# CONTENTS

## INTRODUCTION
- Tort Liability ................................................................. iv
- Do You Need a Professional Engineer? ................................... v
- Documentation ..................................................................... v
- Management Systems ........................................................ vi

## 1. ROAD SAFETY BASICS
- Drivers and Other Road Users ................................................. 2
  - Pedestrians and Bicyclists .................................................. 3
  - Expectancy ....................................................................... 3
  - Driving is Hard Work ......................................................... 3
  - Information ....................................................................... 4
  - Decision ........................................................................... 4
  - Action ............................................................................... 4
- Roads and Their Environment ................................................... 5
  - Functional Class ................................................................ 5
  - Traffic Speed .................................................................... 5
  - Land Use .......................................................................... 5
  - Stopping Sight Distance ..................................................... 6
  - Intersection Sight Distance .............................................. 6
  - Roadside Safety ............................................................... 6
- Vehicles ................................................................................ 6
  - Traffic Volume .................................................................. 8
- Conclusion ........................................................................... 8

## 2. SOLVING TRAFFIC SAFETY PROBLEMS
- Identifying Problems and Solving Them ..................................... 9
  - Information Gathering ........................................................ 10
    - Road Safety Studies ...................................................... 10
    - Road Safety Audits ....................................................... 11
    - Crash Analysis .............................................................. 11
    - Condition Diagrams ....................................................... 13
    - Traffic Volume .............................................................. 14
    - Speed Studies ............................................................... 15
    - Other Traffic Studies .................................................... 15
- Identify Factors Contributing to Crashes ................................... 15
- Select the Appropriate Countermeasure ................................... 16
- Evaluate Success ................................................................... 17
- Prioritize Work .................................................................... 17
- Existing Safety Problems ....................................................... 18
  - Opportunity ...................................................................... 19
  - Bang for the Buck ............................................................ 19
  - Put It All Together ........................................................... 20
- Summary ............................................................................. 21
### 3. TRAFFIC CONTROL DEVICES

- Standard, Guidance, Option, and Support ........................................... 23
- Traffic Control Device Principles .......................................................... 24
- Primacy .................................................................................................. 24
- Signs ..................................................................................................... 25
  - Sign Types ......................................................................................... 25
  - Placement .......................................................................................... 27
  - Lateral Offset .................................................................................... 27
  - Longitudinal Placement and Advance Posting Distance ................. 27
  - Height ............................................................................................... 29
  - Size .................................................................................................... 29
  - Retroreflectivity ............................................................................... 30
- Signposts .................................................................................................. 30
- Pavement Markings .................................................................................. 31
- Delineators .............................................................................................. 32
- Traffic Control Device Maintenance ....................................................... 32
  - Inventory ............................................................................................ 33
- Summary .................................................................................................. 33

### 4. ROADWAYS

- Appropriate Standards .............................................................................. 35
- Consistency .................................................................................................. 36
- Stopping Sight Distance ............................................................................ 36
- Cross Sections ............................................................................................ 40
  - Cross Slopes ...................................................................................... 40
  - Lane Widths ....................................................................................... 40
  - Shoulders ............................................................................................ 41
  - Parking ................................................................................................ 42
  - Curbs .................................................................................................. 43
  - Sidewalks ............................................................................................. 43
- Road Surface .................................................................................................. 44
- Curves ....................................................................................................... 44
  - Delineating Curves ............................................................................ 44
  - Safety Widening for Curves ................................................................. 44
  - Superelevation .................................................................................... 46
  - What to watch for when superelevating curves .......................... 46
  - Realignment ....................................................................................... 47
- Vertical Curves ............................................................................................ 47
- Pavement Edge Drop-Offs .......................................................................... 47
- Summary .................................................................................................. 48

### 5. IMPROVING ROADSIDE SAFETY

- Will Guardrail Solve the Problem? ............................................................. 49
- Clear Zones ............................................................................................... 49
  - Types of Run-Off-Road Hazards ......................................................... 50
- Treatment of Roadside Hazards ................................................................. 51
  - Is the Potential Hazard Dangerous? ................................................... 51
  - Can You Remove the Hazard? ............................................................ 51
Can You Relocate it to a Place Where It is Less Likely to be Hit? .................. 51
Can You Reduce Crash Severity? .................................................. 52
Will Guardrail Improve Road Safety? ......................................... 52
Would Delineation Guide Drivers Around the Hazard? ............... 52
Is the Solution Feasible and Cost-Effective? ............................... 53
Is the Potential Hazard Dangerous? ......................................... 53
Guardrail ................................................................. 53
Slopes .................................................................. 53
Guardrail and Curb ......................................................... 53
Deflection Distance ........................................................ 54
Flexible Systems .......................................................... 55
Semirigid Systems ......................................................... 56
Barrier Length ................................................................ 57
Terminals .................................................................. 57
Transitions .................................................................. 58
Prioritizing Roadside Improvements .......................................... 58
Maintenance ................................................................. 59
Roadside Maintenance .................................................... 59
Guardrail Maintenance ................................................... 59
Ditches ...................................................................... 61
Bridges ..................................................................... 62
Summary ................................................................. 63

6. INTERSECTIONS, RAILROAD
GRADE CROSSINGS, AND DRIVEWAYS

Intersections ................................................................. 65
Intersection Sight Distance ........................................... 68
Intersection Control Type ............................................... 70
No Control ................................................................. 70
Yield Control ............................................................. 71
Stop Control ............................................................... 71
Two-way stop control .................................................. 71
All-way stop control ................................................... 71
Traffic Signals and Roundabouts ................................. 72
Lighting .................................................................. 73
Street Name Signs ....................................................... 73
Pedestrian Crosswalks ............................................... 73
Highway-Rail Crossings ............................................... 74
Driveways ................................................................. 75
Access Management .................................................. 75
Permits .................................................................. 75
Driveway Design ......................................................... 76
Sight Distance .............................................................. 76
Summary ................................................................. 77
Local (cities, towns, Tribes, and/or counties) governments are responsible for constructing and maintaining the majority of road mileage in the United States. Many of these roads are in rural areas where traffic volumes can be low, but speeds may be high. The combination of rural environment, unforgiving roadsides (rocks, trees, utility poles, etc.), distance from emergency medical services, and speeding has made these roads the most deadly in the Nation. Statistics show that 30 percent of the Nation’s fatal crashes occur on local rural highways. This reality challenges smaller road agencies to reconcile cost-effective road improvements with the need to increase safety.

Roadway Safety Fundamentals is designed to help local and Tribal road agency professionals understand the critical relationships between roads, roadside, road user behavior, and safety. Because many of these agencies have no licensed professional engineers on staff, this publication reviews the proper use of common traffic control devices such as signs, lane markings, and lighting. It also addresses the use and effectiveness of roadside barrier systems, especially different guardrail systems.

This manual is an expanded revision to a manual of the same title developed for the Cornell Local Roads Program in cooperation with the New York State Department of Transportation’s Traffic Engineering and Safety Office in Poughkeepsie. A technical working group was established to modify its content for a national audience. Technical committee members were:

- James Mearkle, P.E., former Safety Technical Assistance Engineer, Cornell Local Roads Program.
- Ronald Eck, Ph.D., P.E., Director, West Virginia Technology Transfer Center and Professor of Civil and Environmental Engineering, West Virginia University.
- Russell Hanson, Superintendent, Randall County (Texas) Road Department.
- Richard Rolland, Director, Northwest and Alaska Tribal Technical Assistance Program, Eastern Washington University.

Road Safety Fundamentals identifies the core concepts local and tribal road agency professionals can use to evaluate and improve their safety operations. Throughout the process, the manual encourages agencies to document decisions and actions for future agency reference and as safeguards against potential litigation. Information in the manual will help road agency professionals use a systematic approach to improve safety and roadways in a manner that makes best use of resources and manpower.

ACKNOWLEDGEMENTS

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INTRODUCTION

The social and economic cost of traffic crashes in the United States is tremendous. Consider 2002, the last year for which statistics are available. Police across the nation reported more than 6.3 million crashes that year. More than 42,800 people lost their lives in 2002; another 3 million people were injured. These are not really statistics; the numbers are real people who are our families, friends, and coworkers.

Figure 1 shows the number of fatalities from motor vehicle crashes according to highway functional class. The Federal Highway Administration (FHWA) classifies roads for data and planning purposes. (See chapter 1 for more information on road classification.) Notice that more people lost their lives in crashes on arterials (which includes Interstates and expressways), and there were significantly fewer fatal crashes on collector and local roadways. For example, crashes on rural arterials accounted for nearly 30 percent of highway-related fatalities while crashes on rural local roads accounted for less than 12 percent of highway-related fatalities.

However, the total number of crashes gives an incomplete picture. Arterials have more crashes because they carry more traffic. Engineers look at crash rates when comparing roads that carry different amounts of traffic. By dividing the number of crashes by the traffic volume, different roads can be compared. Typically, the number of crashes per 100 million vehicle-miles traveled (100 M VMT), or the number of fatalities per 100 M VMT are used. These rates show that local roads deserve much more attention than they typically get.

The FHWA uses three functional road classifications: Arterial, Collector, and Local roads. Each classification includes a category for rural and urban roads. Classification is based on access and mobility. Jurisdictions, including Indian lands, may adopt their own classifications. As the classification is being updated, refer to 25CFR170 (2004) for the most current information.

LTAP and TTAP centers are encouraged to research and report their own safety data and insert it here.
Understanding roadway characteristics is important, especially when you consider who controls the roads. In the U.S., 75 percent of all roads are controlled by local (cities, towns, and counties) and Tribal jurisdictions. The Bureau of Indian Affairs (Department of the Interior) owns most non-County and -State roads on Indian reservations. State agencies control less than 20 percent, and the Federal government controls less than 5 percent. Arterial roadways are the most frequently traveled, while local roads are the least traveled. Yet, when we consider fatal crash rates, the local road class exceeds the arterials. Table 1 shows the fatal crash rates for each roadway functional class shown in figure 1. For instance, in 2002, there were 3.63 fatalities per 100 M VMT on rural local roads, compared to 1.77 on rural arterials. In urban areas, the rates are 1.45 fatalities per 100 M VMT on local roads, and 0.90 on arterials. Rural roads have higher fatality rates because of higher travel speeds.

<table>
<thead>
<tr>
<th>Roadway Functional Class</th>
<th>Rural Arterial</th>
<th>Rural Collector</th>
<th>Rural Local</th>
<th>Urban Arterial</th>
<th>Urban Collector</th>
<th>Urban Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal Crash Rate (per 100 M VMT)</td>
<td>1.77</td>
<td>2.90</td>
<td>3.63</td>
<td>0.90</td>
<td>0.80</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Now think about fatality rates and how a transportation agency budgets: More money is spent for safety improvements on higher functional class roadways. Economically, this makes sense because these roads carry most of the traffic.

Transportation agencies are hard pressed to maintain their roads, much less make improvements. This brings us to the concept of cost-effectiveness. Cost-effectiveness is a way to compare how much an improvement will cost to how much it will reduce the number or severity of crashes. For example, if $5,000 of guardrail means that a $100,000 injury crash is now a $5,000 property damage crash, then it is cost-effective. On the other hand, installing the same guardrail next to a flat field could turn a $100 towing bill into a $5,000 property damage crash. Another example is installing curve signs to warn motorists of a sharp turn. Installing a large arrow sign costing less than $250 can reduce run-off-road, fixed object crashes by 43 percent. 

Investing in safety improvements for an entire roadway system is typically not cost-effective. As this manual will demonstrate, your best action is to identify locations with a history of safety problems and apply an appropriate safety solution, also called a countermeasure. It is also cost-effective to anticipate safety problems and make appropriate safety enhancements where crashes are likely to occur.

**Tort Liability**

The reality is that it is impossible to prevent all crashes. Crashes will occur, and lawsuits may arise from them. The word tort means a wrong or an injustice. Tort law comprises the legal rules that determine when one party should be required to pay money to compensate another party for personal injury or property damage. A governmental entity can be held liable for negligence or for any other wrongful conduct. Tort law applies to lawsuits in which the plaintiff seeks to recover money to compensate for personal injuries or property damage caused by the defendant. A good road safety improvement plan is an effective way to reduce your risk of tort liability. It can reduce the number of crashes, the loss of lives, and the economic costs related to them. Reducing the number of crashes also reduces your agency’s exposure to tort liability.
In order to recover money damages from a road agency in a tort case, the plaintiff must prove the following four elements:

1. That the agency owed a duty.
2. That the agency violated that duty (e.g., the road was not reasonably safe).
3. The violation of the duty was a probable cause of the harm.
4. The plaintiff was actually damaged.

Roadway agencies have a duty to keep their highways reasonably safe. Liability claims are typically categorized as:

- Damage caused by design, construction, or maintenance problems.
- Damage caused by work zone or other operations activities.
- Failure to correct hazardous conditions in the highway right-of-way within a reasonable time period.

Notice means that the road agency knew or should have known of the defect.

- **Actual notice** means the agency received notice of a defect, either in writing or from a police officer.
- **Constructive notice** means that the agency should have known about the defect, either because it was obvious or because it existed for a period of time and should have been recognized during basic operational activities.

Once a defect is known, the road agency has a duty to correct the problem in a reasonable time. Liability laws vary by jurisdiction, so local and Tribal governments should get legal advice from the local risk manager or State transportation agency.

**Do You Need a Professional Engineer?**

There will be times when you need the services of a licensed professional engineer (P.E.). For example, registered engineers are typically required to endorse design plans for construction. You may also need an engineer when a permit is required for your project, and the permitting agency requires certification by a professional engineer. Certain immunities are afforded by laws in each jurisdiction in highway engineering practice. Because these laws vary, local and Tribal governments are encouraged to seek legal advice.

**Documentation**

It is important to document what you do and the decisions you make, including a decision not to do something. The results of decisions you make today may be factors in lawsuits many years from now. Your department could be sued tomorrow because of a decision your predecessor made years before retiring.

Prepare documentation to support your decisions as you make them. Make sure it is complete, dated, signed, and file it where you can easily retrieve it. Good records can prove a disputed case better than memory can. Roadway safety items that should be documented include:

- Highway defect notices and how the agency addressed them.
- Road and roadside condition surveys, including ditch depths and slopes.
- Records of road patrols and inspections, even if no defects are found.
- Date, location, and description of road maintenance activities.
- Sign inventories.
- Road work plans, including construction drawings, as-built plans, and work zone traffic control plans.
- Traffic studies.
- Road safety audit report.
Any time you deviate from a standard practice, it is very important that you write down what you did and why. Depending on the nature of the change, you may need to have an engineer evaluate the condition.

When no defects are found during a patrol or inspection, write it down. Be sure to include the date and time of the inspection, weather conditions, site conditions, and other important information about the location.

Management Systems

Management systems help transportation agencies keep track of important information, like sign inventories, pavement conditions, or drainage facilities. They help agencies prioritize maintenance and repairs based on safety effects, level of deterioration, and cost. Properly used, they can help improve services and keep costs down by helping the agency select the right project at the right time. Management systems can be developed for highway pavements, bridges, highway safety, traffic congestion, and Intermodal transportation facilities.

A Safety Management System (SMS) is a systematic method used by local and Tribal decision makers to identify, prioritize, correct, and evaluate the performance of transportation safety investments. Used effectively, a SMS can reduce highway crashes and their associated economic impacts on society. The FHWA provides helpful information about implementing local and tribal highway safety management systems.

Refer to the FHWA’s website for information about Safety Management Systems: [http://safety.fhwa.dot.gov/]

If your agency does not have Internet access, consult an LTAP or TTAP center.
1 ROAD SAFETY BASICS

The best way to reduce traffic crashes is to understand what causes them. A good way to do this is by separating the highway transportation system into three broad categories:

- The driver (includes all road users such as bicyclists and pedestrians).
- The vehicle.
- The road and its environment.

The causes of most crashes will usually fit into one of these categories. Many will involve more than one.

*Human factors* refer to people and the things they do, or fail to do, that can cause a crash. Human factors covers drivers whose attention is distracted, are tired or ill (and may have taken medication that makes them drowsy), or use alcohol or drugs. Age also affects a driver’s ability to be safe on the roadway. For example, older drivers often have vision problems at night while younger drivers tend to take more risks on the road. Vehicle factors may be mechanical failures, such as bad brakes or tires. Road-related factors can be limited sight distance, poorly marked roads or missing road signs, or sudden changes in roadway width. Weather is always a major factor affecting road conditions, and too often, drivers fail to consider wet roads or fog when they drive.

Police officers investigating traffic crashes usually list factors that contribute to a crash. Figure 2 is based on studies of these police reports of traffic crashes. As the figure illustrates, driver error is the cause of most crashes, followed by road condition as a contributing factor 34 percent of the time—although it may be more. A vehicle defect or malfunction is involved 12 percent of the time.

“Most crashes are attributed to human error, but in almost all cases the human error was the direct result of poor design.”

—Donald Norman, *Design of Everyday Things*
For road department officials, the 34 percent of crashes where the road is involved is both a problem and an opportunity. This is where lawsuits come from, but it also means that the highway community has opportunities to prevent more crashes. Notice that figure 2 also indicates that the investigating officer lists a driver factor in addition to the roadway in 27 percent of crash cases. It tells us that something about the road led the driver to make a mistake, or the driver made a mistake and the road did not allow for recovery from the mistake.

When we consider road transportation as a system, it is clear that we can directly control some factors, but not others. For example, engineering is one aspect of the road transportation system that we can control. When we eliminate shoulder edge drop-offs, we can reduce crashes attributed to roadway condition. Crashes caused by vehicle defect or malfunction, however, cannot be addressed by road departments.

Road agencies have little control over drivers and weather, so we rely on enforcement and education as ways to prevent some crashes associated with driver error. If the parts of the system that can be controlled (roads and vehicles) are designed to allow for those we cannot (road users and weather), the system as a whole will work better.

Start by looking at factors related to the drivers, roads, and vehicles that make up the highway transportation system. Figure 3 shows an example of all three factors.

**Drivers and Other Road Users**

While motor vehicles are typically the largest group of road users, others have the right to use the road. As the photo in figure 3 illustrates, this can include pedestrians and bicyclists. The amount of engineering and financial resources required to enhance safety on roadways largely depends on the amount and type of traffic using the roadway. For example, motor vehicles are often the only users of low-volume roads in rural areas. Often times, low-cost treatments such as adding signs and more visible lane markings can improve safety performance. On the other hand, it makes sense to install sidewalks to safely separate pedestrians from motor vehicle traffic. If a road carries a large numbers of bicyclists, paved shoulders are a good idea, especially if the road carries high-speed or truck traffic. So, when you plan a road project, always consider the types of traffic using the road as you make safety decisions.
**Pedestrians and Bicyclists**

As noted, we should make decisions on road projects based on the types of traffic using the road. Pedestrian and bicycle traffic is an exception to this practice. Pedestrians (and bicyclists) will usually avoid a road if they feel uncomfortable or unsafe using it. If few people walk along a road, it may mean sidewalks are needed, rather than there is no demand for them. When you see worn paths alongside the road, or destinations people would want to walk to (like convenience stores), then sidewalks will make pedestrians safer and walking easier. Remember that many pedestrians are children, senior citizens, and persons with disabilities who cannot drive. Sidewalks can dramatically improve their quality of life, and improve their safety.

A surprising number of pedestrian crashes happen in rural areas because drivers do not expect them, and road departments do not allow for them when the road is designed. In rural areas, sidewalks are often not needed. We can improve safety for the few pedestrians on rural roadways with many of the same measures we use to improve the safety of motor vehicle drivers, such as improving sight distance and adding shoulders.

**Expectancy**

As drivers gain experience they expect things to happen as they always have. For example, drivers expect that a green light on a traffic signal will be followed by a yellow light. Or drivers adjust their speed as they look at an upcoming curve because it looks similar to other curves they have driven. This is called *expectancy*. If a signal changes from green to red, or a curve becomes suddenly tighter halfway through, a driver’s expectancy is violated, and the driver may react in an erratic or incorrect way.

The more experienced the driver, the greater the expectancy, which leads to quicker and more accurate reactions as long as driver expectancy is met. A sudden change in road conditions violates driver expectancy and increases the likelihood of driver error and reaction time because the driver takes longer to understand the situation and respond to it. If the extra time is not available, the result may be a crash. That is why expectancy violations cause problems, and removing expectancy violations helps improve safety. For example, advance warning signs can help reduce the surprise. You may need to install oversized or repeated signs to make sure you get the driver’s attention. Perhaps you can add STOP AHEAD signs and oversized STOP signs at a location where drivers run STOP signs.

