently and at high quality instead of temporary traffic control for road users.
**Personal Protective Equipment (PPE).** One of the most important safety measures for individual workers is the most basic—a highway safety vest. PPE products are designed to make roadway workers highly visible to approaching motorists. Besides a vest, retroreflective pants, gloves, hats, and other apparel can provide conspicuity for workers. All PPEs are not created equal, however, so standards have been developed to ensure workers are wearing apparel that provides adequate visibility. The MUTCD references, “Performance Class 2 or 3 requirements of the ANSI/ISEA 107–2004 publication entitled *American National Standard for High-Visibility Safety Apparel and Headwear*.”

**Channelization.** The same devices discussed for tapers (cones, channelizers, drums, barrels) can also be used as a visual deterrent to keep motorists from crossing into the work area.

**Positive Protection.** More effective, yet also more expensive, positive protection includes a number of different types of barriers, including concrete, water-filled, metal, and plastic. Standards dictate details of these devices, including the materials used in production, designs, anchor locations, and the tested results of impact by a motor vehicle.

**Intrusion Alarms.** In some cases an intrusion detection system, sometimes placed on a channelizer near the beginning of the work area, can alert workers that a vehicle has encroached into the work area.

### 7.4 OTHER WORK ZONE TYPES

Beyond the standard work zone described in Section 4, there are a number of other work zone types.

**Mobile Work** includes continuous moving work zones like pavement marking and street sweeping. This category also includes intermittent moving work zones like mowing and pothole patching. With all mobile work operations, it is important to have one of both of the following:

- A separate vehicle (or vehicles) providing warning devices for approaching road users.
- High-intensity rotating, flashing, oscillating, or strobe lights, signs, or special lighting.
One-lane, Two-way Operation is a special condition common to two-lane roads. When one of the lanes is being worked on, the other handles both directions of traffic. In this situation one or more of the following temporary traffic control applications is needed.

- **Flagging operations.** Flaggers typically hold a paddle with STOP on one side and SLOW on the other. At least two flaggers work in tandem to provide alternating right-of-way on a single travel lane.

- **Pilot vehicle.** In very long one-lane, two-way operations, it can be useful to have a pilot vehicle lead a queue of motorists through the work zone.

- **Temporary signals.** If the distance is relatively short (e.g., across a small bridge), then an automated traffic signal system can provide safe one-lane, two-way operation. A typical setup includes two traffic signals connected by hardwire or wireless communication. These signals operate similarly to two flaggers—alternating right-of-way for each direction. This setup may also include detection between the signals to ensure no one is driving the “wrong way” against the green signal.
CHAPTER 8

COUNTERMEASURE IMPLEMENTATION

*Everything should be made as simple as possible, but not simpler.*

—Albert Einstein

Once practitioners select the appropriate countermeasures, it is important to implement the treatments successfully. This chapter describes various approaches to implementation. In most cases a successful safety program uses a combination of the approaches described below.

8.1 SPOT LOCATION TREATMENTS

One method of treating safety needs, once countermeasures are identified, is to invest in a number of spot locations that have exhibited risk factors—previous crash history, roadway attributes, traffic volumes, and so on—as described in Chapter 2. For the crash history criterion, locations with a significantly higher number of crashes than others can be considered for safety treatment, focusing on countermeasures proven to reduce the identified crash types.

8.1.1 DESCRIPTION, BENEFITS, AND DISADVANTAGES

A benefit of the spot location approach is its focus on an identified set of finite locations, and that those locations exhibited a history of crashes (i.e., a “worst first” approach). Intersections are an often-identified set of locations for spot treatments because they are easily identifiable in crash reports.
This approach assumes that—barring intervention by safety professionals—the history of crashes would continue along the same path in the future. Evaluating treatments using this method is relatively simple, involving counting the number of crashes before and after the treatment.

The spot location approach is limited to a relatively small number of treatments in most situations due to resource limitations (e.g., project funding, staffing, and so on). Because of this, it is difficult for this approach alone to result in a significant reduction in severe crashes for an entire jurisdiction.

The spot location approach also requires elevated accuracy of crash treatments data. If a jurisdiction is choosing a relatively low number of treatments (for example, their top 20 curves then near-perfect location choices are essential. In addition, spot location crash analysis is limited without incorporating additional data—traffic volume, roadway attributes, contributing circumstances, and other information. A lack of data elements limits the effectiveness of this approach.

Over time safety practitioners attempt to address enough “bad” locations they will eventually fix them all. After screening the agency’s network, the analyst identifies the “worst” locations. Once these locations are chosen, safety funds focus on this small number of locations. The locations are fixed, and then the data analysts find the “next worst” set of locations for improvement the next year. In the meantime the overall number of severe crashes in a city, county, or state often remains largely the same. The agency may end up with a few “fixed” intersections and segments, but also many continue to suffer a consistent level of fatalities and serious injuries on their roadways.