**Driving is Hard Work**

Although most of us take it for granted, driving is hard work because it requires us to do several things at the same time. When we drive, we control the vehicle; slow down, speed up, and turn; guess what other road users might do and decide whether we need to do something to avoid them—all while steering the vehicle from where we were to where we need to be. There are limits to how much information we drivers can process at a time. However, when there is too much information for drivers to accurately or safely process, they make mistakes. The message for road departments is road design and traffic sign layout should give drivers enough time to make several easy decisions rather than forcing them to make one complex decision in a hurry.

There are three distinct phases to the task of driving: information, decision, and action. Roadway information leads the driver to decide to do something. The results of that action provide more information, which then starts the process over again.

Further complicating the task of driving are distractions for the driver both inside and outside the vehicle. Maybe the cell phone rings or the driver remembers an important call that should be made. The song on the radio ends and the driver decides to find another channel. Perhaps a passenger asks a question or points out something of interest along the roadside. Maybe the trip must be made during a severe rain or snow storm. Possibly it is just a beautiful day to drive through a scenic area, tempting the driver to focus on something other than the road.
Whatever it is that draws the driver’s attention from the road, it is clear that driving a vehicle of any size in anywhere requires the driver’s full attention. And it is the road department’s job to minimize surprises on the road.

**Information**

The two information phases are to notice information and recognize its meaning. As the following list indicates, you can help drivers do both:

- Signs have standardized shapes and colors to help drivers easily recognize their message. Rely on the Manual on Uniform Traffic Control Devices (or applicable state manual) for information on sign design and messages.
- Avoid designing roads with sharp curves just over hillcrests.
- Use consistent design curve radii so drivers are not surprised by curves that are too sharp or too gradual.
- Place signs at locations where drivers expect them and can see them.
- Most drivers can read only three or four familiar words at a glance, so avoid overloading them with information. Always consider information needs of both older and novice drivers.
- Install and use approved traffic control devices properly.
- At least annually, inspect road signs for loss of retroreflectivity. Depending on the material used, pavement markings may need to be checked twice a year. As signs and pavement markings fade, they are difficult to see at night.
- Repeat messages to motorists. For instance, using chevron signs on a curve can reinforce a curve warning sign. Another common example is the repetitive nature of work zone signing. In a typical road work sign series, the first sign, ROAD WORK AHEAD, is a general warning to motorists. The second sign, ONE LANE ROAD AHEAD, alerts drivers what exactly they should expect. The third sign, FLAGGER AHEAD, tells what they need to do.

**Decision**

Road users combine the information they gather with their driving experience; then they make a decision. It takes skill and experience to make the right decision. Drivers must pay attention so they can keep track of several information messages at once, yet ignore what they do not need. These are skills that novice drivers are still learning and older drivers sometimes find difficult to process.

We help all drivers reach the right decision by separating information and decision points. It is easier to make several simple decisions, one after the other, than it is to make one complex decision in a hurry.

**Action**

Action happens when the driver makes a decision and does something. The results of the action provide more information, which, as indicated above, starts the process over again.

For a road to be safe, the driver needs time to respond. Reaction time is the time it takes for the driver to notice a condition, decide what to do about it, then do it. The more information a driver must process, or the more complex the decision required, the longer it takes the driver to react.

Although a perception-reaction time of 2.5 seconds is commonly used in highway design, driver response times can range from 1.5 seconds for a simple decision like initiating a panic stop to 15 seconds for a complex decision like choosing the correct exit in a convoluted highway interchange.
Roads and Their Environment

To assess the safety of a road, we must know how drivers use it. Your assessment should include the types of traffic on the road, the number and type of road users on an average day, and how fast they travel.

**Functional Class**

We classify a road based on the role it plays in the transportation network:

- **Local roads** provide limited mobility and are the main access to residential areas, businesses, farms, and other local roads. Through traffic is usually a small percentage of total traffic. Posted speeds are usually between 20 and 45 mph (30 and 70 km/h). These are the majority of roads in the U.S.

- **Collectors** are major and minor roads that provide access to neighborhoods and carry traffic from local neighborhood road networks to arterials. They offer less mobility than arterials at lower speeds and for shorter distances, and they balance mobility with land access. Posted speed limits on collectors are usually between 35 and 55 mph (55 and 90 km/h).

- **Arterials** are high-speed highways that carry large amounts of traffic. They connect (as possible) the Nation’s regional urbanized areas, cities, and industrial centers. The arterial class typically contains most access-controlled facilities; however, this functional class is not restricted to access-controlled roads. Posted speed limits usually are between 45 and 70 mph (70 and 110 km/h).

- **Freeways** are grade-separated arterials that primarily carry through-traffic at high speeds. Junc-tions with other roads occur at interchanges. Driveway access on freeways is prohibited. Interstate highways are freeways.

Design standards are tied to functional class. More design effort and money is spent on higher functional classes. For example, lanes on freeways are wider than lanes on local roads. If you are not sure what functional class a road belongs in, contact your Federal, State, local, or Tribal transportation agency.

**Traffic Speed**

Traffic speed is affected by many aspects of the roadway environment. Speed is an important consideration as you decide road cross-section width, horizontal and vertical curvature, driveway spacing, sight dis-tance, roadside design, and sign placement. The section on Speed Studies in chapter 2 addresses traffic speed consideration in greater detail.

**Land Use**

The type of land use in an area will affect traffic on the road. Common examples are rural residential subdivisions with light, low-speed traffic, or regional shopping center streets with congested, low-speed traffic, closed drainage, and curbs.

Land use affects the amount and type of traffic the road carries. Roads in agricultural areas should be wide enough for the farm machinery that uses the road. Commercial areas will get more trucks and may need wider streets. Residential neighborhood roads can be designed for slower speeds than rural collector roads.

One pitfall to avoid is classifying a road solely on land use. You must take into account the volume and type of traffic on a road. A residential street that services a larger area may need to be classified as a collector or even a minor arterial.
**Stopping Sight Distance**

Stopping sight distance is the distance a vehicle travels between the time the driver sees a problem until the vehicle stops. It is the distance covered as the driver works through the information, decision, and action phases of driving. It also includes the time it takes to stop once the driver applies the brakes. Road designs should provide drivers with enough time to see objects in the road and be far enough away to come to a controlled stop before hitting the object. Chapter 4, *Roadways*, discusses stopping sight distance in more detail.

**Intersection Sight Distance**

Intersection sight distance is often greater than stopping sight distance, especially at two-way stop-controlled intersections. A driver at an intersection needs to be able to see far enough to decide whether it is safe to proceed. Intersections require drivers to evaluate a number of factors in addition to traffic speed. For example, the intersection sight distance depends on what the driver intends to do at the intersection—continue through or make a left or right turn—and the traffic control such as a signal, STOP or YIELD sign. Chapter 6, *Intersections, Driveways, and Railroad Crossings* discusses intersection sight distance in detail.

**Roadside Safety**

The roadside area refers to the area between the outside shoulder edge and right-of-way limit. When drivers leave the roadway and enter the roadside area, they may encounter fixed objects such as guardrail, telephone or utility poles, trees, or steep embankment slopes. Nearly one-third of fatal highway crashes are the result of a single-vehicle running off the road and colliding with a fixed object or overturning. As such, roadside design is an important safety consideration. Roadside safety is discussed in detail in chapter 5, *Improving Roadside Safety*.

**Vehicles**

Road departments cannot control the vehicle aspects that can be a factor in highway crashes. That is the job of other Federal and State government agencies. At the local and Tribal road department level, however, the types of vehicles using the road affect many of your road design decisions. For example, tractor-trailers need more room to turn than passenger cars.

Vehicle types are grouped into classes called design vehicles. Common design vehicles are passenger cars, single-unit trucks, buses, tractor-trailers, and recreational vehicles. Design vehicles influence roadway layout and operations because a road design must handle the largest vehicle expected to use it frequently. Use the single-unit truck like fire trucks, maintenance trucks, and heating oil trucks as the smallest design vehicle for streets and highways. If a high number of tractor-trailer trucks will use the road, use the larger design vehicle.

Use turning templates to tell whether an intersection layout is wide enough to handle various design vehicles. Figure 4 shows a template for a single-unit truck with a 30-foot wheelbase (SU-30). Templates are printed on clear plastic in common engineering scales. Place the template on the plan sheet. If the lines showing the vehicle wheel paths cross the lines showing the pavement edges, the intersection is not wide enough to handle that type of vehicle. The templates show the capabilities of a typical vehicle in that class, given a good driver. It is good practice to allow several feet on either side of the vehicle path as a buffer. The American Association of State Highway and Transportation Officials’ (AASHTO’s) *A Policy on Geometric Design of Highways and Streets*, usually referred to as the *AASHTO Green Book*, contains turning templates for all design vehicles. Other design vehicle dimensions that influence road safety and operations are height, width, ground clearance, and weight.
Figure 4. SU turning template.

Figure 4 shows the dimensions and vehicle turning path for a single-unit truck. The AASHTO Green Book contains turning templates for 19 other vehicles. Contact your LTAP or TTAP center for assistance in obtaining turning movement templates.
**Traffic Volume**

Crash frequency is linked to traffic volume. The number of crashes typically increases as traffic volumes increase. Traffic volumes are linked to land use. Commercial, industrial, and residential land generates more traffic than agricultural land. Expect that open land developed in your area will increase traffic volumes, and the number of traffic crashes. Minor problems that previously had no role in traffic crashes can also become contributing factors to crashes as volumes increase. When FOR SALE signs start appearing on open land in your area, your road department should consider them warning signs. See chapter 2 for traffic volume studies.

**Conclusion**

Detailed investigations of man-made catastrophes often reveal a chain of events leading to the incident. An old saying cautions that an incident happens when nine things go wrong, and a catastrophe occurs when ten things go wrong. From a road safety viewpoint, if you can break a link in the chain of events, you can often prevent a crash.

As this chapter has demonstrated, road users, vehicles, and the roadway environment can all contribute to crashes. Engineering measures can reduce crashes, but enforcement, education, and legislative action are also effective crash-prevention measures. Good examples of raising driver awareness about road safety include the effect Mothers Against Drunk Driving (MADD) has had on reducing drunk driving and the rise in the use of safety belts. In most cases, where a road condition is a factor in a crash, a driver factor also contributes to the crash. Consider the older driver with poor night vision or the novice driver who speeds even as signs warn of sharp turns. Combining poor night vision with old, faded signs and pavement markings could also contribute to a crash. Chevron signs on curves could help prevent them. The road department’s job is to make roads reasonably safe, which will in turn help the driver and the vehicle travel safely on them.
2 SOLVING TRAFFIC SAFETY PROBLEMS

Because road agencies usually have limited funds with which to meet a growing number of projects, your safety goal should be to apply the right solution to the right problem on the right road at the right time. This is why problem solving and planning are important.

The first goal for improving road safety is to stop crashes before they happen. By removing the problem, you may be able to prevent crashes. For example, you can improve the roadside by removing trees rather than installing guardrail. The second goal is to reduce the seriousness of crashes when they do happen. Back to our roadside hazard example: If we cannot remove the tree (rock, structure, utility pole) or make the roadside safer, then guardrail is a good way to reduce crash severity.

Identifying Problems and Solving Them

The following 5-step basic method can help you solve roadway safety problems:

1. Identify the type of problem and the factors contributing to it.
2. Select a solution, also called a countermeasure. Ask yourself:
   a. Which solution will give you the best results for the least cost?
   b. Will the solution correct the problem, or just move it down the road?
   c. Will a countermeasure cause more problems or different problems? If so, is it worse than the problem you are trying to solve?
3. Install the countermeasure.
4. Evaluate whether or not it worked.
5. If not, you may need to return to Step 1 to ensure you understand the problem.

Step 1, correctly identifying the problem, is the most important step in solving safety problems. If you are not aware of a problem, you can’t fix it and if you mis-diagnose a problem, you will install an inappropriate countermeasure wasting time and money.

There are several ways a road department can learn about problems. Sometimes it arrives as a complaint from a citizen. Departments must respond to written complaints because, in legal language, you have been given actual notice of a possible problem. Study the problem and keep a record of your decision, even if you decide there is no action that can be or should be taken.

Your department might receive a complaint in the form of a suggested solution, such as when someone requests the department to install a STOP sign or traffic signal. Your first reaction may be to ignore the complaint because you already know that many people request STOP signs be installed in the mistaken belief that they reduce speeding. And, the person complaining probably is not a traffic or safety engineer. But wait. Maybe the solution offered is just the wrong one, but there may still be a real problem. Perhaps the driver cannot see vehicles approaching from a side street. When you visit the intersection, you realize the individual is right; it is difficult for drivers to see oncoming traffic. They cannot see, however, because trees or shrubbery have grown and now block drivers’ sight distance. You now know that the better response is to remove the brush or trees and correct the sight distance problem. But you will not know unless you look. Again, always document your action.
The best way to avoid getting an actual notice and prevent a potential lawsuit is to find problems before someone else does. As discussed in the section on liability, constructive notice means there is an obvious safety problem in the road, the department should have known about it, but did not. Your road agency’s ongoing maintenance should include regular road inspections, with added inspection after bad storms to check for damage and debris. Also, encourage your crews and coworkers to report potential problems they see.

If you want to find out more about liability, there are others in your area who can help. For example, consult a liability or risk management expert in your jurisdiction for more information about road inspections. Your LTAP or TTAP center can also provide assistance on liability issues.

Other good sources about potential problems are the emergency service personnel, the police and emergency medical technicians who are called to crash scenes. They will notice when crashes tend to happen at certain locations.

You should also consider a highway safety investigation. These involve conducting a road condition survey and either a crash analysis, a road safety audit, or both.

The skid marks in figure 5 are an example of how to identify a safety problem. In this case, the curve on the stop-controlled approach makes the intersection difficult to see at night.

Information Gathering

Remember why step one in problem solving is so important: The best countermeasure will not solve the wrong problem. Gathering information, the right information, will help you identify the real safety problem. Traffic safety studies are a good way to collect information related to road conditions or traffic characteristics.

Road Safety Studies

There are two main types of road safety studies. A road safety audit is a formal study by an independent audit team that evaluates the safety performance of a road or intersection. The audit can be of an existing roadway or one in the planning stages. A traffic crash study uses police crash reports to decide the cause of crashes. The following sections explain in more detail why a road safety audit is proactive, where a traffic crash study is reactive.
**Road Safety Audits**

Road safety audits have been conducted internationally since the 1980s. The Pennsylvania Department of Transportation (PennDOT) conducted the first U.S. road safety audit in 1997. Since then, the number of State and local jurisdictions using this tool to improve safety continues to increase.

Again, the road safety audit is a formal examination of the safety performance of an existing or future road or intersection by an independent audit team. Following the assessment, the team prepares a brief report identifying potential safety issues. The jurisdiction owning the road or intersection then responds to the problems identified and determines the action(s) it will take, or documents the reason for not acting on a suggestion. Road safety audits of existing roads are sometimes called road safety audit reviews.

We say that road safety audits are proactive because the team looks for potential safety issues before someone is injured or killed. Road safety audits can take place at any stage of a project, or on existing roads. Audits of existing roads will examine crash data, but that data is not the focus of the team’s work. Rather, the team audit report usually ranks the urgency of defects found. The team may give a low-priority rating to a location where a crash is unlikely, but a serious defect that potentially could cause frequent or severe crashes would receive a high-priority rating. These priorities provide road departments with a cost-effective way to evaluate problems and focus resources wisely.

Road safety audits are not free—they will cost your department or jurisdiction time or money. For example, an economical method is to build an independent team by using experts from nearby jurisdictions. Choose team members who will be objective and whose experience relates to the project under study. So, you probably would not ask a design engineer whose specialty is Interstates to audit the safety of a gravel road. Keep the teams small, 3 to 5 people, but choose ones with a broad range of expertise.

Road safety audits typically cost $2,000 to $5,000 or more, depending on the scope of the audit. Hint: Check if there are funds available from your State’s safety funds to conduct and put into practice the results of your audit.

There have been concerns that conducting road safety audits could increase a jurisdiction’s liability; just the opposite should be true. Implementing a plan to reduce the crash potential of a roadway by using a proactive tool can be used in defense of tort liability. The first step in the process to improve safety is to identify and document safety issues on an existing road or intersection. It would be difficult to fault a jurisdiction for proper documentation, communication, and logically prioritizing an agency’s plan to address safety issues.

**Crash Analysis**

Crash analysis involves studying police crash reports to find common factors in crashes. It can reveal insightful data that has real advantages. If a lot of similar crashes occur at the same location, the answer may be obvious. For example, if there are more crashes in wet weather; look for slippery pavement or drainage problems.

A collision diagram can be a useful tool for identifying common crash types or conditions that frequently exist during crashes at intersections or on road segments. To prepare a collision diagram, you will need to know the layout of the intersection or the road segment. You will also need the police crash reports to construct the diagram. Figure 6 is a sample collision diagram showing a four-leg intersection and indicating where eight crashes occurred over a 3-year period. It also shows the vehicle movement and crash severity; crash type, date, and time; and identification number for each incident.
Understand that there are some serious drawbacks to crash analysis. First, you need enough quality data to get a good perspective on the area and its problems, but you cannot conduct an analysis until several years after a project has been completed. Therefore, crashes have already happened, and people may have already been hurt. Also, it is only as good as the information in the police officers’ reports.

More importantly for local jurisdictions, a crash analysis will not work as well on low-volume roads. Rather than 3 years of crash data, you may need 10 years or more before a pattern emerges. Also, current local crash surveillance systems may not be able to precisely locate crashes occurring between intersections. However, the new Traffic and Criminal Software (TraCS) will improve crash reporting accuracy.

There was one fatal, three injury, and four property damage only (PDO) crashes at the intersection shown in figure 6. There were two crashes involving vehicles turning left on the eastbound approach. There were also two sideswipe crashes involving vehicles traveling on the westbound approach. Two rear-end crashes occurred on the southbound approach. Six crashes occurred during daylight hours.

**Figure 6. Sample collision diagram.**
**Condition Diagrams**

Condition diagrams are drawings, roughly to scale, that show the locations of curves, traffic control devices, guardrails, steep embankments, pavement edge drop-offs, and fixed objects such as trees and structures. Figure 7 is an example of a condition diagram.

A condition diagram is very useful when you want to consult a colleague or refer to a manual because it can help you remember details about the location you are investigating. It also provides a record for later use, should another problem occur nearby.

To prepare a condition diagram, you will need a measuring wheel (or a distance-measuring instrument), a clipboard and paper, and a pencil. A tape measure may also be useful to measure offsets and lane

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**Figure 7. Sample condition diagram.**

There are several safety problems evident in figure 7. Try to identify them and then refer to the end of the chapter for the solution.
widths. Start at a location that will be easy to find again, such as a cross culvert, and set the wheel to zero. Walk toward the end of the study area, and measure the locations of:

- Intersections and driveways.
- Signs.
- Fixed objects.
- Guardrails and steep embankments.
- Culverts and bridges.
- Pavement edge drop-offs.
- Lane and shoulder widths.
- Curve start and end points.
- Crests and low points.
- Any other significant feature.

When you have finished this, make a drawing of the road and mark the locations of items you recorded. Remember, this diagram could be subpoenaed in a court case, so have a plan to remedy any defects you find. You may also use the diagram to show a missing sign on the date of the condition diagram.

### Traffic Volume

The best way to measure traffic volume is with portable traffic counters on the roadway. If counters are not available, use the peak hour traffic volume to estimate the average daily traffic (ADT). This is easier than standing out on the roadside all day. Use the following procedure to estimate ADT:

- Count the number of vehicles passing a point on the roadway in 15-minute increments during the peak travel hour. Peak weekday travel hours are usually between 4 p.m. and 6 p.m. The peak hour is the four consecutive 15-minute periods with the highest number of vehicles. For example, it may be between 4:45 p.m. and 5:45 p.m.
- Calculate the total number of vehicles traveling during the peak hour and divide by a value between 0.08 and 0.12 for rural areas or by a value between 0.12 and 0.18 for urban areas.

To illustrate the concept, consider the 15-minute traffic volumes in table 2. The peak hour occurs between 4:45 p.m. and 5:45 p.m. (shaded area of table 2). The total number of vehicles counted is 640. Because the area is rural, you must divide 640 by a value between 0.08 and 0.12. This is because peak hour traffic usually represents about 8 to 12 percent of the total daily volume in a rural area. We used 0.10 for this example; the ADT is then 6,400 vehicles per day.

<table>
<thead>
<tr>
<th>Table 2. Traffic volumes for a rural highway.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time Period (15-minute intervals)</strong></td>
</tr>
<tr>
<td>4:00 – 4:15 p.m.</td>
</tr>
<tr>
<td>4:15 – 4:30 p.m.</td>
</tr>
<tr>
<td>4:30 – 4:45 p.m.</td>
</tr>
<tr>
<td>4:45 – 5:00 p.m.</td>
</tr>
<tr>
<td>5:00 – 5:15 p.m.</td>
</tr>
<tr>
<td>5:15 – 5:30 p.m.</td>
</tr>
<tr>
<td>5:30 – 5:45 p.m.</td>
</tr>
<tr>
<td>5:45 – 6:00 p.m.</td>
</tr>
</tbody>
</table>
**Speed Studies**

You may have heard traffic engineers and planners refer to the 85\textsuperscript{th} percentile speed. The term refers to the speed at or below which 85 percent of all drivers drive at a specific location under the best possible conditions—good weather, visibility, and traffic volume conditions. In other words, 15 percent of traffic exceeds this speed. The 85\textsuperscript{th} percentile speed is used to make decisions about everything from curve design to appropriate speed limit. It assumes that most drivers assess road conditions and drive at a speed that is comfortable for them on that roadway. The 85\textsuperscript{th} percentile speed is sometimes called the prevailing speed or the running speed.

You can measure the 85\textsuperscript{th} percentile speed with police radar or laser speed-measurement unit. But the instruments can be costly and because road departments will not use them for enforcement, expensive police radars are not needed. Non-enforcement radar units can cost less than $300. If radar is not available, and traffic volumes are moderate, you can follow other vehicles and note the speed they are driving. You will need to do this several times to get a good idea of the range of travel speeds on the road. You can also use a stopwatch to record the time it takes a vehicle to pass points of a known distance on a highway.

To get a statistically valid measurement of the 85\textsuperscript{th} percentile speed, measure the speed of at least 50 cars, but 100 measurements are better. More measurements yield better accuracy. On low-volume roads or when using the car-following method, 50 observations may be impractical. You may be forced to make an estimate based on too few observations. Yet, having some data is better than just guessing. For many traffic applications, the 85\textsuperscript{th} percentile speed is rounded up to the nearest 5 mph, so high accuracy is not always needed.

**Other Traffic Studies**

Depending on what information is needed, there are other types of traffic studies you can conduct. Some of these include delay studies, intersection turning counts, or traffic signal studies. The Manual of Transportation Engineering Studies from the Institute of Transportation Engineers (ITE) has information on conducting many kinds of traffic investigations.\(^{(4)}\)

**Identify Factors Contributing to Crashes**

Identifying the cause of a crash pattern is like putting together pieces of a puzzle. Sometimes the pieces fit easily. Common examples are run-off-road crashes on the outside of a curve, or wet pavement crashes.

Other times, it can be a problem to fit together the right pieces. As an example, consider one case involving a nighttime crash pattern at a State line. Until an investigator happened to drive across the State line at night, no one had realized that there was no transition from the brightly lit section in one State to the unlit side in the neighboring State. If crashes happen during certain conditions such as rain or darkness, visit the site at night or when it is raining, and see what you can learn. If you have an unusual crash pattern, pay close attention to site conditions.

Another example crash investigation case involved vehicles running off the road on an inside curve in wet weather. As investigators evaluated the scene and started to put together the puzzle pieces, they saw that the road had been repaved starting at the middle of the curve. As vehicles crossed from worn concrete to new asphalt, the sudden increase in tire traction caused vehicles to veer toward the center of the curve. Had this been a two-way road, there probably would have been a related crash pattern of vehicles sliding off the outside of the curve as they crossed from asphalt to concrete.

To find patterns, look for similarities between crashes: Similarities in types of crashes, weather patterns, or other contributing factors can provide valuable clues as to why crashes occur. Several highway agencies...
have developed **go bags** for collecting evidence at crash sites. Go bags usually include camera, notepad, and safety vest. Other necessary go-bag gear includes plastic zip-loc bags with labels for collecting evidence, stop watch, flashlight, calculator, spray paint, hand level, measuring wheel, 100-ft tape measure, stringline, nails, hammer, and orange traffic cones.

### Select the Appropriate Countermeasure

Understanding what factors create a problem is the key to finding the right solution. The solution, or countermeasure, should target a particular crash type or contributing factor. Remember, the goal is to reduce the number and severity of crashes while understanding that no one solution solves all safety problems and no one countermeasure works for all types of crash patterns.

Traffic signals, for example, do not always reduce the number of crashes. They usually reduce the number of right-angle crashes, but installing a signal may increase the number of rear-end crashes. If an intersection has had few right-angle crashes, then increasing rear-end crashes may be worse than reducing right-angle crashes.

Some transportation agencies publish crash reduction factor lists that describe the rate you can expect a given countermeasure to reduce crashes. In one example, adding arrow signs or chevrons to a bad curve reduced run-off-road crashes by 34 percent. Table 3 shows common crash reduction factors.

**Table 3. Common crash reduction factors.**

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Crash Reduction Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance warning sign with advisory speed plaque</td>
<td>20 to 36</td>
</tr>
<tr>
<td>Chevron alignment signs (two or more)</td>
<td>49</td>
</tr>
<tr>
<td>Centerline with no passing zones</td>
<td>36</td>
</tr>
<tr>
<td>Edgelines alone</td>
<td>8</td>
</tr>
<tr>
<td>Lighting at intersections</td>
<td>50 to 80</td>
</tr>
<tr>
<td>Rumble strips on two-lane highways</td>
<td>20 to 49</td>
</tr>
<tr>
<td>Rumble strips on multi-lane highways</td>
<td>15 to 70</td>
</tr>
<tr>
<td>Use of warning sign pairs</td>
<td>30 to 40</td>
</tr>
<tr>
<td>Advance warning signs with flashers</td>
<td>25 to 62</td>
</tr>
<tr>
<td>Converting two-way stop to all-way stop at intersections</td>
<td>53</td>
</tr>
<tr>
<td>(this countermeasure may increase rear-end crashes)</td>
<td></td>
</tr>
<tr>
<td>Converting yield to stop control at intersections</td>
<td>82</td>
</tr>
<tr>
<td>Converting two-way stop to signal control at intersections</td>
<td>70</td>
</tr>
<tr>
<td>Addition of left-turn lane(s) at intersections</td>
<td>7 to 48</td>
</tr>
<tr>
<td>Addition of right-turn lane(s) at intersections</td>
<td>4 to 26</td>
</tr>
<tr>
<td>Addition of exclusive left-turn phasing at intersections</td>
<td>25 to 36</td>
</tr>
<tr>
<td>Use of oversized signs</td>
<td>20</td>
</tr>
</tbody>
</table>
As you consider countermeasures, your first decision should be to keep it simple—and inexpensive. Realigning a curve can reduce run-off-road crashes by 79 percent, but it is a very expensive solution. Try installing curve and chevron signs first. If they do not work well enough, then consider more costly options. Use the more costly alternatives only when they are really needed.

**Evaluate Success**

After you install a countermeasure, make sure it works. If you had a history of crashes before the change, compare the crash frequency before the change to the frequency afterward. Did it go down? If not, look into other countermeasures. You may also find changes you did not expect. For example, prohibiting left turns at an intersection may increase the number of left-turn crashes at the next intersection.

If the number of crashes prior to the work was small, it may be that watching the traffic is more useful than conducting a formal before-and-after crash study. If you needed 5 years of crash records for the before study, you may need at least 5 years before you can make any conclusions about its effectiveness. For example, after installing the countermeasure, watch traffic to see if fewer drivers make erratic maneuvers.

**Prioritize Work**

One of the hardest parts of developing a highway safety improvement plan is deciding where to start. Where you start will be affected by conditions often beyond your control. Face it: Money is always a problem. Whether your agency is a small village government or the FHWA, the need always exceeds available resources. Another reality: Everything a road department does is important, and many projects will also improve safety. But prioritizing safety improvements, along with projects to manage the road surface and improve drainage, and everything else the department does, can help you make the best of limited resources.

Regardless of how you decide to begin, always prioritize your projects. Road agencies may be reluctant to do this because they feel that a prioritized list of safety improvements could cause problems. For example, if there is a lawsuit, an attorney could argue that the client or vehicle was injured because a hazard should have had a higher priority than it received. On the other hand, prioritizing work is also a legitimate defense, if you have gone through the planning process to set priorities. If you do not prioritize, it will not matter where you start because problems will be fixed in a haphazard way.

Below are five factors to help you prioritize safety improvements:

- Existing safety problems.
- Opportunity.
- *Bang for the Buck*—what you can get for your effort and money.
- Available resources the amount you can afford to spend on personnel time, equipment, and money for the project.
- Opportunity cost—what other problems could you solve with the same resources? Is this the best use of your resources? Would it be better to reconstruct a single intersection, or upgrade traffic signs at all of your intersections for the same cost?

The first three factors tend to be most important at the local level. For local and Tribal agencies, resource availability is usually the limiting factor.
**Existing Safety Problems**

Organize safety problems by location, in the following order:

- Frequent or severe crashes occur.
- Crashes occur occasionally.
- Crashes are rare.

Next, consider how to rate crashes. Crash **severity** refers to how bad the crashes are, such as fatal, serious, or minor. Severity is the result of speed and the type of crash. Crash **probability** indicates how often you expect crashes to occur in the future. Use the crash history of a location to find probability. When you combine severity and probability, you can identify a priority. It follows that locations with frequent, severe crashes should have the highest priority. Likewise, give locations with few minor-crash patterns a low priority. Rare severe crashes and frequent minor crashes are in between. Table 4 illustrates this concept.

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>FREQUENT</td>
</tr>
<tr>
<td>Serious</td>
<td>HIGH</td>
</tr>
<tr>
<td>Minor</td>
<td>MEDIUM</td>
</tr>
</tbody>
</table>

In addition to crash rate, locations where severe crashes occur should get high priority.

You must also consider speed as you prioritize safety improvements. Common sense tells us that the faster the vehicle travels, the higher the risk of injury or fatality when that vehicle collides with a fixed object (tree, fence, telephone pole, bridge abutment). Traffic engineers use math to calculate the risk of an injury or death in a crash. For our purposes, consider someone in a car traveling at 60 mph (100 km/h) that crashes into a fixed object is 16 times more likely to be killed in the crash than someone in a vehicle crashing into the same object at 30 mph (50 km/h). The risk of the individual being injured is 4 times greater when the vehicle travels at 60 mph (100 km/h) than at 30 mph (50 km/h).

Some crash types are also more likely than others to cause death and injuries. The following crash types cause high rates of fatalities nationwide:

- Fixed object crashes—32 percent.
- Right-angle crashes—22 percent.
- Head-on crashes—10 percent.
- Pedestrian crashes—12 percent.

*How do your State’s crash statistics compare with those shown?*
Opportunity

Road agencies have lots of opportunities to discover situations that could later cause problems and cost time and money. As you plan or do work on the roadway, look around. From a legal standpoint, it is hard to argue that you did not know about a pothole if you cleaned the drain inlet right next to it last month.

We also know that traffic speeds often increase after pavement work. The number of run-off-road crashes tends to go up after resurfacing, and because these crashes happen at higher speeds, they tend to be more severe. So, look for opportunities to improve safety during a project. Repair roadside hazards like too-deep ditches or fixed objects at the same time you repair pavement. Chapter 5 covers these hazards.

Combining projects is also a good way to save time and money. For inexpensive projects like installing signs, just driving to the site can be a large slice of the total cost. By also doing other work nearby, you reduce that cost.

Sometimes, working in an area requires you to upgrade facilities, such as sidewalks. You can allow the existing sidewalks to remain, or you can rebuild a sidewalk, but by rebuilding, you are required to bring it up to current Americans with Disabilities Act (ADA) standards. You may be required to make improvements when you rebuild the road next to the sidewalk.

You might also wonder whether a traffic improvement plan is worth the cost and effort, especially when that time and money could go into making improvements, rather than just planning them. The term describing opportunities lost while you evaluate an option is the opportunity cost. If you choose to spend part of your budget on rebuilding a road, the opportunity cost is everything else you could have funded with that money, but chose not to.

But the opportunity cost is not necessarily money lost. Consider the opportunity cost of not planning. What is the cost of installing guardrail in a place where it is not needed? Whether you use road safety audits or more traditional crash pattern analysis techniques, proper planning always helps you avoid costly mistakes. Under the Transportation Equity Act of the 21st Century (TEA-21), State and metropolitan planning organization (MPO) processes are required to consider safety in transportation planning. This is an opportunity for road agencies to proactively incorporate safety into the transportation network.

Once your department has a safety improvement program in place, discuss it with your municipal insurance agent. You could benefit from a loss-control analysis that could reward the department in lower premiums. The bottom line: If you have had liability claims, feel you are likely to have future claims, or have to insure against claims, then you can afford to have a safety improvement plan.

Bang for the Buck

It may seem heartless, but all decisions are ultimately based on available money and resources. Economists and highway engineers use benefit/cost ratios to set priorities. On one side of the equation are the benefits of the project. On the other are the improvement costs. Safety projects are designed to reduce the number or severity of crashes. These cost reductions are compared to the actual costs, such as design, installation, and maintenance.

Sometimes, a safety improvement will have crash costs of its own. A guardrail 6 ft (1.8 m) away from the edge of the road will probably be hit more often than a tree 12 ft (3.6 m) away, but crashes with a properly designed guardrail will be less severe than crashes with a tree.

You can find additional information about Safety Conscious Planning at [http://www.fhwa.dot.gov/planning/scp]. Local and Tribal agencies that do not have access to the website are encouraged to seek guidance from an LTAP or TTAP center.
An improvement will be cost-effective when:

<table>
<thead>
<tr>
<th>Reduced crash frequency</th>
<th>Installation cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced crash severity</td>
<td>Maintenance costs</td>
</tr>
<tr>
<td>+ Reduced liability costs</td>
<td>+ Cost of more frequent, but less severe crashes</td>
</tr>
<tr>
<td>Total benefits</td>
<td>&gt; Total Costs</td>
</tr>
</tbody>
</table>

Economists use various factors involving interest rates and inflation to compare the cost of an improvement today with a crash it prevents many years from now.

When you consider the costs of traffic crashes, it is easy to see that effective improvements can pay for themselves quickly. Table 5 shows the estimated cost per crash, based on FHWA statistics. If you are planning to readjust the figures shown in table 5, use the gross domestic product implicit price deflator. For instance, adjusting the fatal crash rate to 2010 dollars would require multiplying the crash cost shown in table 5 ($3.09 million) by the inflation index over the 6-year period between 2004 and 2010.

### Table 5. Cost per crash.

<table>
<thead>
<tr>
<th>Crash severity</th>
<th>Average cost per crash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property damage only</td>
<td>$6,000</td>
</tr>
<tr>
<td>Moderate injury</td>
<td>$47,000</td>
</tr>
<tr>
<td>Serious injury</td>
<td>$176,000</td>
</tr>
<tr>
<td>Severe injury</td>
<td>$575,000</td>
</tr>
<tr>
<td>Critical injury</td>
<td>$2,320,000</td>
</tr>
<tr>
<td>Fatality</td>
<td>$3,090,000</td>
</tr>
</tbody>
</table>

**Put It All Together**

With so many factors, prioritizing your projects is hard work. Do you address the location with a high crash rate, or the one the department scheduled to chip-seal this summer? Perhaps you have two crash problems you want to treat, but you can only afford one. Will you improve the curve that was the site of 10 run-off-road crashes in the last year? Or will you consider the intersection with 10 right-angle crashes in the same year?

First, check the crash reduction factors in table 3: Chevron alignment signs on curves reduce run-off-road crashes by 49 percent and oversized STOP signs reduce intersection crashes by 20 percent. The curve signs will probably reduce the run-off-road crashes to five a year. The oversized STOP signs will probably reduce the intersection crashes to eight a year.

Next, look at crash severity. If there are no fixed objects on the outside of the curve and the embankment is flat enough to allow a vehicle to stop safely without rolling over, the right-angle crashes are probably more severe, so the crashes prevented by the oversized STOP signs may be more serious.
Now, what else is the department doing? If you plan to install street name signs because of 911, it will be a good opportunity to install oversized STOP signs, because you are installing signs anyway.

**Summary**

The first phase of improving highway safety is to identify the problem. Failure to understand the problem you need to solve means that any solutions you try will be shots in the dark. They may succeed, but they are just as likely to make things worse. Only when you are sure you have identified the problem can you select the right countermeasure. Select countermeasures based on the expected benefit (such as crash reduction) and the required implementation cost. Always evaluate how well a countermeasure works. If you think it does not work, try another countermeasure and evaluate whether or not it solved the problem.

When you prioritize safety work, always document the rationale behind it. If you do not, it will be hard to prove your plan had merit. Courts have accepted a legitimate ordering of priorities as a defense against liability claims. Documentation supports the validity of your prioritized plan.

The steps to appropriate documentation include:

- Identify the site with a safety problem.
- Visit the site and record important conditions, including intersection dimensions; road segment, signs, pavement markings; number of lanes and lane width; available clear zone; horizontal curvature and grades; and lighting conditions.
- Research and record the crash characteristics including number of vehicles, crash type, day of week, time of day, vehicle speeds, and the crash location.
- Prepare a report of the findings.
- Select an appropriate countermeasure and record the reason for choosing it.
- Evaluate countermeasure effectiveness and report the findings.

---

**Condition Diagram Solution (see figure 7)**

<table>
<thead>
<tr>
<th>Location (feet from southern end of roadway)</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Exposed culvert headwalls; the creek is parallel to the road prior to the headwall – guardrail may be needed depending on the roadside slope and depth of water</td>
</tr>
<tr>
<td>10</td>
<td>Tree on outside of curve</td>
</tr>
<tr>
<td>48</td>
<td>Utility pole between guide rail and roadway</td>
</tr>
<tr>
<td>228</td>
<td>Tree on outside of curve</td>
</tr>
<tr>
<td>248</td>
<td>Intersection sign is too close to intersection</td>
</tr>
<tr>
<td>330</td>
<td>Curve sign is too close to curve</td>
</tr>
<tr>
<td>350</td>
<td>Pine trees may block intersection sight distance</td>
</tr>
<tr>
<td>350 to 400</td>
<td>Skewed intersections like these are more likely to have crashes</td>
</tr>
</tbody>
</table>
3 TRAFFIC CONTROL DEVICES

Traffic control devices are driver information sources—signs, traffic signals, pavement markings, delineators, work zone devices—along the roadway. Transportation departments nationwide use these devices to communicate the information that helps drivers travel safely.

The Manual on Uniform Traffic Control Devices (MUTCD), usually referred to as the MUTCD, is the FHWA’s official standard regulating how road agencies throughout the United States use traffic control devices. It was developed to ensure consistency and uniformity in traffic control devices throughout the United States. The purpose of this chapter is to introduce you to some of the MUTCD regulations that affect the day-to-day decisions about roads.

There are 10 Parts of MUTCD and each describes approved traffic control devices as well as how, when, where, and why to use them:

1. General
2. Signs
3. Markings
4. Highway Traffic Signals
5. Traffic Control Devices of Low Volume Roads
6. Temporary Traffic Control
7. Traffic Controls for School Zones
8. Traffic Controls for Highway-Rail Grade Crossings
9. Traffic Controls for Bicycle Facilities
10. Traffic Controls for Highway-Light Rail Transit Grade Crossings

A STOP sign, YIELD sign, double-yellow line, and green light mean the same thing to drivers in New York, Missouri, or Utah. Therefore, drivers who see these traffic control devices understand the message and should be prepared to react, regardless of the location.

To foster this uniformity, the MUTCD defines traffic control devices as all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, or bikeway by authority of a public agency having jurisdiction. The MUTCD is recognized as the national standard for all traffic control devices installed on any street, highway, or bicycle trail open to public travel. Some States publish their own manuals, and others publish supplements to the MUTCD. These supplements are required to be in compliance with the MUTCD. Indian Tribes may or may not follow the MUTCD. The Bureau of Indian Affairs (BIA) owns most non-State or non-county roads on the reservations and, as a Federal agency, BIA is required to follow the MUTCD.

You can see the MUTCD online at [http://mutcd.fhwa.dot.gov/]. You can purchase print versions of the MUTCD through AASHTO, ITE, or the American Traffic Safety Services Association (ATSSA).

Standard, Guidance, Option, and Support

The MUTCD not only specifies the use and appearance of traffic control devices, it also gives road departments guidance in how they are used. The MUTCD uses the terms standard, guidance, option, or support to advise road agencies how to use the devices:
STANDARD designates a mandatory, required, or strictly prohibited practice. Shall specifies a requirement is mandatory. Standards are sometimes modified by options.

GUIDANCE states a recommended but not mandatory practice where a department has some leeway when engineering judgment or engineering study confirms another practice to be appropriate. This is referred to as a deviation. The term should is typically used for guidance statements. Guidance statements can be modified by options. Always document your reasons for any deviation.

OPTION indicates there is no intended requirement for a particular design or application. Options may contain permitted alternatives to a specific standard or guidance. The term may is typically used with the option statement.