**MAD NURSE**

In 1986, Firebird Software Ltd. produced a video game for the Commodore 64 called *Mad Nurse*. The premise of the game was simple: You are a nurse in a multilevel nursery, and your job is to keep the babies in the nursery from harming themselves. Your charge is easy enough: put the babies in their cribs. But the perils are endless, including knives, poison, toilet bowls to climb into, and an elevator shaft.

As the levels became more and more difficult, the end result of Mad Nurse was disastrous.1

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1 For additional information about Mad Nurse, see www.lemon64.com/?mainurl=http%3A//www.lemon64.com/games/details.php%3FID%3D1565.
The historic spot location approach to address traffic fatalities has similarities to Mad Nurse. We identify the locations of the currently identified problems, and then we move to the next location.

And the next.

The situation gets worse over time as motorists make poor choices more often. The results can be a group of exhausted traffic safety engineers and little change in the overall number of roadway fatalities.

8.1.2 TIERED COUNTERMEASURES

In developing possible countermeasures based on safety analysis, practitioners review a range of solutions related to cost and time needed to implement. In most cases low-cost solutions can also be implemented quickly, and some can be conducted immediately following problem identification. For example, an intersection could have limited sight distance due to vegetation along the roadside blocking views; this can be addressed by maintenance staff clearing brush the same day it is discovered.

Some solutions are medium-term or long-term depending on their cost and complexity. These may require programming, budgeting, environmental study, design, and a construction contract.

It is common to identify and implement a solution from each of the categories (short-, medium-, and long-term) at the same location. A high-volume intersection could receive vegetation clearing immediately, signing and pavement marking improvements within a few months, and a full redesign (to a roundabout, traffic signal, or interchange) a few years later. Each of the treatments provides value to improve safety at that location.

8.2 SYSTEMIC APPROACH

A weakness of using only the spot location approach is a failure to heed the power of randomness. In some cases, the location of a single severe crash event does not provide enough information to make a valid judgment on the relative safety of that location. Past performance does not always indicate future results.
8.2.1 DESCRIPTION

Given the number of roadway users and the billions of miles they drive each year, traffic crashes are relatively rare events, making it difficult to pinpoint locations of need. Additionally, the factors that go into determining the severity of a traffic crash are numerous, including:

- Type of crash (e.g., run off road, rear-end)
- Number of vehicles involved
- Speed of the vehicle(s)
- Weather conditions
- Age and health of drivers and passengers
- Use of safety belts or helmets
- Fatigue or impairment level of the driver(s)

8.2.1.1 Severe Crash Locations Are Random

Few, if any, of these criteria are location-specific. History has shown that severe traffic crashes tend to “bounce around” a jurisdiction. It is unlikely that a location with one fatal crash will suffer another, regardless of whether treatments are installed. There comes a point when chasing fatal crash locations around a city, county, or state is not an effective means of keeping people safe.

8.2.1.2 Severe Crash Types Are Predictable

It is difficult to predict the locations of future fatal and serious injury crashes, but we can—with staggering accuracy—predict the contributing factors related to severe crashes (e.g., unbelted occupants, lane departure, impaired driving). The most common contributing circumstances to fatal traffic crashes are consistent over time.

8.2.1.3 Focus on the Predictable

By shifting our focus from the random to the predictable, safety engineers can more effectively address safety needs on their roadway systems. The end result can be an improved safety management program and a reduction in the annual number of traffic deaths and serious injuries.
During analysis, the criteria used to identify locations for treatment can include historical crash data, traffic volume, roadway attributes (e.g., shoulder width and type), and geometric features. The results for systemic implementation are usually a much larger system of treatment locations. Examples include a corridor, an entire route, a list of intersections, or all roadways with certain attributes (e.g., horizontal curves with a certain radius).

Due to the high number of treatment locations (often hundreds or thousands, versus just a few with the spot location approach), the quantity and quality of data required are less stringent. It is important that the countermeasures are low-cost and relatively easy to implement, as they will be blanketed over a large portion of the roadway system.

Though applicable anywhere, the systemic approach has particular value for rural roads. Most rural situations include crashes dispersed widely among the road system without obvious spot locations for safety investment. Systemic installations to improve large portions of the system can provide long-term benefits on rural roads.