SUPPORT is an informational statement that is not a recommendation, prohibition, or other enforceable condition. Support statements do not include the words shall, should, or may.

Traffic Control Device Principles

For a traffic control device to be effective, it should meet these five principles:

- Fulfill a need.
- Command attention.
- Communicate a clear, simple meaning.
- Command respect.
- Give enough time for response.

If a traffic control device fails to meet these basic needs, road users may ignore, misunderstand, or overlook it, and the device will not meet the need it is meant to fulfill.

Primacy

Primacy, a human factors principal, is the relative importance of each level of driver performance—control, guidance, and navigation—and the information associated with each level. In the context of this Guide, primacy can be used to establish the priority and relative importance of signs and other traffic control devices, especially when they need to be placed in close proximity to each other. A principal criterion upon which primacy is assessed is the level of consequence if the motorist fails to see or comprehend the information. At the low end, failing to see a parking restriction sign may result in a fine, but at the high end, failing to see a STOP sign may result in a fatality if a resulting crash occurs.

As a guideline, in order of importance, signs fall into the following categories:

1. Regulatory signs that control traffic, such as STOP, YIELD, or DO NOT ENTER.
2. Critical warning signs, such as STOP AHEAD or CROSS TRAFFIC DOES NOT STOP.
3. Other warning signs, such as CURVE AHEAD, LOW CLEARANCE, and SOFT SHOULDER signs.
5. Other regulatory signs, such as speed limits or parking regulations.

A common situation where this primacy principle can be applied is when there is a need for two or more advance warning signs and determining where they should be placed with respect to each other. On a curved approach to a stop-controlled intersection, give the STOP AHEAD sign priority of placement over a curve warning sign. Knowing there is a need to stop ahead will prepare the motorist for the maneuver required, as well as the need to negotiate the curve.
Signs

**Sign Types**

*Regulatory signs* tell road users about traffic regulations and laws. Road departments use them to control vehicle and pedestrian movements. Examples include STOP signs, NO PARKING signs, and speed limit signs. Figure 8 shows common regulatory signs. Many regulations are unenforceable unless the proper signs are posted. Regulatory signs remind drivers of statutory rules, but statutory rules do not need signs to be enforceable. For example, we know it is illegal to park a vehicle in front of a fire hydrant, whether or not a sign prohibits it. To prohibit parking where it would otherwise be legal requires *no parking* regulations and signs.

The Uniform Vehicle Code of your state covers use of traffic regulations. Appropriate enabling ordinances or legislation must be in place before a regulatory sign is installed. To learn more about the extent of your agency’s authority, refer to your jurisdiction’s vehicle code.

Most regulatory signs are rectangular and taller than they are wide. Exceptions include STOP and YIELD signs. White, black, and red are used for regulatory signs.

Regulatory signs can promote smooth, orderly traffic flow, but only when they are properly used and enforced. When used incorrectly, they can cause more problems than they solve. For example, unnecessary STOP signs cause needless air and noise pollution. Drivers often disobey regulations they think are unnecessary. These road users may intentionally disregard what they believe are irrelevant or unrealistic traffic regulations. Other roadway users may expect them to obey the regulation, and act accordingly, with potentially fatal results. For example, a pedestrian may assume an approaching driver will stop at the STOP sign. A serious injury could occur if the driver does not stop.

*Warning signs* tell road users to be cautious because of a condition on or near the roadway. Warning signs are especially helpful to drivers who are not familiar with the road. Use warning signs only where needed because overuse can lead to disrespect for all warning signs, which reduces their effectiveness. Figure 9 shows common warning signs.

As you decide whether a warning sign is needed, consider whether the hazard can be removed. If removing the hazard is impossible or not cost-effective, install the warning sign. If you plan to remove the hazard eventually, install a sign to warn traffic of the condition until you can remove the hazard.
Warning signs are usually diamond-shaped, with black text or symbols on a yellow background. Road work warning signs should have orange backgrounds. An exception is the railroad crossing sign. It is always round and always has a yellow background, even when used in a work zone.

The fluorescent yellow-green background is optional on certain warning signs, including pedestrian, handicapped, bicyclist, and school signs. Fluorescent yellow-green signs are gaining popularity because they are more conspicuous and more easily seen in bad weather.

![Common warning signs](image9)

**Figure 9. Common warning signs.**

Guide and information signs provide navigation and service information to drivers. These signs include route markers, destination signs, and information signs. They have green, blue, or brown backgrounds and white letters. Guide signs in work zones should be orange with black lettering. Figure 10 shows common guide signs.

By giving information to drivers when they need it, we can reduce the unpredictable behavior of drivers who suddenly realize they are going the wrong way or just missed a turn.

![Common guide signs](image10)

**Figure 10. Common guide signs.**
**Placement**

Place each sign for maximum visibility and effectiveness. The sign location must fit in with the layout of the highway. You must justify any variation from MUTCD practices or applications with an engineering study or engineering judgment. If a sign is placed in a location other than that shown in the MUTCD, document and file the reasons for this placement for future reference. The MUTCD describes sign placement information.

Take the time to check all sign locations; make sure that nothing blocks a motorist’s view of the sign and that it is visible at night. Avoid placing signs in dips, beyond hillcrests, or at other places where motorists cannot see them in enough time to react safely. Make sure that a new sign does not block a motorist’s view of an existing sign. Always consider the possibility that a sign could be hidden by parked trucks or summer foliage or be a hazard to pedestrians.

Locate ground-mounted signs on the right side of the roadway facing approaching traffic, unless another location is required or permitted. Consider signs in any other position to be less important to those in the usual location.

**Lateral Offset**

Where conditions permit, place signs on roads without curbs so that there is a lateral or side clearance of at least 12 ft (3.6 m) from the edge of the travel lane to the near edge of the sign, or 6 ft (1.8 m) from the edge of the shoulder, where the shoulder is more than 6 ft (1.8 m) wide. When there is something in the way, or the sign will not be visible, the best course is to locate the sign as far from the edge of shoulder as possible.

In areas where space is limited, use a minimum lateral offset of 2 ft (0.6 m). On curbed roads where sidewalk width is limited or where poles are close to the curb, locate the edge of the sign 1 ft (0.3 m) or more from the face of the curb. Place the sign farther from the curb, if possible, to reduce the chance of a vehicle hitting it. This is especially true on corners where trucks turn frequently. Always ensure that the sign and signpost will not block the sidewalk.

**Longitudinal Placement and Advance Posting Distance**

Longitudinal placement is the distance along the road from a sign to the condition, regulation, or action to which it refers. Where you place signs along the highway depends on the type of sign, the nature of the message, and for many signs, the prevailing traffic speed.

Where you place signs in relation to each other depends on sign type and highway characteristics. Try to erect signs individually, except when they supplement each other, and always try to space signs far enough apart so that motorists have time to make reasonably safe decisions. Remember: Drivers react best when they only have to make one decision at a time.

Where physical conditions limit visibility, adjust the sign location. For example, drivers may miss a ground-mounted sign placed immediately beyond an overpass. You can improve the sign’s visibility and effectiveness by placing it before or well past the overpass. You can usually place guide signs beyond the overpass, but try not to reduce the distance between a warning sign and the condition it warns about. As always, if you must adjust a sign’s location, document your reason and file it for future reference.

Normal traffic speed and the action required by the driver will influence the distance between the posted warning sign and the hazard. The travel distance is the distance the driver needs to understand and react to the sign message and to perform any necessary action. The distance between the sign and the hazard is called the **advance posting distance**.
The MUTCD developed two advance posting distance category guidelines.

**Category A** signs are warning signs used when drivers need to reduce speed or change lanes in heavy traffic. MERGE and RIGHT LANE ENDS warning signs are examples of Category A signs. Table 6 shows advance posting distances for Category A signs.

**Table 6. Advance posting distance for Category A signs.**

<table>
<thead>
<tr>
<th>Posted or 85th percentile speed (mph)</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance posting distance (ft)</td>
<td>225</td>
<td>325</td>
<td>450</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td>850</td>
<td>950</td>
<td>1100</td>
<td>1200</td>
<td>1250</td>
<td>1350</td>
</tr>
<tr>
<td>Posted or 85th percentile speed (km/h)</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Advance posting distance (m)</td>
<td>60</td>
<td>100</td>
<td>150</td>
<td>180</td>
<td>220</td>
<td>260</td>
<td>310</td>
<td>350</td>
<td>380</td>
<td>420</td>
<td>460</td>
<td></td>
</tr>
</tbody>
</table>

**Category B** warning signs are used with advisory speeds. Curve signs and turn signs are common examples. Tables 7 and 8 show advance posting distances for Category B signs.

**Table 7. Advance posting distance for Category B signs (U.S.).**

<table>
<thead>
<tr>
<th>Posted or 85th percentile speed (mph)</th>
<th>0h</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deceleration to listed advisory speed (mph) for the condition&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>175</td>
<td>175</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>325</td>
<td>325</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>475</td>
<td>475</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>550</td>
<td>550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>650</td>
<td>650</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Typical conditions are when road users must reduce speed to perform a maneuver.

<sup>b</sup> Typical condition is to warn of a potential stop.
Table 8. Advance posting distance for Category B signs (metric).

<table>
<thead>
<tr>
<th>Posted or 85&lt;sup&gt;th&lt;/sup&gt; percentile speed (km/h)</th>
<th>Deceleration to listed advisory speed (mph) for the condition&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>70</td>
<td>50 40 30</td>
</tr>
<tr>
<td>80</td>
<td>80 60 55 50 40 30</td>
</tr>
<tr>
<td>90</td>
<td>110 90 80 70 60 40</td>
</tr>
<tr>
<td>100</td>
<td>130 120 115 110 100 90 70 60 40</td>
</tr>
<tr>
<td>110</td>
<td>170 160 150 140 130 120 110 90 70 50</td>
</tr>
<tr>
<td>120</td>
<td>200 190 185 180 170 160 140 130 110 90 60 40</td>
</tr>
<tr>
<td>130</td>
<td>230 230 230 220 210 200 180 170 150 120 100 70</td>
</tr>
</tbody>
</table>

<sup>a</sup> Typical conditions are when road users must decrease speed to perform a maneuver.
<sup>b</sup> Typical condition is to warn of a potential stop.

Advance placement distances for posted or 85<sup>th</sup> percentile speeds less than those shown in tables 7 and 8 depend on site conditions and other signing to provide adequate warning for a driver.

**Height**

The MUTCD specifies the minimum height of signs so that road users can see them. In urban areas or other locations where other vehicles may block a driver’s view, install signs 7 ft (2.1 m) above the edge of the roadway. In rural areas, 5 ft (1.5 m) is the minimum. Install directional, regulatory, and warning signs on freeways and expressways at least 7 ft (2.1 m) above the pavement edge. If a secondary sign is mounted below a major sign, install the major sign at least 8 ft (2.4 m) and the secondary sign at least 5 ft (1.5 m) above the pavement edge.

On sidewalks or other pedestrian areas, position the sign high enough so pedestrians are not likely to hit their heads on the bottom of the sign panel. At such locations, the clearance to the bottom of the sign must be at least 7 ft (2.1 m).

The MUTCD does not specify the maximum height of signs, but sometimes it is useful to place the sign higher than normal, for example, so it can be seen over a crest in the road.

**Size**

The MUTCD provides standard sign sizes. Where standard size signs fail to have the desired effect, using larger signs may provide the necessary emphasis. First, check to make sure the existing sign meets the five basic principles of a traffic control device.

A person with 20/30 vision can read a standard highway sign 30 to 40 ft (9.1 to 12.2 m) away for each inch of letter height. So, we can recognize 8-in-(200-mm-) tall letters 320 ft (100 m) to 480 ft (150 m) away. Symbol signs (bike lane, pedestrian crossing) are often legible from a much longer distance, but they may be harder to understand.
To learn more about retroreflectivity, please refer to the FHWA's NIGHT LIGHTS brochure: [http://safety.fhwa.dot.gov/fourthlevel/sa03027.htm]

If your transportation agency does not have equipment to measure retroreflectivity, consult your local LTAP or TTAP center for guidance.

Both U.S. Route 15 guide signs are visible at night while the State Route 7 sign is not. The State Route 7 sign has lost its retroreflective properties and should be cleaned or replaced.

**Retroreflectivity**

Regulatory, warning, and guide signs are important and drivers need to see them. That is why the MUTCD mandates these signs shall be retroreflective or lighted so they have essentially the same appearance day and night. Materials used for signs should provide nighttime visibility equal to daytime visibility. Black portions of a sign face need not be reflectorized.

Figure 11 shows a set of route guide signs. Two signs are clearly visible at night while one is not. The figure demonstrates how sign retroreflectivity levels can fade over time. It can be difficult to notice this degradation during the daytime, so plan periodic nighttime inspections. Portable retroreflectometers are a good way to measure retroreflectivity levels of traffic signs. Brightness can also be reduced because of mud or debris splatter. In this case, washing a sign with a soft sponge and mild soap will remove dirt and restore retroreflectivity.

**Signposts**

Signposts are not much of a hazard to road users in terms of annual fatalities in most areas, but it is one highway departments directly control.

One problem with signs is they must be close enough to the road for road users to see, which is at odds with ensuring a clear roadside area that allows drivers who lose control to return safely to the roadway. Various types of breakaway post systems have been developed to solve this problem. These posts are designed to break away in a controlled way when hit, which allows a vehicle to safely pass over or under the sign. Many times, the base post is undamaged and reusable, which reduces the labor needed to repair the sign. The MUTCD requires that ground-mounted signposts be breakaway, yielding, or shielded when located within the clear zone. (Chapter 5 discusses clear zones.)

For breakaway signposts to work properly, the top of the stub must be less than 4 in (100 mm) above the ground. There have been cases where tall stubs have damaged fuel tanks and caused fires. Figure 12 shows examples of properly and improperly installed breakaway signposts. Nonbreakaway posts can cause a vehicle to roll over.

During your sign inventory inspection, check base-post heights in areas where erosion could occur. If enough soil washes away, the breaking point of a correctly installed breakaway post may be higher.
When repairing signposts or installing new sign posts, it is a good idea to use breakaway hardware.

**Pavement Markings**

Pavement markings guide and regulate traffic. They improve the safety of a roadway by informing the driver without taking attention from the roadway. We use pavement markings to guide traffic through sharp or multiple curves, delineate road width reductions, and mark no-passing zones. They are especially useful in reducing run-off-road and crossover crash problems.

Pavement markings are required on roads with three or more lanes. Centerline markings are recommended on:

- Two-way paved urban arterials and collectors 20 ft (6.1 m) wide or more with an ADT of 4,000 vehicles per day or greater.
- Two-way paved rural arterials and collectors 18 ft (5.5 m) wide or more with an ADT of 3,000 vehicles per day or greater.

Centerline pavement markings are required on urban roads that carry more than 6,000 vehicles per day with traveled ways 20 ft (6.1 m) or wider. Edgelines are required on freeways, expressways, and rural arterials with a traveled way width of 20 ft (6.1 m) or more and an ADT of 6,000 vehicles per day or greater. Edgelines are recommended on rural arterials with a 20 ft (6.1 m) or wider traveled way and an ADT of 3,000 vehicles per day or greater.

The three categories of pavement markings are long lines (center and edge lines), transverse lines (stop lines and crosswalks), and special markings (words and symbols).

Reapply pavement markings as needed to maintain good visibility. Failure to do so can mean increased liability risk to the jurisdiction. Once your department decides to use pavement markings, continue periodic maintenance to avoid the risk of liability unless a formal engineering study shows the money is better spent elsewhere. Document study findings and file them for future reference.

Pavement markings become less effective as the markings wear. New markings provide much better guidance than worn ones, especially at night. Much the same way that reduced retroreflectivity makes signs difficult to see at night, pavement marking reflectivity is often lost before wear is apparent during daylight.
Several States supplement pavement markings with milled or other types of rumble strips. The case for using rumble strips is that the abrupt change in sound and pavement texture alerts drivers that they are leaving the roadway, crossing the centerline, or approaching a STOP sign. Rumble strips are commonly used on Interstates, and are increasingly being used on two-lane rural roads.

Using pavement markings can also reduce crashes. Table 3, chapter 2, shows that using edgelines can reduce crashes by 8 percent. Using centerline markings with no passing zones can reduce all crash types by 36 percent.

**Delineators**

Delineators are reflective roadside markers used to guide traffic at night, during adverse weather, through work zones, and at locations with confusing alignment features. Delineators can be embedded in the centerline or edgeline or mounted on posts at curves. These are often referred to as *cat’s eyes*. Delineators are a good safety device because they are less affected by inclement weather than pavement markings, and delineators do not have to be replaced as often because traffic does not drive on them.

Road agencies use post-mounted delineators along the entire road or just through short stretches where the horizontal alignment changes (such as curves). Pavement embedded white delineators are used on both sides of two-way roads, and on the right side of one-way roads. Yellow delineators are used on the left side of one-way roads, and in the median of divided roads.

Post-mounted delineators are normally placed between 2 and 8 ft (0.6 and 2.4 m) beyond the edge of the shoulder. They are mounted 4 ft (1.2 m) above the roadway edge on suitable posts. Normal spacing is 200 to 530 ft (60 to 160 m) apart, but space them closer together on curves. You can look up spacing on curves in the MUTCD or calculate them with the formula $3 \times (R – 50)^{1/2}$, where $R$ is the curve radius in feet. To calculate spacing in metric units, use $1.7 \times (R – 15)^{1/2}$. The minimum spacing should be 20 ft (6.1 m) on curves.

**Traffic Control Device Maintenance**

Installing a traffic control device means the department accepts the responsibility to maintain it. When a sign or pavement marking deteriorates to the point it no longer functions as intended, it is a liability risk. Worn pavement markings and faded signs are of use to no one except lawyers. Also, be on the lookout for signs obscured by trees or other vegetation.

Prioritize repairs based on the primacy of the sign and its condition. As noted above, retroreflective properties often degrade and road departments need to ensure sign inspection includes nighttime review. In terms of priority, important signs, and signs in poor condition should be higher on the department’s list.

When a device is no longer needed, remove it. Perhaps traffic patterns changed, laws or ordinances updated, or perhaps the device was ineffective to begin with. Removing a traffic control device requires careful consideration. Ask yourself whether the device is no longer needed. Is there something else you could install to increase road safety? Whatever your decisions, record the details and keep them for future use. You may find yourself defending an action in the future.

**Inventory**

A complete inventory is one of the most useful tools for effectively maintaining your traffic control devices. An inventory helps you plan and budget your maintenance efforts and it makes replacing missing signs easier. The initial inventory can be labor-intensive, but once completed, it is easy to maintain and well worth the effort.
There are several ways to keep your inventory. It can be as basic as a paper system such as index cards or in a binder. It can be more high-tech and take advantage of computer software. Regardless of the method you use, it should be flexible enough so that you can add new signs and delete removed signs. It is also a good place to document repairs. Computer inventory systems also allow you to add information on sign condition, and based on the condition and the primacy of the sign, prioritize repairs. Figure 13 is an example of a sign in poor condition. Be sure to include the sign location in an inventory of signs requiring replacement.

![Figure 13. Sign in poor condition.](image)

The STOP sign in figure 13 is in poor condition. Because of its wear, retroreflective properties have degraded. The sign should be replaced with a new sign.

**Summary**

The MUTCD provides standards and other guidelines for using traffic control devices, which are the way highway departments communicate with drivers. They should fulfill a need, command attention, convey a clear meaning, command respect, and give adequate time for drivers to respond. Regulatory, warning, and guide signs have standard colors, size, and placement guidelines—all are outlined in the MUTCD. Agencies should routinely check signs to monitor their retroreflective properties, especially at night. Pavement markings and delineators guide drivers by highlighting edgelines and lane lines, especially at night and in poor weather. Agencies should routinely monitor and evaluate their effectiveness. Developing an inventory of signs, pavement markings, and delineators is a useful way for agencies to effectively manage traffic control devices. Although labor intensive at first, an inventory can help improve traffic control device maintenance.
ROADWAYS

The highway transportation system is typically divided into the driver, vehicle, and the roadway and its environment. As noted in chapter 1, road condition is listed as a contributing factor in 34 percent of highway crashes. Roadway features such as travel lanes, shoulders, roadside slopes, horizontal curves, and vertical curves all influence safety. Figure 14 shows a two-lane highway in a rural setting. This chapter explains many of the roadway features seen in figure 14.

Appropriate Standards

Road agencies use many references for road design standards. AASHTO’s *A Policy on Geometric Design of Highways and Streets*, also called the *Green Book*, is one of the most commonly used highway design references. Be aware, however, that the Green Book has information about local roads, but it is largely written for those who design collectors, arterials, and freeways.

If the road carries fewer than 400 vehicles a day, use the AASHTO’s *Geometric Design Guidelines for Very Low-Volume Local Roads*. The key is to choose the standard most appropriate for your roads and then use it consistently.

Remember: Standards are not a substitute for good judgment. Meeting all the standards does not necessarily mean a road will be safe; and not meeting them does not always mean it will be unsafe. However, if your judgment tells you that a standard is not the best way to solve a safety problem, be sure to document your reason. Depending on the degree and type of practice or application, you may need to get documented advice of a professional engineer.
Consistency

Many traffic crashes occur at places where the road character changes. Transitions from straight to curved alignments, reduced lane width, and borders between rural and built-up areas are examples of character changes that could cause safety problems.

Where possible, maintain a constant road width and character. Where change is necessary, use signs and pavement markings to warn drivers about the change and guide them through it. Always try to make changes where drivers can see them. For example, locate curves before hillcrests, not just over them.

Stopping Sight Distance

A driver’s ability to see the roadway ahead is critical for safety reasons. The available stopping sight distance is the distance necessary for a vehicle to stop before it reaches an object in its path. Think of the sight distance as the space between when a driver identifies and processes information, decides on a course of action, and acts. The action can be as simple as deciding to change lanes and turning on the turn signal, or more complex such as rounding a curve and seeing a cow standing in the roadway. If the action requires the vehicle to stop, the sight distance will also include the vehicle braking distance. Table 9 shows stopping sight distance values on grades.

Gravity also plays a role. Braking distances are longer on downhill sections and shorter on uphill sections. Sometimes, meeting the distances in table 9 is not enough. The design reaction time used in calculating stopping sight distance is 2.5 seconds. Where complex decisions or maneuvers are required, longer reaction times are needed. On slippery pavements or unpaved roads, braking distances are likely to be longer.

Trucks are larger and heavier than cars so it is reasonable that they need longer distances to stop than other vehicles. Truck drivers can, however, usually see farther because they sit higher in a larger vehicle. On hillcrests, this is usually enough to compensate, but on horizontal curves, sight obstructions are often too high that even truck drivers cannot see over them. On horizontal curves in steep downhill sections, the higher driver’s eye height often is not enough to compensate for the longer stopping distances. In these cases, provide more than the minimum stopping sight distance.
On low-volume roads drivers may need less sight distance because the chances of a multi-vehicle crash are lower. For roads with fewer than 400 vehicles per day, AASHTO’s *Guidelines for Geometric Design of Very Low-Volume Local Roads* indicates that it is rarer for vehicles to stop in the roadway as compared to high-volume roads. As a result, perception-reaction time is less because drivers are aware of locations where vehicles may be stopped. Table 10 shows design stopping sight distance values for newly constructed low-volume roads.

**Table 9. Stopping sight distance on grades.**

<table>
<thead>
<tr>
<th>Design Speed (mph)</th>
<th>Stopping Sight Distance (ft)</th>
<th>Design Speed (km/h)</th>
<th>Stopping Sight Distance (m)</th>
</tr>
</thead>
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<td></td>
<td>Downgrade 3%</td>
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Distances calculated in the table are based on the following equation: 

\[
3.68V + \left[ \frac{V^2}{30(0.35 + G)} \right],
\]

where V is the design speed in miles per hour and G is the percent grade divided by 100. When on an upgrade, add the G term and when on a downgrade subtract the G term in the equation. For example, a vehicle traveling on a 3% downgrade on a roadway with a design speed of 35 miles per hour requires the following stopping sight distance: 

\[
3.68(35) + \left[ \frac{35^2}{30(0.35 + 0.03)} \right] = 257 \text{ ft}.
\]

Note: The stopping sight distance equation shown above assumes that the perception-reaction time for drivers is 2.5 seconds and the deceleration rate of the vehicle is 11.2 ft/sec\(^2\). When on a level roadway surface, the G term in the equation is zero.

Table 10. Stopping sight distance values for low-volume roads.

<table>
<thead>
<tr>
<th>Design Speed (mph)</th>
<th>Stopping sight distance (ft)</th>
<th>0–100 veh/day</th>
<th>100–250 veh/day</th>
<th>250–400 veh/day</th>
<th>All locations</th>
<th>“Lower risk” locations¹</th>
<th>“Higher risk” locations²</th>
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<th>Design Speed (mph)</th>
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<th>100–250 veh/day</th>
<th>250–400 veh/day</th>
<th>All locations</th>
<th>“Lower risk” locations¹</th>
<th>“Higher risk” locations²</th>
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¹ away from intersections, narrow bridges, highway-rail grade crossings, sharp curves, and steep downgrades
² near intersections, narrow bridges, highway-rail grade crossings, sharp curves, and steep downgrades


To measure stopping sight distance, use an average eye height of 42 in (1080 mm) and an object height of 24 in (600 mm) (see figure 16). On horizontal curves, measure stopping sight distance along the center of the inside lane, as shown in figure 17.
Figure 16. Measuring stopping sight distance on a crest.

To learn more about sight distance on horizontal curves, refer to the AASHTO Green Book.

Figure 17. Measuring stopping sight distance (S) on a horizontal curve.
Cross Sections

The cross section of a road is what you would see if you removed a slice across it and looked at it end-on. From a safety standpoint, we are interested in cross slopes, lane widths, shoulders or curbs, and roadside slopes. Figure 18 illustrates these cross-section elements. Chapter 5 discusses roadside slopes.

Cross Slopes

Cross slope refers to the slope of the road from side to side. Except in curves, you want the road to be higher in the middle than the edges so water can drain off the roadway. This is called the crown of the road. Curves are often banked, or superelevated so the outside edge of the road is higher than the inside edge.

Normal cross slope for paved roads is 1.5 to 2 percent (nearly 1/4 in vertically/ft laterally). Gravel roads should have a steeper cross slope, 2 to 6 percent (approximately 1/4 to 3/4 in/ft). Cross slopes that are too steep can be difficult to drive on in winter weather.

Lane Widths

The lane width needed for a given road depends on the functional class of the road and the amount and speed of traffic it carries.

For most roads, lanes should be between 9 and 12 ft (2.7 and 3.6 m) wide. Twelve-ft (3.6-m) lanes are standard for higher road classifications (such as freeways and expressways). Eleven-ft (3.3-m) lanes are acceptable in urban areas with limited right-of-way. Low-speed roadways can often operate safely with lanes 10 ft (3.0 m) wide, unless they carry an unusually large number of trucks. For low-volume roads, 9-ft (2.7-m) lanes can be acceptable.

On curbed roads, add an additional 1 to 2 ft (0.3 to 0.6 m) of width to the lane next to the curb. This helps keep vehicles from hitting the curb or shying away from it toward the next lane. Also, providing space between the travel lane and the curb permits bicyclists to share the road safely.

A major safety improvement on narrow roads is to widen the lanes. This improvement can reduce the number of head-on, sideswipe, and run-off-road crashes. It also makes more room for trucks, agricultural equipment, and bicyclists. Widening is a relatively expensive option, so it is best used where there are safety or operational problems. It is easier to justify the cost on roads carrying more than 1,000 vehicles per day. Another cost-effective improvement is to widen intersections or tight-radius curves rather widening an entire road. The cost of wider lanes is often more reasonable for new roads and major reconstruction projects. When widening roads or intersections for safety or operational purposes, be careful not to sacrifice the quality of the roadside. Poorly designed roadides can increase the severity of crashes that do occur. Figure 19 shows expected crash reductions for travel lanes on two-lane rural highways.
The accident modification factors in figure 19 show that lanes narrower than 12 ft (3.6 m) increase the expected crash frequency based on the factors shown. These factors are applicable to single-vehicle run-off-road, multiple-vehicle same direction sideswipe, and multiple-vehicle opposite direction crashes. For instance, a roadway carrying 2,000 vehicles per day with 11-ft (3.3-m) lanes can expect 5 percent more crashes than the same roadway with 12-ft (3.6-m) lanes.

**Shoulders**

Shoulders are often not economically justified on low-volume roads. Their value increases, however, as traffic volumes and speeds increase. Shoulders improve road safety by:

- Allowing for driver error and providing space to make evasive maneuvers.
- Increasing sight distance for through vehicles and for vehicles entering the roadway.
- Providing structural support to the pavement.
- Moving water away from the travel lanes, reducing damage to the base and subgrade, as well as reducing hydroplaning, splash, and spray.
- Providing space for maintenance operations, portable maintenance signs, and snow storage.
- Reducing conflicts between motor vehicles and bicyclists and pedestrians.
- Making pedestrians more visible to motorists.
- Allowing for easier turning from travel lanes to side roads.
- Providing more room for turning trucks and space for off-tracking of truck rear wheels in curves.
- Providing space for disabled vehicles, mail delivery, and bus stops.

You can grade, stabilize, or pave shoulders. On minor rural roads, consider providing 2-ft (0.6-m) wide shoulders. If pedestrians or bicyclists will use a shoulder, pave it 4 ft (1.2 m) or more wide. Wider shoulders are used on higher volume and higher speed roads. Shoulders are normally 10 ft (3.0 m) wide on higher type facilities such as freeways and expressways.

Refer to the AASHTO Green Book for more information about shoulders and their appropriate width.
Paved shoulders usually have a cross slope of 2 to 6 percent (1/4 to 3/4 in/ft). Typically, the slope for gravel shoulders is 4 to 6 percent and 6 to 8 percent for turf shoulders. On the outside of banked curves, reduce the shoulder cross slope to keep the difference between the lane cross slope and shoulder cross slope less than 1 in/ft (8 percent). Differences of more than 8 percent can cause stability or control problems when a vehicle drifts onto the shoulder. For example, if a road in a curve is banked at 4 percent, reduce the slope of the outside shoulder from 6 to 4 percent or flatter.

Figure 20 shows expected crash reductions for shoulders on two-lane rural highways. These factors are applicable to single-vehicle run-off-road, multiple-vehicle same direction sideswipe, and multiple-vehicle opposite direction crashes. For instance, a roadway carrying 2,000 vehicles per day with 2-ft (0.6-m) shoulders can expect 30 percent more crashes than the same roadway with 6-ft (1.8-m) shoulders.

Parking

Parking is an issue with its own set of safety problems. For example, in built-up areas, on-street parking can be a factor in a lot of crashes, but eliminating parking can anger local business owners and residents. On the other hand, parked vehicles can also help reduce traffic speeds, separate pedestrians from vehicle traffic, and promote local business. In more congested areas, the best way to improve safety may be to replace on-street parking with municipal lots.

Angle parking is especially troublesome. Because drivers backing out of a parking space have difficulty seeing approaching traffic, try to limit it to parking lots. Avoid it on roadways. Reverse-angle parking is similar to standard angle parking, except that vehicles stop and back into a parking space. There is better visibility, however, because vehicles drive forward out of the parking space. Figure 21 shows an example of reverse-angle parking.
Parallel parking has fewer problems but road departments need to manage it in developed areas. Try to prohibit parking near curves or other places where a vehicle cannot be seen while parking or leaving a parking area. Never allow vehicles to park where they will cause visibility problems, such as near intersections or midblock crosswalks.

Curbs

Curbs have many uses such as channeling storm water into drain inlets or controlling access to driveways. They can separate sidewalks from the rest of the road. Avoid using curbs on high-speed roads where they can cause a vehicle to jump a guardrail or be a factor in rollover crashes.

You can install a vertical face curb to keep drivers on the roadway, but it will not prevent a vehicle from leaving the road on purpose or keep a driver from losing control of the vehicle.

A sloping curb discourages drivers from leaving the roadway but vehicles can drive over it at a slow speed. Start the approach ends of sloping curbs at ground level and gradually build up to full height to prevent scraping of the vehicle underside.

Sidewalks

Sidewalks provide a safe place to walk and road agencies should provide them in built-up areas where walking is common. On slow and medium speed roads, curbs usually have sidewalks, but be aware that curbs will not protect pedestrians from vehicles. A buffer space or planting strip between the sidewalk and the curb provides a bit more safety and comfort for pedestrians. It also provides room for snow storage. It is best not to use curbs on high-speed roads. Instead, install a wide planting strip to separate the street from the sidewalk.

Sidewalks are usually 4 to 8 ft (1.2 to 2.4 m) wide, which allows pedestrians, stroller pushers, and others to pass easily. Sidewalks should have cross slopes of 1/4 in/ft (2 percent). This slope allows water to drain off the surface, but is not steep enough to cause problems for wheelchair users.

Whenever you build a sidewalk, always review Americans with Disabilities Act (ADA) Accessibility Guidelines for design details. For example, when sidewalks are less than 5 ft (1.5 m) wide, a 5 ft-by-5 ft (1.5 m-by-1.5 m) area provides passing space for intervals less than 200 ft (60 m) apart. Also, where curbs are used with sidewalks, ADA requires ramps so wheelchair users can more easily cross streets. Detectable surfaces, surfaces with distinctly different textures, are required on ramps to alert visually impaired pedestrians to where the sidewalk ends and the intersection begins.
Another good reference is the FHWA’s Designing Sidewalks and Trails for Access, Part II: Best Practices Guide, which has more information on sidewalk and curb ramp design. Also check with your local jurisdiction regarding sidewalk maintenance laws.

**Road Surface**

A road surface management plan adds to your safety plan. Slippery pavements, often caused by polished aggregate or bleeding asphalt, play a part in wet weather crashes. If a high proportion of crash reports cite wet pavement, the problem could be drainage or slippery pavements. Poor drainage, in addition to weakening the pavement, can cause vehicles to hydroplane. Vehicles have less traction on rough roads, and potholes and bumps can damage safety-related equipment like suspensions and tires. If severe enough, rough roads can also cause loss-of-control crashes.

Loose dirt or gravel on the road surface can damage windshields or cause a vehicle to skid. Loose gravel can be loose aggregate from the road itself. You can reduce this on chip-sealed roads by using the right proportions and types of stone and emulsion and by brushing loose aggregate after the emulsion sets. Dirt and gravel can also be tracked onto the road from intersecting gravel roads or driveways. A paved apron on the first 10 ft (3.0 m) of an unpaved road or driveway can reduce tracking; also, a thick bed of gravel is a good way to clean tires at construction entrances.

**Curves**

Curves are often locations of safety problems, especially run-off-road crashes. The best way to treat problem curves is to install curve-warning signs, road delineators, chevron signs, pavement edgelines and centerlines, or some combination of the above. Realigning the road is an expensive option, so consider less-expensive options first.

Be alert for other problems on curves, such as:

- Sight distance problems caused by obstructions on the inside of the curve.
- Fixed objects, especially on the outside of the curve. (Do not neglect the inside of the curve. Run-off-road crashes to the inside are less common, but they happen.)
- Unexpected curves at the end of long straight sections.
- Curves that get tighter (increasing sharpness or decreasing radius).
- Curves hidden by hillcrests.

**Delineating Curves**

You can install traffic control devices to improve the safety of problem curves. The most common method is to provide advance warning with a curve sign. Other methods work by giving extra visual cues to drivers, such as post-mounted delineators, chevron or arrow signs, and pavement markings. These are especially helpful at night.

It is helpful to install delineators on curves when there is evidence that drivers are having difficulty staying in a lane. Look for skid marks or a history of repeated run-off-road or crossover (head-on and opposite direction sideswipe) crashes.

**Safety Widening for Curves**

Widening the roadway or adding shoulders gives a second chance to drivers who find themselves in trouble in the curve.
Widening the travel lanes gives drivers a margin of error and allows trucks to navigate the curve without having the back wheels cross the line into the other lane or the shoulder. A more cost-effective solution may be to simply widen the entire roadway. Table 11 shows that the width to be added is a function of the curve radius and the speed of traffic. The values in Table 11 are the width added to accommodate single-unit trucks on 20-ft (6-m) roadways. Widening is expensive and the safety benefits may be nominal if widening is less than 2 ft (0.6 m) on curves. Figure 22 shows pavement widening for horizontal curves.

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<th>Design Speed (mph)</th>
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</tr>
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</table>

Source: A Policy on Geometric Design of Highways and Streets (AASHTO, 2001)
Superelevation

By banking a curve so the inside of the curve is downhill, gravity will pull the vehicle toward the inside of the curve. Combined with its forward motion, this helps the vehicle navigate the curve.

The degree of banking on a curve depends on the curve’s radius and the design speed of the road. Higher speed roads need more banking. Tables have been developed to show the many possible combinations of radius and speed for superelevation rates. Check the AASHTO Green Book for more information about superelevation.

There is a practical limit in northern States because a steeply banked curve is hard to drive on during winter weather. In States with little snowfall, avoid banking curves in rural areas more than 12 percent and not more than 4 percent in low-speed urban areas. In States where snowfall is common, bank curves no more than 8 percent in rural areas.

What to Watch for When Superelevating Curves

Use transitions to change the cross slope from normal crown to a banked curve. Making this transition too abruptly will create bumps at the beginning and end of the curve. These bumps can be severe enough to startle the driver or potentially cause loss of control. The transition length can vary from 100 to 650 ft (30 to 200 m), depending on the speed, degree of banking, and the number of lanes to be banked. When only a short distance separates two curves in opposite directions, it can be difficult to provide enough transition length.

If you add banking to a curve with existing guardrail, you may need to change the guardrail height. Guardrail may not work properly if the rail section is too low or too high above the road. You may have to reset or replace the guardrail to use superelevation. Chapter 5 presents information about allowable guardrail heights.

Another problem with superelevation is the difference in slope between the travel lane and the shoulder. This is called the rollover rate. If rollover rate is more than 8 percent, it can send vehicles onto the shoulder and cause a crash. For example, if a curve is banked at 4 percent, reduce the cross slope of the shoulder on the high side to 4 percent or flatter.
**Realignment**

If less-expensive methods fail, you may have to realign the curve to improve safety. The design and construction will be costly because a professional engineer should design the new alignment and right-of-way takings will probably be involved. A cost-effectiveness study is definitely worthwhile before you start a realignment project.

**Vertical Curves**

Changes in grade are connected with vertical curves. Curves at the tops of hills are called *crest curves*, and curves in valleys are called *sag curves*. Crest curves occur where a steep climb becomes less steep, or a gentle downgrade becomes steeper. Sag curves occur where a steep downhill grade becomes less steep, or a gentle upgrade becomes steeper. A sharp crest vertical curve can block the driver’s ability to see other vehicles, objects in the roadway, intersections, and curves.

Cutting down a crest vertical curve usually requires full-depth reconstruction and may involve right-of-way takings because of roadside cuts. An alternative is to use signs to warn of road conditions on the far side of the crest. These include STOP AHEAD, INTERSECTION AHEAD, CURVE AHEAD, or HILL BLOCKS VIEW signs. Placing signs before the crest ensures drivers will see them in time to respond. Mount signs that cannot be moved, like STOP signs or curve warning chevrons, higher above the ground so they are visible over the top of the crest.

Sag vertical curves can cause problems at night if headlights do not shine high enough to illuminate the roadway ahead. This is not usually a major problem because the lights of other vehicles should make them visible. If sag vertical curves cause problems at night, installing overhead lighting can help.

**Pavement Edge Drop-Offs**

A drop-off at the pavement edge can cause a vehicle to leave the road. Figure 23 is an example of a pavement edge drop-off. The usual response to a pavement edge drop-off is for the driver to jerk the steering wheel to get the tires to climb back up the drop-off. The minimum steering angle required to climb up the edge of the pavement is too sharp once the vehicle returns to the roadway. This can send the vehicle into the path of oncoming traffic or off the left side of the road.

![Figure 23. Pavement edge drop-off.](image)
The chance a driver will lose control depends on the height and the shape of the drop-off. Vertical drop-offs are more likely to cause a driver to lose control than are sloped or rounded ones. Vertical drop-offs of more than 3 in (75 mm) are dangerous to motor vehicles. Lower shoulder drop-offs can cause bicyclists to fall toward the travel lane.

There are several ways to reduce the effects of pavement edge drop-offs. Install a paved or stabilized shoulder where traffic continually wears away gravel or grass shoulders. In curves, the back wheels of trucks will often wear down an unpaved shoulder to create a drop-off. Safety widening can prevent this. Building the pavement edge with a one-on-one slope reduces the steering angle needed to return the vehicle to the pavement.

Resurfacing operations can also create drop-offs. On the other hand, resurfacing is an opportunity to repair existing drop-offs. Soft or loose shoulders can cause a similar effect because of the sudden increase in traction when tires leave the shoulder and return to the pavement. Stabilizing or paving the shoulder can prevent this.

As an interim measure, install SOFT SHOULDER or LOW SHOULDER warning signs until you can repair the condition.