8.2.2 BENEFITS OF THE SYSTEMIC APPROACH

Approach benefits include the following:

- The systemic approach treats a high number of locations, making the entire system safer.
- Low-cost solutions can be implemented more quickly than large projects. Often a full project development process is unnecessary. For example, an agency can install warning signs with its own maintenance forces.
- Systemic solutions can prevent future crashes before they occur by blanketing large portions of the roadway with treatments. This can lead to the reduction of overall crashes of a particular type, even if some individual locations do not see a decrease.
- Data needs are reduced significantly. It is not as vital to choose the “perfect locations” when a practitioner is addressing hundreds of them with low-cost solutions. Therefore, the limitations of crash and roadway data are less problematic.
8.2.3 DISADVANTAGES OF THE SYSTEMIC APPROACH

The disadvantage of the systemic approach is that it can be more difficult to sell the concept to decision makers, leadership, and the general public. Installing chevrons at hundreds of curves over multiple years is not as exciting as a large intersection redesign or a bridge replacement. The value of this approach is the reduction in crashes, not a media story, so it is sometimes more challenging to secure public funding for these low-cost treatments. Additionally, no single location is likely to experience a great reduction in crashes (most treatments reduce crashes of a particular type by 15 to 30 percent), so the before/after safety story is not as exciting as single large projects that could eliminate severe crashes at a single location.

This drawback can be mitigated with education of decision makers and the public, and by creative marketing of the treatments. For example, a state DOT may hold a press conference to show a single installation of a low-cost treatment (e.g., rumble strips, signing) while sharing the state’s plan to treat hundreds of miles with a similar treatment to reduce crashes and save lives.

8.3 POLICY-LEVEL APPROACH

To make long-term safety improvements in a jurisdiction it is important to not only address current safety needs with reactive treatments, but also to consider policies that will make the overall system safer in the future. The longest-lasting safety efforts are changes to agency policies that leave a legacy of safety extending well beyond current projects, and even current practitioner’s careers.

For example, an agency may begin with a single centerline rumble strip project at a spot location exhibiting a history of centerline crashes. After installation and evaluation, the agency may develop a program of centerline rumble strips along corridors based on crash history, traffic volume, and/or roadway width. Over time the agency could develop a policy to install centerline rumble strips on all roads meeting certain criteria that may or may not include crash history. This design element could become part of standard operating procedure, being used in standard design plans, similar to how an element like basic pavement marking is included on all highway projects today.
8.4 COMPREHENSIVE SAFETY: THE 4 Es

The comprehensive approach incorporates the 4 Es of safety:

- Engineering
- Enforcement
- Education
- Emergency Medical Services (EMSs)

This approach recognizes the other factors related to safety, understanding that not all locations can be addressed solely by infrastructure improvements. Some locations or crash types may include frequent driving violations that can be addressed with visible, targeted law enforcement solutions. Educational efforts can supplement enforcement to reduce occurrences of unsafe driving behavior.

Figure 8.1. Speed enforcement on an arterial

When a crash occurs—especially one involving injuries—the first hour immediately following the crash (called the “Golden Hour”) is extremely important to the long-term effects of the crash on those involved. emergency medical response, ability to provide service on scene, and the
proximity to a trauma center with emergency services capabilities are vital to save lives and prevent life-changing injuries.

8.5 COMBINING APPROACHES

In practice no single approach should be used alone, as each has merit. Implementing the spot location, systemic, comprehensive, and policy approaches in combination provides the best opportunity for successful safety management.

They can also be implemented as a hierarchy. The entire system can become safer over time as decision makers and designers modify policies. Low-cost systemic treatments and behavior-focused strategies can then be blanketed along corridors and systems meeting certain safety-related criteria. At locations continuing to show a higher-than-expected number of crashes after these treatments, practitioners can next install higher-cost spot location countermeasures.
CHAPTER 9

FUTURE OF TRAFFIC SAFETY

Even though the future seems far away, it is actually beginning right now.
—Mattie Stepanek

In this book you have learned the basics of identifying safety needs, selecting countermeasures to address those needs for intersections, lane departures, and work zones, and implementing the selected strategies. The conclusion of this book describes the future of traffic safety—a vision for the eradication of roadway fatalities.

9.1 ZERO ROADWAY DEATHS: AN ATTAINABLE GOAL

Transportation safety has changed significantly since the turn of the century, especially since the passage and eventual implementation of U.S. federal transportation legislation in the 2000s. Increased safety funding available to state DOTs through SAFETEA-LU, MAP-21, and FAST, and the obligation of those safety dollars toward projects, has contributed to a significant reduction in traffic fatalities. State and local agencies are changing the way they address safety, and new technologies are connecting vehicles to each other, other road users, and the roadway infrastructure. Additionally, vehicle safety standards and crash testing have led to major safety improvements in vehicle designs.

The “Toward Zero Deaths” vision is not simply rhetoric, but a real belief that approaching zero traffic fatalities in the United States can be a reality. Each death on our roadways is a real person whose life ended too soon.

There is precedence for significant reductions in traffic deaths. Fatalities peaked in the United States at more than 51,000 in 1979, and then reduced slowly through the 1980s and 1990s to approximately 42,000 by the
Another significant reduction occurred from 2000 to 2013, when fewer than 32,000 people were killed in traffic crashes in the United States.