**Summary**

This chapter addressed the relationship between safety and roadway design. It is important to provide a roadway operating environment that motorists expect. Crashes occur when motorists do not expect or anticipate changes in the roadway environment (such as reduced width or tangent to curved alignments). Be sure there is enough stopping sight distance at all points along a roadway so motorists have time to see an object and come to a controlled stop before striking it. Wider lane and shoulder widths have better safety performance than narrow lanes and shoulders. Delineate and widen horizontal curves to improve safety performance. Furthermore, try to remove trees, brush, or rocks on the inside of curves that can block a driver’s view of the roadway. Crest vertical curves also limit visibility. When designing and constructing vertical curves, be sure there is enough sight distance for the driver to clearly see the roadway ahead. Finally, be aware that construction and maintenance operations can create pavement edge drop-offs. Use a stabilized shoulder or pavement widening to prevent these drop-offs.
Improving Roadside Safety

Single-vehicle, run-off-road crashes account for approximately 30 percent of highway fatalities. These fatalities result vehicles colliding with a fixed object (such as trees, utility poles, or unshielded bridge rail ends) or rolling down or off dangerous slopes.

Strategies to help reduce run-off-road crash problems include:

- Use methods such as signing, pavement markings, delineation and superelevated (banked) curves to help drivers stay on the road.
- Remove or relocate hazards to a place where they are less likely to be hit by vehicles leaving the roadway.
- Reduce crash severity by making roadside hardware crashworthy or traversable and shielding fixed-object hazards with guardrail.

This chapter discusses the latter two approaches. For information on delineation and banked curves, see chapter 3, Traffic Control Devices, and chapter 4, Roadways.

Will Guardrail Solve the Problem?

Guardrail is meant to protect traffic from hazardous objects or slopes. You could install it everywhere there is a potential hazard along the roadside, but that would be expensive. Or, you could install it at locations where run-off-road crashes have occurred, which means people may already have been hurt and you may already be facing a lawsuit. A compromise is needed, so the practical approach is to install guardrail only where it can significantly improve public safety and not waste public money.

Your first action should always be to remove hazards because guardrail itself can be a hazard to drivers. If hitting the guardrail would be worse than hitting the hazard, then the choice should be not to install guardrail. About 30 percent of crashes involving a guardrail result in injuries or fatalities, which is why you should install guardrails only when they pose a lesser risk for drivers than colliding with other roadside hazards. Remember that the guardrail will probably be hit more often because it will be closer to the road than the object it shields.

A primary factor in your deliberation should be cost-effectiveness. If the guardrail costs (installation, maintenance, and costs of crashes with the rail) are higher than the benefits (reduced crash severity), guardrail is probably not your best solution.

Also, once you install guardrail, you are responsible for maintaining it. If your agency cannot commit to regular guardrail inspection and prompt repair of damage from crashes or corrosion, then consider other remedies.

This chapter should help you decide whether guardrail will improve safety on your agency’s roads.

Clear Zones

The clear zone is the area along the roadside that is free of fixed objects or dangerous slopes. Fixed objects include utility and light poles, trees, or boulders. The ground should be relatively flat and gently graded. Rounded changes in slope will help a driver regain control of the vehicle and return to the roadway.

Once you build a clear zone, you’re committed to maintaining it—keeping it free from fixed objects or hazardous slopes. The desired clear zone width depends on the nature of the road and is based on factors like the amount of traffic on the road, the design speed, slope of the roadside, and how the road curves.
On new roads, provide the widest possible clear zone width. For more information on desired clear zone widths, see the AASHTO Roadside Design Guide or the AASHTO Guidelines for Geometric Design of Very Low-Volume Local Roads.\textsuperscript{(10,16)}

On curbed roads, locate obstructions such as utility poles or fire hydrants as far beyond the curb as practical. Curb won’t prevent a car from leaving the road. At medium to high speeds, a vehicle hitting the curb can cause a driver to lose control. Rather than keeping the vehicle away from the sidewalk, hitting the curb can actually turn a vehicle toward the sidewalk. Because curbing will not protect pedestrians, try to add a buffer area between the sidewalk and the curb more than 1.5 ft (0.5 m) beyond the curb where possible.

Traffic speeds are generally higher on rural roads, so try to include wider clear zones. The clear zone should be wider where the roadside slopes down and away from the edge of the road, and on the outside of curves. Don’t neglect the inside of curves. Vehicles do run off the road on the inside of curves, and fixed objects on the inside of curves can also restrict driver sight distance.

On rural local roads, try to include clear zones of 10 ft (3.0 m) from the lane edgeline. Consult the AASHTO Roadside Design Guide for recommended clear zones on collector and arterial roadways.

Right-of-way or terrain can make it difficult to achieve or maintain desired clear zone width on existing roads, but try to make improvements where and when they are needed. Focus your efforts on locations where run-off-road crashes occur. Agencies usually use 3 years of crash data, but 5 to 10 years of crash data will probably be needed before problem areas become apparent on low-volume roads.

After you treat the existing problem locations, concentrate on areas where crashes are likely to happen. These locations include curves, downhill sections, and places where the road character changes, such as when a roadway narrows at a bridge.

### Types of Run-Off-Road Hazards

The three types of run-off-road hazards are roadside objects, roadside hazards, and slopes.

**Roadside objects** include fixed objects that could punch through the vehicle into the passenger compartment. Fixed objects are relatively unyielding obstacles such as utility poles, trees and boulders. Other common fixed objects include:

- Culvert headwalls and bridge walls or railings.
- Large mailboxes or multiple single mailboxes placed close together.
- Trees 4 in (100 mm) or more in diameter or smaller trees less than 7 ft (2.1 m) apart.
- Cross culverts 3 ft (0.9 m) or more across.
- Parallel culverts (driveway or crossroad pipes) 2 ft (0.6 m) or more wide.
- Other objects more than 4 in (100 mm) high.

Groups of mailboxes mounted on a flat board are hazards because the board is at the same height as most vehicle windshields. When hit, the mailbox can break free from the support posts and crash through the vehicle windows at about head height, causing severe, often fatal injuries.

**Roadside hazards** such as rock cuts and guardrail can extend along the road for a distance.

**Slopes** are hazardous when they can cause a vehicle to roll over or launch it into the air. Side slopes such as ditch slopes or embankment slopes run parallel to the road. Transverse slopes slant at an angle to the road and include creek beds and embankments for other roads, driveways, and railroads.

The three categories of side slopes indicate how steep they are:
- **Recoverable** slopes are flatter than 4:1 (horizontal:vertical). A driver has a good chance to regain vehicle control and return to the roadway.
- Nonrecoverable slopes are between 4:1 and 3:1. A vehicle on a nonrecoverable slope will probably stay upright, but the slope is too steep to allow return to the roadway and the vehicle will end up at the bottom of the slope.
- Critical slopes are steeper than 3:1. When possible, avoid or shield them because they dramatically increase the chances of a severe rollover crash.

Except for new construction or full reconstruction of a road, you can retain 2:1 slopes less than 5 ft (1.5 m) high without guardrail. But then not much fill material is needed to flatten a low, steep slope to 3:1 when right-of-way or adjacent landowners allow.

Transverse or cross slopes are often found where side roads, driveways, and drainage channels cross the highway. On high-speed roads, these slopes should be gentle, 10:1 or flatter, so they don’t ramp a vehicle leaving the roadway into the air.

Treatment of Roadside Hazards

Ask yourself the following questions as you consider what to do with a hazard that reduces the available clear zone distance:
- Is the potential hazard dangerous?
- Can you remove the hazard?
- Can you relocate it to a place where it is less likely to be hit?
- Can you reduce crash severity if the hazard is hit?
- If you can’t remove, relocate, or modify the hazard, will adding guardrail make the road safer?
- Would delineation help guide drivers around the hazard?

Is the Potential Hazard Dangerous?

When you know something on the roadside is a hazard, do something about it. To decide how dangerous the hazard is to drivers, ask yourself:
- Is there a fixed object in the clear zone?
- Is there an object in the clear zone that could punch into the passenger compartment when struck?
- Is there a critical slope near the road?
- Is there a fixed object at or near the bottom of a nonrecoverable slope?

Look at the clear zone for that stretch of road. If the obstacle or slope in question is closer to traffic than everything else nearby, then fixing it may improve the safety of the road. On the other hand, removing one tree from a 3,000-ft (0.9-km) long woodlot won’t make much of a difference.

Can You Remove the Hazard?

Your best option is to eliminate the hazard. For example, a vehicle running off the roadway can pass safely over a tree stump cut flush with the ground.

Can You Relocate It to a Place Where It is Less Likely to be Hit?

Moving an object farther from the road or from the outside of a curve to the inside can reduce the chances that the hazard will be hit. You can extend cross culverts to move the culvert end out of the clear zone, and move utility poles farther from traffic.1)
Can You Reduce Crash Severity?

If you can’t remove or relocate the hazard, then try to reduce the severity of a crash. There are three main ways to do this:

- Install signposts, light and utility poles on breakaway bases to reduce collision forces. Breakaway hardware is designed to separate in a controlled way when hit, allowing the vehicle is able to pass under or over it.

- Upgrade drainage features so that vehicles leaving the roadway can drive over them. For example, placing grates over culvert ends allows a vehicle to drive over the opening rather than fall into it (this also improves safety for your mower operators). Figure 24 shows a typical culvert end section that allows vehicles to safely pass over the opening. Flattening ditch foreslopes and backslopes makes them safer for a vehicle leaving the roadway.

- Use crash cushions and impact attenuators to soften the collision with hard objects. The problem is their high installation and maintenance costs, so they’re rarely used on local roads.

Extending culverts can reduce the amount of water they can carry, so be sure you aren’t exchanging one problem for another. If the new pipe will be 50 ft (15 m) or longer, get expert engineering advice.

The bars on this cross-culvert end section allow vehicles to drive over the culvert rather than fall into it.

Will Guardrail Improve Road Safety?

Remember that striking guardrail can cause injuries, so install it only where crashing into the hazard would be worse than striking the guardrail.

If a potential hazard is located in the clear zone and you can’t reasonably remove, relocate, or modify it to be crashworthy, then consider installing guardrail. For a fatal-at-any-speed hazard (body of water, large propane tank), it is reasonable to assume that an errant vehicle could reach it, provide a strong barrier system to shield it such as strong-post W-beam guardrail or box beam.

Would Delineation Guide Drivers Around the Hazard?

Signs, pavement markings, rumble strips, and post-mounted delineators are a good way to define the edge of the road or mark hazardous conditions. Delineation helps guide careful drivers around obstacles, although it does not help drivers who lose control of their vehicles. Examples of delineation include chevrons on curves and object markers at narrow bridges.
If you can’t remove, relocate, modify, or shield a hazard with guardrail, then install signs and delineation to warn drivers that they need to be alert for the hazard. Installing these devices is especially helpful where crash records show frequent nighttime run-off-road crashes.

Delineation can also be used to make guardrail more visible to drivers. This is especially helpful when brown rustic rail is used.

Delineation can be a low-cost temporary solution when installing guardrail is necessary but will be delayed by limited budget, time, or personnel. Just make sure the temporary measure doesn’t become permanent when guardrail is truly needed.

**Is the Solution Feasible and Cost-Effective?**

This is probably the hardest question. At what point is the cost of an improvement more than the crash cost savings you can expect from it. Because guardrail needs a clear deflection zone behind it, it may be impossible to install guardrail without narrowing the road. On low-volume roads, the deflection distance of some guardrail systems may exceed the available clear zone width.

**Guardrail**

Once you decide that guardrail can solve your safety problem, the next step is to select the appropriate type and then design it. There are several types of guardrail and it is important to understand the advantages and disadvantages of each type so you choose the one that best meets your needs. Have a professional engineer design safety hardware like guardrail.

Researchers test roadside hardware to make sure it is safe and effective. National Cooperative Highway Research Program (NCHRP) Report 350 presents roadside hardware test criteria. Research tests used a 4,400-lb (2,000-kg) pickup truck to test the strength of the system and a 1,800-lb (820-kg) passenger car to make sure the system won’t cause unacceptable injuries. NCHRP Report 350-compliant hardware is required on National Highway System roads, and is a good idea elsewhere. A list of compliant hardware is available online at [http://safety.fhwa.dot.gov/report350hardware].

The following represent different applications of guardrail to common highway safety problems.

**Slopes**

A vehicle going off the top of an embankment can often become airborne. Guardrail is not effective when installed on any slope steeper than 6:1. You can use cable guardrail at any offset on slopes as steep as 6:1. When guardrail other than cable is to be installed on a 6:1 slope, it must be installed at least 12 ft (3.6 m) beyond the breakpoint (where the slope gets steeper). Vehicles may go over metal beam installed less than 12 ft (3.6 m) beyond the breakpoint.

**Guardrail and Curb**

When a vehicle hits a curb, it will usually bounce upward. Even at moderate speeds, the bounce can be high enough to vault the vehicle over the guardrail. If possible, don’t use curb with guardrail. Figure 25 illustrates a vehicle colliding with a curb. Because the guardrail is located behind the curb, the vehicle can bounce high enough to vault the barrier.

*If you need to use guardrail behind a curb, consult the AASHTO Roadside Design Guide for placement guidelines.*
The car in figure 25 vaulted the guardrail because it struck the curb first, thus the car was airborne before reaching the guardrail.

Figure 25. Car vaulting over guardrail after hitting a curb.

**Deflection Distance**

Guardrail is generally classified as flexible, semirigid, or rigid. Class is based on the deflection distance of the rail. Deflection distance is how much the rail can be expected to bend under impact (see table 12).

Table 12. Guardrail deflection distance.\(^{(10)}\)

<table>
<thead>
<tr>
<th>Rail class</th>
<th>Rail type</th>
<th>Post spacing, ft (m)</th>
<th>Deflection distance, ft (mm)</th>
<th>Test conditions</th>
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<tbody>
<tr>
<td>Flexible</td>
<td>Cable</td>
<td>6.5 (2.0)</td>
<td>6.8 (2.1)</td>
<td>4,400-lb pickup truck traveling at 60 mph; 25-degree impact angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0 (3.0)</td>
<td>7.8 (2.4)</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>16.0 (5.0)</td>
<td>9.2 (2.8)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>16.0 (5.0)</td>
<td>11.5 (3.5)</td>
<td>4,500-lb passenger car traveling at 60 mph; 25-degree impact angle</td>
</tr>
<tr>
<td></td>
<td>W-beam (weak post)</td>
<td>12.0 (3.6)</td>
<td>6.5 (2.0)</td>
<td>4,400-lb pickup truck traveling at 45 mph; 25-degree impact angle</td>
</tr>
<tr>
<td></td>
<td>Modified W-beam</td>
<td>12.0 (3.6)</td>
<td>7.0 (2.1)</td>
<td>Same as weak-post W-beam with 60 mph impact speed</td>
</tr>
<tr>
<td></td>
<td>(weak post)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semirigid</td>
<td>Box Beam</td>
<td>6.0 (1.8)</td>
<td>5.5 (1.7)</td>
<td>4,400-lb pickup truck traveling at 60 mph; 25-degree impact angle</td>
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<tr>
<td></td>
<td>Blocked-out W-beam</td>
<td>6.3 (1.9)</td>
<td>2.9 (0.9)</td>
<td>4,400-lb pickup truck traveling at 60 mph; 25-degree impact angle</td>
</tr>
<tr>
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<td>(strong post)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blocked-out Thrie-beam</td>
<td>6.3 (1.9)</td>
<td>1.9 (0.6)</td>
<td>4,400-lb pickup truck traveling at 60 mph; 25-degree impact angle</td>
</tr>
<tr>
<td></td>
<td>(strong post)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modified Thrie-beam</td>
<td>6.3 (1.9)</td>
<td>2.0 (0.6)</td>
<td>4,400-lb pickup truck traveling at 60 mph; 25-degree impact angle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.3 (1.9)</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>3.0 (0.9)</td>
<td>20,000-lb school bus traveling at 56 mph; 15-degree impact angle</td>
</tr>
</tbody>
</table>
Flexible Systems

Flexible guardrail systems include cable guardrail and weak-post corrugated (W-beam) guardrail. These systems tend to be forgiving when hit because they deflect considerably under the impact, which reduces the collision forces on vehicle occupants. But the systems have limitations.

**Cable guardrail** is the least expensive, but it requires maintenance because it loses effectiveness when cable tension is not maintained. After it is hit by a motor vehicle, snowplow, or agricultural equipment, the whole length of the rail is ineffective until crews repair it. Therefore, you shouldn’t consider cable guardrail unless the agency commits to maintaining and repairing it, especially on high-speed or high-volume roads. Of course, the cables are not usually damaged by the crash, and you’ll often need to replace only the posts and tension springs.

Cable guardrail deflects up to 11.5 ft (3.5 m) in a collision. Because it is a relatively soft system, vehicle occupants are less likely to be injured. On the other hand, this deflection requires the same clear area behind the rail. On low-volume roads, if you have enough deflection distance for cable guardrail, you may not need guardrail. Figure 27 is an illustration of cable guardrail used in the median on a divided, multi-lane highway.

---

*The guardrail system shown in figure 26 will deflect up to 6.5 ft (2.0 m) when struck by a vehicle. The design as shown will not prevent a vehicle from colliding with the trees.*
Weak-post W-beam guardrail is also inexpensive, but costs more than cable. Collision damage tends to be more localized than a similar impact with cable guardrail. At speeds over 45 mph (71 km/h), light trucks (pickups and SUVs) tend to go over or through it. A modification to the standard weak-post system redirects vehicles at impact. The rail mounting height is higher and can successfully redirect pickup trucks traveling at 60 mph (88 km/h) at a 25-degree impact angle. The modified system contains backup plates at each post and rail splices centered at the midspan between posts rather than at the post location.

W-beam guardrail can also act as a snow fence and may cause significant snow drifting on the road. Figure 26 shows an example of weak-post W-beam guardrail.

**Semirigid Systems**

Semirigid systems include box beam and strong-post W-beam guardrail. They deflect less than flexible systems. This means they are more likely to cause an injury in a crash, but they can be used when the hazard is closer to the road. Semirigid guardrail can also be set back from the road, which reduces the chances of crashes. They are also more durable, and often remain serviceable after minor impacts.

Box beam guardrail is a 6-in (150-mm) square steel tube mounted on light posts. It gets its rigidity from the stiffness of this tube. The tube acts as a beam, spreading the impact force over several posts. The box beam guardrail must be long enough to function properly.

Because of the stiffness of the rail, it cannot be curved in the field. Curved rail sections can be manufactured, but this increases initial cost, repair cost, and repair time.

Box beam is one of the most expensive of the commonly used rails. Only concrete barriers and aesthetic rails are more expensive.

Blocked-out strong-post W-beam guardrail uses the same rail section as the weak-post system, but blocks are mounted on heavier posts. Blocks hold the rail away from the post because the posts are rigid enough that vehicles can snag on them. This could cause high collision forces or roll the vehicle over, which increases the chance of injury. Always use blocks with heavy posts. Use plastic or wood blocks because recent testing has shown that the thinner web sections of traditional steel blocks tend to collapse under impact and allow the vehicle to snag on the post.

Strong-post W-beam guardrail with blocked-out posts can often survive multiple moderate- to low-speed crashes before losing effectiveness. Its rigidity increases risk to vehicle occupants, but reduced safety may be offset by its durability. Strong-post W-beam guardrail is more expensive than flexible systems. Figure 28 shows an example of strong-post W-beam guardrail.

In figure 28, the strong-post W-beam guardrail is used to prevent errant vehicles leaving the roadway to the right from colliding with the light pole in the roadside.

Figure 28. Strong-post W-beam guardrail.
**Thrie-beam guardrail** is a stronger version of the W-beam blocked-out guardrail. It contains one more corrugation in the rail element and can more effectively withstand moderate- and low-speed impacts. The rail is also mounted higher on the Thrie beam, which increases its ability to redirect large vehicles. Standard systems with wood or plastic posts and block-outs have been successfully crash tested using pickup trucks. A modified Thrie-beam with steel posts and block-outs has been developed. The rail height is higher than that on the standard Thrie beam and it has been successfully crash tested using pickup trucks, single-unit trucks, and school buses.

**Rigid systems** are concrete barriers (see figure 29). Their expense usually rules out their use on local roads, so they are not discussed here.

![Figure 29. Concrete barrier.](image)

**Barrier Length**

Guardrail has to be long enough to protect traffic from the hazard it shields. The basic rules are simple, but curves, hills, and other common features can quickly complicate a design. For this reason, have a professional engineer design rail installations. But there are some general rules to follow.

Avoid short gaps. For instance, if another run of guardrail starts less than 200 ft (60 m) away, consider combining the two rails into one longer rail. On two-way roads, the trailing end of the guardrail run must be long enough to protect traffic going off the left side of the road.

For bodies of water, large stands of trees, or steep embankments that aren’t easily bypassed, the rail should be long enough so that when a vehicle gets behind it will be able to come to a safe stop before reaching the hazard.