The timeline may be long—potentially beyond any of your careers, and maybe your lifetime—and the efforts undoubtedly will be great. That said, zero is a real goal, a noble goal, and a goal worth our time and effort to pursue.

9.2 ADDRESSING IMMEDIATE NEEDS

Frequently we are faced with addressing immediate needs due to high-profile events or an emerging crash trend at a specific location. These reactive solutions have been the basis of traffic safety efforts for decades, and they have proven successful, though limited in scope. Two distinct approaches have been used by highway agencies and promoted by safety leadership: Spot Location and Systemic.

Some road user behavioral issues can be addressed in real time with law enforcement efforts. Officers can recognize pretrip decisions, like impaired driving and lack of safety belt use, through traffic stops and special efforts. Agencies can also address on-road actions such as speeding and aggressive driving by identifying these motorists and writing citations for this behavior.

The value of this approach is its immediacy. There are real problems now—nearly 90 lives lost every day on roadways in the United States alone—that can be treated to prevent traffic fatalities right away. However, these treatments cannot fully address the long-term need.

9.3 FOCUSING ON SAFETY CULTURE

Long-term change in traffic safety will require a change in the culture of safety, both by road users and by agencies responsible for operation of roadways. Nicholas Ward of Montana State University once stated that “A culture-based approach is complementary to, but fundamentally different in form and philosophy from traditional traffic safety interventions including engineering, enforcement, and education. By treating the origin of risk behaviors (pathogens), cultural-based interventions are proactive and transformational in their treatment approach.”
9.3.1 PUBLIC AGENCY CULTURE

In most highway agencies there is a split between “safety funding” and “other funding.” As traffic safety becomes normalized in an agency’s culture, these funding philosophies should merge so that safety is considered and incorporated into every project regardless of funding source or the initial purpose-and-need, and every choice made by a roadway agency considers safety as a primary criterion.

9.3.2 ROAD USER CULTURE

It is generally not considered a privilege to maintain a driver’s license and operate a motor vehicle, especially in the United States. For example, in the 1960s and 1970s the social attitude of driving while intoxicated was not as stringent as today, even with extremely high traffic fatality numbers as a result. Even though it is both illegal and socially unacceptable today to drive under the influence of controlled substances, impaired drivers still contribute to approximately 40 percent of traffic fatalities.

Changing the culture of road users will be internal (e.g., convincing people that wearing a safety belt is an automatic part of operating a vehicle) and external through aggressive public policy (e.g., installing ignition interlock that disallows a vehicle to start unless all passengers are buckled). Similar to the change in the tobacco smoking culture in the past three decades, a culture shift will be challenging, and when successful the change will be revolutionary.

9.4 EMBRACING THE FUTURE

There is an inherent weak link in the system—us. Every driver makes a mistake nearly every time he or she gets behind the wheel. Add to that the size and speed of vehicles and the general unforgiving nature of the roadway and roadside, and every trip has a risk of injury or death. The long-term vision for traffic safety must include reducing the influence of this weak link.

9.4.1 ACTIVE TRANSPORTATION AND TRANSIT

The past decade has experienced a significant increase in active transportation and transit use, and some studies have indicated a reduction of motor vehicle miles traveled in the past few years. More commuters are choosing transit
options over single vehicle travel, and more people are living, working, and playing closer to home. Others (especially older and younger dwellers) are moving to urban centers as cities become more desirable, leading to reduced miles traveled by vehicle and increased person-miles traveled by foot and bicycle.

9.4.2 CONNECTED VEHICLES AND VEHICLE-TO-INFRASTRUCTURE TECHNOLOGIES

All trips will not be made via active transportation and transit, and even bicyclists and pedestrians will still share the road system with passenger cars, delivery vehicles, and large trucks. Technology is available now, and will disseminate quickly into the fleet, which allows vehicle drivers and other road users to connect to each other and the infrastructure around them. This could result in increased safety as the technology assists motorists with some driving activities (e.g., lane tracking, emergency braking).

9.4.3 AUTONOMOUS VEHICLES

The final step is the vehicle driving itself, taking control out of the hands of drivers who have proven poor at the task, and instead programming vehicles to handle these activities autonomously. There will be challenges, especially when an autonomous vehicle is inevitably involved in a severe crash, but this move toward cooperative control and autonomous vehicle technology will have a significant and positive effect on traffic safety.

9.5 CONCLUSION

The vision of “Toward Zero Deaths” is a roadway system that approaches no fatalities or severe injuries. Some severe crash events may still occur (as they do on airplanes and trains), but they will be few-and-far between, rather than the daily death toll of roadways today. Addressing immediate needs is the first step, followed by a shift in the traffic safety culture of highway agencies and the road-using public. As technological advances continue, connected and autonomous vehicles will provide a real opportunity to approach zero fatalities.
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