**Terminals**

Guardrail terminals have two main functions. First, they anchor the ends of the rail to resist the tension in the rail when struck. Second, they must be crashworthy. Several modern terminals used on high-speed roads are designed to absorb the impact and bring the vehicle to a controlled stop.

Many early terminal designs were severe hazards. If hit end-on, they would often puncture the vehicle and crash into the passenger compartment, with severe results. The early terminals also did not anchor the rail very well, so the rail could not withstand side impacts nearly as well as a properly anchored rail. The common practice of burying the end of the rail without an anchor reduces the problem of potential impaling, but it can launch an errant vehicle into the hazard or into a severe roll.

The best way to end a guardrail is to anchor it in a backslope, although this can be difficult when the guardrail must cross a ditch to get to it. Make certain the height from the bottom of the ditch to the rail
does not exceed the limits shown in table 12. Vehicles that run into ditches tend to follow the ditch and the
ditch will guide the vehicle into the guardrail. If the rail is too high, it may hit the windshield instead of the
bumper. Providing a rub rail can eliminate this problem.

**Transitions**

Be very careful when making transitions from one type of guardrail to another or from guardrail to bridge
rail. Avoid sudden changes in stiffness or lack of continuity. See the AASHTO *Roadside Design Guide* for
standard transition designs that gradually stiffen the rail and add additional posts.

**Prioritizing Roadside Improvements**

To use funds and personnel efficiently, prioritize your roadside improvements based on the likelihood of a
crash and the severity of a crash, should one occur. Several factors affect the probability of a crash:

- Crash history.
- Prevailing speed along the road.
- Traffic volume on the road.
- Location of the hazard.

Recurring run-off-road crashes at a location is a good indicator there will be more. On higher volume
roads, crash records will show where crashes already occur. Recall that crash records are not as useful
on lower volume roads because crashes do not occur as often, and it may take many years of data to see
a pattern. However, you will see the physical evidence of unreported crashes such as scars on trees or
damaged guardrail. A higher-than-expected pattern of similar crashes at the one location is called a *cluster*.
Finding and correcting the cause of the cluster can improve safety.

Give higher speed roads a higher priority. Crashes tend to happen more frequently on higher speed
roads because drivers have less time to react and avoid a crash at high speeds than at lower speeds.
Vehicles leaving the roadway will travel farther before coming to a stop, so a fixed object at a given dis-
tance from the road is more likely to be hit on a high-speed road than on a low-speed road.

Crash severity increases sharply with speed, therefore, the severity of crashes depends on the speed
at impact and the nature of the object struck. Give severe hazards a higher priority than less severe ones
because high-speed crashes are much more likely to be fatal than those at lower speeds.

The location of the hazard is important because objects closer to the road are the ones likely to be hit.
Also, improve places where run-off-road crashes tend to happen. This includes areas on the outside of
curves and on downgrades.

As noted, some hazards can be fatal at any speed. These include propane tanks and other hazardous
materials storage; cliffs and high, steep embankments; and bodies of water deeper than 1 ft (0.3 m) (if the
vehicle lands on its roof, the water need not be very deep to drown an incapacitated crash victim).

Other objects can be fatal at low speeds. These include spearing hazards like *boxing glove* or *dovetail*
guardrail ends that can go through the windshield and cause fatal head injuries. Another hazard that
penetrates the windshield is the flat board on mounted posts that hold multiple mailboxes.

Collisions with massive fixed objects are often fatal, and unfortunately, most run-off-road fatalities
are in this category. Examples include overpass abutments and concrete or masonry walls, trees with a
diameter of more than 4 in (100 mm), and embankments more than a few feet high and steeper than 3:1.
Maintenance

Good maintenance is as crucial to safety as good roadside design. Likewise, a roadside barrier will not function if it is badly corroded or damaged by crashes. Roadside safety improvements must be maintained to provide a safe driving environment. This section presents some tips for maintaining roadsides.

Roadside Maintenance

Maintain roadside clear zones to prevent tree growth. Mow clear zones at least once a year unless more is needed to ensure drainage or sight distance. Also, mow the areas behind guardrails to prevent trees from growing in the deflection zone (see table 12).

Pay close attention when cleaning ditches so you do not make the ditch deeper than it needs to be. Also, keep foreslopes and backslopes as gentle as possible. Rounded changes in slope help keep vehicles from becoming airborne or unstable and make it easier for the driver to regain control.

Be aware of what landowners adjacent to the roadway are doing. Dangerous mailboxes, landscape boulders, driveway pillars, or planters can pose serious hazards to the driving public. You have several courses of action available to you. If these objects are in the right-of-way, the jurisdiction can force the landowner to remove them, or the jurisdiction can remove them and bill the landowner. If the hazards are outside the right-of-way, consult with your municipal attorney before acting.

Guardrail Maintenance

Damaged guardrail may not function as designed. In addition to crash damage, corrosion of steel posts and rails and rot in wood posts can reduce the strength of the system.

Conduct periodic guardrail condition inventories to catch guardrail problems before they get out of hand. Supplement periodic inventories with regular patrols looking for problems in general. Look for:

- Crash damage.
- Insufficient deflection distance (see table 12).
- Rail set too high or too low (see table 13).
• Rail too short
  - Fails to protect traffic from the hazard.
• Gaps or breaks.
• Poor transition from one rail type to another (sudden increase in stiffness).
• Rail behind curbs.
• Obsolete and nonstandard rail types, such as:
  - Cobbled-up, nonstandard rail.
  - Rail mounted on concrete posts.
  - External-splice box beam.
• Obsolete or no end sections.
• Rail and post condition.
  - Rust.
  - Rot in wooden posts.
  - Loose or missing bolts.
  - Cable tension.
  - Loss of support behind posts caused by erosion.

### Table 13. Acceptable guardrail heights.\(^1\)

<table>
<thead>
<tr>
<th>Barrier type</th>
<th>Normal Mounting Height, in (mm)(^1)</th>
<th>Acceptable Mounting Height, in (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable(^2)</td>
<td>30 (760)</td>
<td>27 (690)</td>
</tr>
<tr>
<td>Weak-post W-beam(^3)</td>
<td>30 (766)</td>
<td>32 (820)</td>
</tr>
<tr>
<td>Modified weak-post W-beam(^3)</td>
<td>32 (820)</td>
<td>N/A</td>
</tr>
<tr>
<td>Strong-post W-beam(^3)</td>
<td>27 (685)</td>
<td>28 (706)</td>
</tr>
<tr>
<td>Box beam(^3)</td>
<td>27 (690)</td>
<td>N/A</td>
</tr>
<tr>
<td>Strong-post Thrie-beam(^4)</td>
<td>32 (815)</td>
<td>34 (865)</td>
</tr>
<tr>
<td>Modified Thrie-beam(^4)</td>
<td>34 (865)</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete (NJ shape)(^4)</td>
<td>32 (810)</td>
<td>N/A</td>
</tr>
<tr>
<td>Tall Concrete (NJ shape)(^4)</td>
<td>42 (1070)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Notes:
\(^1\) Height normally measured from the ground directly below the barrier.
\(^2\) Measured to the center of the top cable at the mounting point.
\(^3\) Measured to the top of rail at a post.
\(^4\) Measured to the top of the barrier.

When repairing guardrail, keep in mind the questions for treating roadside hazards. If you can remove the need for the rail and the rail itself, you can make the road safer and there will be one less guardrail to maintain. When you remove a guardrail, it’s wise to get a written agreement from a professional engineer to help protect you against any future lawsuits.
An advantage of using standard guardrail types is that parts will be available for a long time, which makes repairs easier. You can also avoid a situation where you may be forced to upgrade it to current standards. Remove and reset too high or too low rail to the proper height, assuming it is otherwise in good condition.

Ditches

A road in poor condition is itself a safety problem, but good drainage is essential to road safety because without proper drainage, a road will quickly deteriorate.

In rural areas, ditches are often used to carry water away from the roadbed. When ditch slopes become too steep, ditches become safety problems. To be effective, ditches should be deep enough to handle the water that flows through them. Sometimes, this conflicts with safety. The foreslope can be too steep and cause a rollover crash. If the vehicle stays upright, the collision with the backslope could be severe enough to cause injuries. If the front bumper digs into the backslope, a vehicle may be spun around violently.

![Figure 31. Ditch types.](image)

Figure 31 shows various roadside ditches. U-shaped ditches (upper left) are hydraulically efficient, but be sure they meet AASHTO guidelines because they can be a safety hazard if not properly designed. Trapezoidal or flat-bottomed ditches (lower left) can be effective and safe. The flat bottom reduces the chance of a crash with the back slope and the ditches are hydraulically efficient. V-ditches (upper right) are easy to construct, but hard to maintain. They are prone to erosion, which causes silt problems downstream and makes the ditch deeper and therefore less safe for vehicles that enter it.

When it is not possible to build a ditch with gentle foreslopes and backslopes within the right-of-way, use a filled ditch with an underdrain. A filled ditch (figure 31, lower right) also provides room for a shoulder where one is needed but no right-of-way is available.

Figure 32 shows preferred cross sections for ditches. Recommended ditches are the shaded area.
Bridges

Bridges are structures that span other roadways, other modes of transportation, waterways, or low-lying areas. They are typically supported by piers and abutments, which create fixed-object hazards on roadways located under bridges. Bridges that are narrower than the approach roadway, including the shoulders, can adversely affect safety. In addition, bridge rail ends are a fixed-object hazard situated close to the travel way.

Try to keep bridge piers and abutments as far away from the roadway as possible. On divided highways with wide medians, the preferred design is for two-span structures with the supports located in the median. Single-span structures are preferred on roadways with narrow medians. Proper roadside barrier systems...
are required when bridge piers and abutments cannot be located beyond the recommended clear zone area. It is important to locate the roadside barrier far enough from the pier or abutment so that when hit, the vehicle does not collide with the structure itself. Use a semirigid barrier system to shield bridge piers located more than 5.5 ft (1.7 m) from the edge of the shoulder. When closer than 5.5 ft (1.7 m) to the shoulder edge, install a stiffer semirigid system or rigid barrier to reduce deflection distance. Recall that you can narrow the post spacing to stiffen semirigid systems. Barrier systems protecting motorists from bridge piers and abutments require an appropriate end terminal.

Bridge rails and parapets are also rigid elements of a bridge structure and collisions with these features can be severe. When crashes with bridge rail or parapets occur, the safety features should redirect the vehicle back onto the bridge. On older structures, curbed sidewalk areas are typically 1.5 to 2 ft (0.5 to 0.6 m) wide. Remember that curbed sidewalks can vault a vehicle. Install a strong-post W-beam or Thrie-beam guardrail flush with the curbed sidewalk to prevent vehicle ramping. A transition is needed when semirigid barriers join a bridge rail. The transition design should be gradual by narrowing the post spacing to prevent vehicle penetration or snagging.

Bridge width should be the same as the roadway width, including the usable shoulders. Position bridge rail at least 2 ft (0.6 m) from the outside edge of the shoulder. When the bridge width is narrower than the approach roadway, use object markers as a transition to signify the narrow bridge. The MUTCD defines a narrow bridge as one with a two-way width between 16 and 18 ft (4.9 and 5.5 m) or a width less than the approach roadway width.

The following are safety enhancements at or approaching bridges:

- Base appropriate signs and markings on the MUTCD.
- Install delineation on roadway approach and bridge.
- Illuminate roadway approach and bridge.
- Install crashworthy transition guardrail.
- Remove fixed objects from roadway approaches.
- Ensure adequate sight distance on roadway approaches.
- Improve cross slopes on bridge to provide adequate drainage.

Summary

This chapter examines safety features along the roadside. Approximately 30 percent of all highway-related fatalities result from single-vehicle run-off-road collisions with a fixed object. Roadside barriers are one alternative to prevent this, but use only when the result of a vehicle striking the barrier is less severe than colliding with the object the barrier is designed to shield. A good way to prevent run-off-road crashes is to provide an adequate clear zone free of fixed objects and other hazards.

Place metal beam guardrail at the top of the embankment slope or at least 12 ft (3.6 m) beyond the change in slope on slopes no steeper than 6:1. When used with a curb, install guardrail flush with or in front of the curb face. Roadside barriers are categorized as flexible, semirigid, or rigid systems. The use of each depends on its ability to contain or redirect vehicles that crash into it. Additionally, you must know the deflection distance of the barrier so that it is properly applied. Roadside barriers must have adequate length to shield motorists from roadside hazards, and each barrier system must have an appropriate end terminal.

As you prioritize roadside safety improvements, always consider the crash history, vehicle operating speeds, traffic volumes, and location of the hazard. Maintenance is a key factor deciding whether to install a roadside barrier. Flexible and semirigid barriers can lose their effectiveness when they are struck. Rigid barriers typically do not lose their effectiveness, but they can be damaged when struck. Conduct periodic roadside inspections to identify and subsequently replace damaged barriers.
Ditches and bridges are other roadside hazards that require attention. The slope of ditches can be a safety hazard. Bridge piers and abutments in the clear zone are also rigid fixed objects; shield them with roadside hardware. Old bridge structures typically were constructed with safety sidewalks that when struck can cause vehicle ramping. You can improve this condition by using guardrail or roadside barriers. Guardrail that joins a rigid bridge rail should be adequately transitioned to prevent vehicle snagging or penetrations. It should also be long enough to prevent errant vehicles from getting behind the rail and into hazard. Bridges should be equal in width to the approach roadway. If not, install appropriate transition and object markers to clearly alert the motorist of the reduced width.
Conflicting traffic flows are inherent problems at intersections, driveways, and railroad crossings. We know this because intersections are the second most common place for fatal crashes—after single vehicle roadside crashes. The severity of crashes at railroad crossings proves the importance of grade crossing safety.

**Intersections**

Intersections are safety trouble spots because they are where vehicle paths cross. Too often, a poor intersection design contributes to safety problems. These problems may not show up at low traffic volumes. If your area is developing, you may start having problems at intersections that were once relatively safe.

Intersections can be classified by the number of roads coming together. There are three-leg or T-intersections, four-leg intersections, and multileg (five or more roads) intersections. Figure 33 shows various intersection types.

Channelized-Y, skewed, and multileg intersections are the most likely to have safety or operational problems.

Three-leg or T-intersections can be safer than four-way intersections because there are fewer conflict points for crashes to happen. To help you consider the potential for safety problems at intersections,
consider that a conventional four-leg intersection has 32 conflict points. A three-leg intersection has only 9 conflict points. Figure 34 shows the conflict points for a four-leg intersection. If you’re building a new road across from a three-leg intersection, locate it at least 300 ft (90 m) from the existing intersection. If that’s not possible, build it directly across from the existing intersection, and change it into a four-leg intersection.

An intersection is *offset* when opposite approaches to it do not line up. Figure 35 shows an offset intersection. Depending on the direction of the offset, this can create safety problems or disrupt traffic flow. For traffic control purposes, consider intersections fewer than 30 ft (9 m) apart to be one intersection.

Intersections with five or more legs often create problems because they make it hard for drivers to watch five or more conflicting traffic flows at the same time. You can sometimes relocate one of the legs and turn a five-leg intersection into a four-leg intersection with a nearby $T$-intersection. This may be a cost-effective solution if there are safety or delay problems.

**Intersecting roads meeting at an angle other than 90 degrees are called skewed intersections, and they can cause problems. First, drivers must look over their shoulders to see approaching traffic. This can be**
difficult for older and disabled drivers and makes it more difficult for all drivers to judge speeds and distances. Figure 36 is an example of the skewed intersection. Second, it increases the distance across the intersection and the time it takes for cross-traffic to clear the intersection.

To avoid these problems, build intersections so the corner angle is between 75 and 105 degrees. Merging traffic flows are an exception; they should meet at 1 to 3 degrees. The idea is for drivers to be able to see conflicting traffic through a front side window or in the mirrors. Intersection angles between 3 and 75 degrees do not permit this. This is also a problem with many channelized right turn lanes. An alternative is to rebuild existing intersections to reduce the skew to less than 75 degrees.

Many older three-leg intersections have a triangular island in the middle. These are called channelized-Y intersections and they often have high crash rates. The angles are part of the problem, as a channelized-Y intersection is essentially three skewed intersections. Again, it is difficult for drivers to turn and see conflicting traffic. Road agencies often rebuild channelized-Y intersections as T-intersections or roundabouts within the existing right-of-way.

Right-turn roadways are added to increase the traffic capacity of an intersection. This is not the same as a channelized Y. If properly designed, turn roadways can add capacity and work safely. Like any other intersection, the skew angle should be less than 60 degrees.

Corner radius is a good example of a balancing act in roadway design. A larger radius can reduce rear-end collisions with right-turning vehicles because it allows the turning vehicle to get out of the way of following vehicles more quickly. On the other hand, wide-open intersections with very large corner radii create problems. Large corner radii increase the distance pedestrians must cross, which increases their exposure to traffic. It is also difficult to place STOP signs where they can be seen, and the intersection layout does not guide drivers to where they should go.

In general, the radius should be large enough for the most common type of heavy vehicle that uses the intersection. Thirty feet is usually enough for school buses and single-unit trucks. Tractor-trailers need more. In rural areas, more room can be beneficial. In areas where pedestrians are common, use larger radii only where needed to accommodate large trucks.
Intersection Sight Distance

As a driver approaches an intersection, several different types of sight distance come into play:

- Stopping sight distance to the intersection.
- Approach sight triangle to the intersecting road.
- Intersection sight distance.

On through-roads approaching intersections, drivers need to see far enough ahead so they can stop safely if a vehicle on the side road makes an unsafe move. This is stopping sight distance, which chapter 4 discusses.

The sight triangle affects the traffic control used at the intersection. If traffic on the side road can see traffic on the main road from far enough away, consider using YIELD signs instead of STOP signs. The AASHTO Green Book covers how to choose between STOP and YIELD signs.

Drivers stopped at an intersection must be able to see far enough to tell if there is a large enough gap in traffic for them to pull into the intersection safely. This is called intersection sight distance. The distance needed depends on the type of intersection control and the maneuver being made.

- **Two-way stop control:** Use tables 14, 15, and 16. Table 14 shows the intersection sight distance required for a vehicle stopped on a minor approach to turn left and accelerate without interfering with major road traffic operations. Table 15 shows intersection sight distance required for a vehicle stopped on a minor road approach to turn right onto or cross a major road.
- **All-way stop control:** A driver on one intersection leg must be able to see the first stopped vehicles on the other legs of the intersection.
- **Traffic control signals:** At signalized intersections, drivers must be able to see the first stopped vehicles on other legs of the intersection. If a traffic signal is placed on two-way operation (flashing yellow on major road approaches and flashing red on minor road approaches), use tables 14 and 15. Where right turns are permitted during a red phase, use table 15.

### Table 14. Intersection sight distance for left turns from stop condition on minor road.\(^{(3)}\)

<table>
<thead>
<tr>
<th>Design Speed on Major Road (mph)</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Car</td>
<td>170</td>
<td>225</td>
<td>280</td>
<td>335</td>
<td>390</td>
<td>445</td>
<td>500</td>
<td>555</td>
<td>610</td>
<td>665</td>
<td>720</td>
<td>775</td>
<td>830</td>
<td>885</td>
</tr>
<tr>
<td>Single-unit Truck</td>
<td>210</td>
<td>280</td>
<td>350</td>
<td>420</td>
<td>490</td>
<td>560</td>
<td>630</td>
<td>700</td>
<td>770</td>
<td>840</td>
<td>910</td>
<td>980</td>
<td>1050</td>
<td>1120</td>
</tr>
<tr>
<td>Tractor-trailer</td>
<td>255</td>
<td>340</td>
<td>425</td>
<td>510</td>
<td>595</td>
<td>680</td>
<td>765</td>
<td>850</td>
<td>930</td>
<td>1015</td>
<td>1100</td>
<td>1185</td>
<td>1270</td>
<td>1355</td>
</tr>
</tbody>
</table>

All values in table 14 were computed for a stopped vehicle to turn left onto a two-lane highway with no median and grades less than 3 percent. Refer to the AASHTO Green Book for grade and multi-lane highway adjustment factors.
Table 15. Intersection sight distance for right turn and crossing maneuvers on minor road.\(^{(3)}\)

<table>
<thead>
<tr>
<th>Design Vehicle</th>
<th>Intersection Sight Distance for Right Turns and Crossing Maneuver from Stop Condition on Minor Road (feet)</th>
<th>Design Speed on Major Road (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>145 195 240 290 335 385 430 480 530 575 625 670 720 765</td>
<td>190</td>
</tr>
<tr>
<td>Single-unit Truck</td>
<td>235 310 390 465 545 620 695 775 850 930 1005 1085 1160 1235</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Vehicle</th>
<th>Intersection Sight Distance for Right Turns and Crossing Maneuver from Stop Condition on Minor Road (meters)</th>
<th>Design Speed on Major Road (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>40 55 75 95 110 130 145 165 185 200 220 235</td>
<td>50</td>
</tr>
<tr>
<td>Single-unit Truck</td>
<td>60 90 120 150 180 205 235 265 295 325 355 380</td>
<td></td>
</tr>
</tbody>
</table>

All values in Table 15 were computed for a stopped vehicle to turn right onto or cross a two-lane highway with no medians and grades less than 3 percent. Refer to the AASHTO Green Book for grade and multi-lane highway adjustment factors.

Figure 37 shows the intersection sight distance required for a vehicle stopped at an intersection where the major road traffic does not stop. As Figure 37 shows, the passenger car is assumed to stop 10 ft (3.0 m) back from the edge of the intersecting road. The sight line for intersection sight distance is based on the position of the driver’s eye, which is assumed to be 14.4 to 17.8 ft (4.4 to 5.4 m) from the same edge.

Table 16 shows the sight distance required for left turns off the major road. The distances shown are sufficient to turn left across the lanes used by opposing traffic. Figure 38 illustrates the line of sight for vehicles wishing to turn left off of the major road.
Table 16. Intersection sight distance needed for left turns off the major road.\(^{(3)}\)

<table>
<thead>
<tr>
<th>Design Vehicle</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
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<th>60</th>
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<td>285</td>
<td>325</td>
<td>365</td>
<td>405</td>
<td>445</td>
<td>490</td>
<td>530</td>
<td>570</td>
<td>610</td>
<td>650</td>
</tr>
<tr>
<td>Single-unit Truck</td>
<td>145</td>
<td>195</td>
<td>240</td>
<td>290</td>
<td>335</td>
<td>385</td>
<td>430</td>
<td>480</td>
<td>530</td>
<td>575</td>
<td>625</td>
<td>670</td>
<td>720</td>
<td>765</td>
</tr>
<tr>
<td>Tractor-trailer</td>
<td>170</td>
<td>225</td>
<td>280</td>
<td>335</td>
<td>390</td>
<td>445</td>
<td>500</td>
<td>555</td>
<td>610</td>
<td>665</td>
<td>720</td>
<td>775</td>
<td>830</td>
<td>885</td>
</tr>
</tbody>
</table>

Intersection sight distance values shown in table 16 were computed for passenger cars making a left turn from an undivided highway. Refer to the AASHTO Green Book to determine the design sight distance for other conditions.

Figure 38. Sight distance needed for left turns off the major road.

Intersection Control Type

Because vehicles paths cross at intersections, road departments typically use some form of traffic control to assign right-of-way.

**No Control**

Where sight distance is good and traffic volumes are very low, uncontrolled intersections may be a good choice. They may even be safer than stop-controlled intersections at low volumes because drivers may be more likely to run a STOP sign if they know there is little chance of a vehicle coming the other way. Drivers are more cautious when they know the other driver does not have to stop. As uncontrolled intersections become less common, however, drivers may assume that if they do not have a STOP sign, then the other
driver must have one. Install traffic control devices if there’s a history of crashes, drivers cannot see vehicles on other approaches to the intersection, or if total daily traffic volumes exceed 400 vehicles.

**Yield Control**

Uncontrolled intersections may not work well when volumes exceed 400 vehicles per day. Use a YIELD sign where there are good sight distances. YIELD signs do not require traffic to stop unless it is necessary to give way to another vehicle. When the intersection is clear, a YIELD sign causes less delay than a STOP sign. Often, drivers need only adjust their speed to yield to another vehicle, not come to a complete stop. YIELD signs should be installed on the minor road.

If sight distance is not good enough for a yield-controlled intersection to operate safely, use stop control.

**Stop Control**

Stop control may be necessary because of sight-distance restrictions, high traffic volumes on the intersecting street, or unusual conditions at the intersection. Stop control can improve safety by assigning right-of-way and reducing the number of right-angle collisions at an intersection, but at the expense of some disadvantages.

STOP signs cause substantial inconvenience and delay to motorists. Be careful about installing too many STOP signs as drivers tend to disregard them if they feel the signs are unnecessary. Too many signs will cause many drivers to run a STOP sign or only come to a rolling stop. Avoid using STOP signs for speed control. There is some evidence that too many STOP signs may actually increase traffic speed between the signs, as drivers try to make up the time lost. STOP signs may also increase the number of rear-end crashes on roads with high traffic volumes.

Stop-controlled intersections are categorized as two-way stop control or all-way stop control. In two-way stop control, traffic on the main street does not stop. All-way stop controlled intersections work best when all the approaches carry similar amounts of traffic.

**Two-Way Stop Control**

Agencies use two-way stop control on minor roads that intersect roads with more traffic. At an intersection, the STOP sign normally controls the road carrying less traffic. Also:

- Install two-way stop control so the highway with the heavier traffic volume has the right-of-way.
- If sight distance is good, YIELD signs may be as safe and cause less delay.
- Use STOP signs at intersections with restricted sight distance.
- Periodically check to make sure traffic patterns have not changed.
- Give right-of-way to higher speed traffic.
- Give right-of-way to the highway appearing to be the major road.
- Some intersections have unusual geometry, unexpected traffic conflicts, or both. Always conduct a traffic engineering study before deciding what kind of stop control to use.
- Don’t be tempted to install STOP signs to control speeding.

**All-Way Stop Control**

All-way stop intersections are becoming increasingly common as communities try to react to increasing traffic and speeding vehicles. Unfortunately, they are not always the most effective tool for the task. All-way stop control works best when volumes of traffic are roughly the same on each approach to the intersection.
See the MUTCD for guidance and other information on all-way stop controlled intersections. All-way stop control may be warranted:

- As a temporary measure until a needed signal can be installed.
- At a location where five or more right-angle or turning crashes have happened in the past 12 months.
- Where there is enough traffic to meet the following criteria:
  - Volume of traffic entering intersection from major street approaches averages at least 300 vehicles for any 8 hours of an average day; and
  - Combined vehicle, pedestrian, and bicyclist volume entering intersection from the minor street averages at least 200 units per hour for the same 8-hour period, with an average delay to minor-street traffic of at least 30 seconds per vehicle during the highest hour; but
  - If 85th-percentile speed of major traffic exceeds 40 mph (60 km/h), the minimum vehicular volume warrants are 70 percent of the above values.

All-way stop control can work when intersection sight distance is too poor for two-way stop control. Otherwise, the disadvantages of all-way stop control are likely to outweigh the advantages, unless the intersection meets one or more of the warrants. Research has calculated the user costs of a typical all-way stop intersection at $210,000 per year. This figure includes fuel, brake wear, delay, and other costs. If the intersection does not meet the warrants listed above, then the benefit to the public is unlikely to exceed the cost.

**Traffic Signals and Roundabouts**

When traffic volumes are too high for stop control, install traffic signals or modern roundabouts. These can be expensive to install and maintain and only experienced, licensed engineers should design them.

Traffic signals work best when most of the traffic is on the main road, with light traffic on the side road and small traffic volumes turning left off the main road. The MUTCD contains eight warrants for traffic signals. If none of the proposed traffic safety warrants are met, signals often cause more problems than they solve. Also, remember to budget for maintenance and power use when you consider installing a traffic signal.

*It is a good idea to review the warrants contained in the MUTCD.*

*Modern roundabouts require traffic entering on the approaches to yield to traffic on the circulatory roadway. Splitter islands are raised or painted areas on an approach used to separate entering and exiting traffic, deflect and slow entering traffic, and allow storage space for pedestrians. A truck apron is located adjacent to the central island to permit large vehicle wheel tracking.*

*Figure 39. Roundabout on Long Island.*
Unlike the traffic circles of the early 20th century, modern roundabouts are safe and efficient. Roundabouts are designed to operate at 15 to 25 mph (20 to 40 km/h), unlike traffic circles, which often operate at 35 to 45 mph (50 to 70 km/h). Roundabouts work well when traffic volumes are nearly even on each approach leg, or when left-turn movements are heavy. They can eliminate head-on collisions and turn right-angle crashes into glancing fender benders. Single-lane roundabouts are often a good alternative to all-way stop control. Multi-lane roundabouts can replace traffic signals, but they can be tricky to design. Small changes in design can greatly affect safety and capacity. So, leave the design to professional engineers with multi-lane roundabout experience. Figure 39 shows a modern roundabout. Please refer to the FHWA's *Roundabouts: An Informational Guide* for more assistance.

**Lighting**

Lighting can improve the safety of intersections, crosswalks, and railroad crossings prone to nighttime crashes. The FHWA indicates that lighting has the highest benefit-cost ratio of any low-cost safety improvement. Installing lighting at intersections or other spot locations (such as highway-rail grade crossings) can reduce nighttime crashes by 50 to 80 percent. Consider installing lighting when the number of nighttime crashes at an unlit intersection is more than one-third that of daytime crashes for the same period. Lighting can also reduce collisions between vehicles and pedestrians.

When considering lighting, budget for electrical costs and bulb changing. New technologies will increase the power efficiency and bulb life.

**Street Name Signs**

Street name signs play an important role in helping drivers reach their destinations safely. Be sure to post street names for both intersecting roads at each intersection. Signs are normally placed on the far right and near left corners for traffic on the major road. Consider placing street name signs in advance of intersections when crossing street traffic volumes are high.

In addition to placement, it is important that drivers can easily read signs. Lettering should be 6-in (150-mm) capital letters or 6-in (150-mm) upper-case letters with 4.5-in (113-mm) lower-case letters (ALBANY ST or Albany St). On multi-lane roads with speed limits greater than 40 mph (60 km/h), lettering should be 8-in (200-mm) high capital letters or 8-in (200-mm) upper-case letters with 6-in (150-mm) lower-case letters. On local roads with speed limits less than 25 mph (40 km/h), letters should be 4 in (100 mm) tall.

**Pedestrian Crosswalks**

Pedestrian crosswalks have special significance in traffic safety because pedestrians are the most vulnerable road users. This is especially true when pedestrians are children or senior citizens. Children do not develop distance judgment skills until around age nine, and their peripheral vision and depth perception are not fully developed. Older pedestrians may slowly, and their vision is often not as good as when they were younger.

Crosswalk markings by themselves do not improve pedestrian safety. In fact, on high-volume roads (12,000 vehicles or more per day) an unmarked crossing may be safer than a marked one. It could be that pedestrians in a marked crosswalk feel more secure and are less alert to oncoming traffic than pedestrians using an unmarked crossing. Use crosswalks to show pedestrians the best place to cross. Then add other devices, such as pedestrian crossing signs or curb extensions to alert drivers to other road users.

The shortest distance between two points is a straight line, so expect pedestrians to take the most direct route. Therefore, locating crosswalks is a compromise between keeping the crossing distance short,
Road Safety Fundamentals

and locating it where pedestrians will use it. Always install crosswalks at right angles to the road; it keeps the crossing distance short.

Several recent innovations such as curb extensions and medians have improved safety for pedestrians. Curb extensions or bulb outs are places where the sidewalk extends into the shoulder or parking lane. This moves pedestrians to where they are more visible to traffic and reduces the distance they have to cross. Medians allow pedestrians to cross the street in two stages rather than dealing with traffic from both directions at once. Raised medians are best for pedestrians, as long as they accommodate disabled pedestrians. Before you make a decision to install curb extensions and medians, consider how they will affect drainage and winter maintenance. Also, make sure curb extensions will not force cyclists into motor vehicle traffic.

![Figure 40. Crosswalk placement.](image)

Figure 40 shows some considerations when placing crosswalks. At intersection A, the crosswalk is on a direct path for pedestrians, but its placement increases the crossing distance. At intersection B, the crosswalk is shorter, but it is out of the direct path, so pedestrians are unlikely to use it. Placement B also reduces the visibility of pedestrians in the crosswalk to drivers turning off of the main road. By reducing the corner radius, intersection C achieves a balance between crossing distance and convenience. The curb extension on the right side also helps reduce the crossing distance and increases visibility of pedestrians about to enter the crosswalk.

### Highway-Rail Crossings

Various signals, signs, and pavement markings communicate traffic control messages at railroad crossings. To be effective, install standard devices the same way every time. For example, traffic control systems at a highway-rail grade crossing must use devices that look the same, send the same message, and are installed the same way, regardless of whether the highway agency or railroad company installs or maintains them.

Local governments may be responsible for only the advance warning signs and, if appropriate, pavement markings. The railroad owner may be responsible for railroad crossing devices such as flashing signal lights, automatic gates, and crossbuck signs. Consult your State transportation agency about railroad ownership laws.

Railroad crossing pavement markings provide additional warning at highway-rail crossings. Use the pavement markings at railroad grade crossings when you have one or more of the following conditions:

- Crossings with railroad crossing gates or signals.
- Crossings if the posted highway approach speed limit is 40 mph (60 km/h) or higher.
- Other locations where significant conflicts could occur between trains and motor vehicles.

---

The Federal Railroad Administration issued an interim final rule requiring that all locomotives sound horns to warn roadway users of public highway-rail grade crossings. The rule becomes effective December 18, 2004.

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Many railroad crossing crashes happen at night. Except for the locomotive, rail cars are often unlit and sometimes dark. This makes trains at uncontrolled crossings hard to see. Some low-cost measures to prevent night crossing crashes include:

- Make sure railroad advance warning signs and crossbucks are in place and reflective sheeting is in good condition.
- Install reflective material on the back of railroad crossbucks and their posts. As the train goes by, the reflective material flashes through gaps in between train cars.
- Overhead lighting makes trains more visible at night. Install one or more lights on each side of the crossing.
- Install crossing signals with flashing lights and gates. When you think a railroad crossing signal may be needed, write your State transportation agency.

**Driveways**

Driveways present an often overlooked potential for crashes. Traffic entering the road from a driveway faces the same conflicts as traffic at an intersection. Therefore, the design and location of a driveway can affect the safety of the road not only for motor vehicles, but also for pedestrians and bicyclists as well.

**Access Management**

Crash rates and congestion increase with the number of driveways added. As a result, more communities are turning to access management to maintain the safety and capacity of their roads. A good way to reduce the number of entrances is to require subdivision lots to share driveways. This improves the safety and traffic flow on the road.

Access management primarily applies to arterial and collector roads because they carry a large volume of traffic. Local roads serve as the main access to land, so it makes little sense to be overly restrictive.

There are many Federal, State, Tribal, and municipal agencies to help jurisdictions develop access management plans.

**Permits**

Jurisdictions should require landowners to obtain a highway work or building permit for construction within the right-of-way of a public road, including driveways. The permit review and inspection process can lessen the safety and operational effects on the road. It will also ensure driveways are built correctly, without damaging the roadway. It allows the jurisdiction to make sure hazardous headwalls or other structures are not built within the right-of-way.

The jurisdiction should require driveways to meet minimum geometry standards. Likewise, insist that poorly designed driveways be brought up to current standards when:

- The property is redeveloped.
- The jurisdiction decrees a change of use.
- The jurisdiction should upgrade nonstandard driveways during construction projects.

An agency can grandfather in an existing nonstandard driveway unless the crash history shows it to be unsafe. Be careful when you handle these types of issues: Forcing alterations to existing driveways is a
good way to become unpopular with the landowners. Also, business owners are sensitive to changes they think may make it more difficult for customers or deliveries. Proper driveway design helps prevent this.

**Driveway Design**

As noted above, studies conclude that the crash rate on a road increases as more driveways are built. For this reason, try to limit minor commercial and residential lots to one driveway.

Driveways should be at right angles to the street. Angled driveways, like skewed intersections, cause problems for older drivers and others with restricted neck movement. Be aware that older drivers are an increasing portion of the driving population. Acceptable angles range from 75 to 105 degrees.

Noncommercial driveways are typically 14 to 24 ft (4.2 to 7.2 m) wide. When you consider access to other properties (commercial or industrial), remember that driveways should be wider. For example, driveways 20 to 30 ft (6.1 to 9.1 m) wide permit single passenger cars to enter and exit a property at the same time. The corner radius must be sufficient to handle vehicles using the driveway. Figure 41 shows dimensions of a typical driveway.

Driveway design should also address pedestrian use and drainage problems. Use a culvert pipe or ditch to remove excess water from the driveway and adjacent roadway surface. Ensure that ditches are parallel to the roadway and culverts are placed underneath the driveway. Avoid vertical headwalls. Sloped pipe ends that match the embankment (see figure 24) decrease the likelihood that a vehicle leaving the roadway will come to a dead stop. The size of a culvert or ditch depends on the amount of expected runoff.

Driveways should also clearly delineate pedestrian walkways. Sidewalks or pavement markings are common methods of delineation. It is important to limit conflicts between pedestrians and motor vehicles at driveway locations. You can do this by using refuge islands in the driveway to limit pedestrian crossing distances. Also, installing a buffer zone between the travel lane on the main highway and the pedestrian walkway provides extra space between vehicles using the driveway and pedestrians using the walkway.

![Figure 41. Typical driveway design dimensions.](image)

**Sight Distance**

Sight distance for driveways is similar to sight distance for intersections. Three types of sight distance are important in driveway design. Drivers turning out of a driveway or making a left turn into it should be able to see oncoming traffic from far enough away to make the turn safely. Tables 14 through 16 show the
sight distance needed for these maneuvers. The minimum allowable sight distance approaching the driveway should be stopping sight distance (see chapter 4). This allows drivers approaching the driveway to see a vehicle pulling out of the driveway in time to stop and avoid a collision.

Often a building lot will be in a location with less-than-desirable sight distance. In this case, locate the driveway at the point along the lot’s frontage with the best sight distance. It is a good plan to have this requirement in the municipal building code. And, whenever property is subdivided, planning boards should require that all parcels have safe driveway locations.

Summary

This chapter addressed safety considerations at intersections, highway-rail grade crossings, and driveways. It also emphasized the need to ensure adequate sight distance. Design intersections so the corner angle is between 75 and 105 degrees. Intersections with larger corner angles make it difficult for drivers to see oncoming traffic. Drivers approaching or stopped at an intersection must be able to see traffic using other approach legs of the intersection. Intersection sight distance varies based on the traffic control (such as stop or signal control) and turning. Make sure pedestrian walkways are clearly delineated at intersections to reduce collisions with motor vehicles.

Signs, signals, and pavement markings deliver traffic control messages at highway-rail grade crossings. Consistent use of these devices improves safety. Examples of traffic control devices at highway-rail grade crossings are advance warning signs, flashing signal lights, automatic gates, and crossbuck signs. Lighting can also improve safety at highway-rail grade crossings.

Driveways that intersect with highways or streets are potential conflict points. Intersection sight distance should be available for drivers making turning maneuvers at driveway locations. Pedestrian and drainage considerations are also important safety issues at driveway locations.
## Appendix A

### Road Safety Review List

Below is a list of things to look for when you perform road safety investigations or inspections. It is neither a checklist, nor is it all-inclusive. Rather, it is intended as a starting point. If you answer no to any questions, you should investigate further and determine what is an appropriate action. Also, just because a condition is not on this list does not mean the road is safe. Judgment is required.

<table>
<thead>
<tr>
<th>Inspection Item</th>
<th>Yes or No</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roadsides</strong></td>
<td></td>
</tr>
<tr>
<td>Are roadsides free of fixed objects or other hazards that could be removed?</td>
<td></td>
</tr>
<tr>
<td>Are roadsides free of fixed objects or other hazards that could be relocated to places they would not be a hazard?</td>
<td></td>
</tr>
<tr>
<td>Are roadsides free of fixed objects or other hazards that could be made traversable, breakaway, or otherwise made safer to hit?</td>
<td></td>
</tr>
<tr>
<td>Are the roadsides free of nonconforming and/or dangerous obstructions that are not properly shielded?</td>
<td></td>
</tr>
<tr>
<td>Are roadsides free of hazardous or nontraversable side slopes without safety barriers?</td>
<td></td>
</tr>
<tr>
<td>Are guardrails free of corrosion and crash damage?</td>
<td></td>
</tr>
<tr>
<td>Do guardrails meet current standards?</td>
<td></td>
</tr>
<tr>
<td>Are drainage features within the clear zone traversable?</td>
<td></td>
</tr>
<tr>
<td><strong>Road surface and pavement condition</strong></td>
<td></td>
</tr>
<tr>
<td>Is the pavement free of defects that may cause loss of steering control or other safety problems (such as frost heaves, pot holes, etc.)?</td>
<td></td>
</tr>
<tr>
<td>Are changes in surface type (pavement begins, changes type or ends) free of poor transitions?</td>
<td></td>
</tr>
<tr>
<td>Does the pavement have adequate skid resistance, particularly on curves, steep grades, and approaches to intersections? (Look for polished aggregate or bleeding asphalt.)</td>
<td></td>
</tr>
<tr>
<td>Is the pavement free of areas where water ponding or sheet flow could cause hydroplaning or other safety problems?</td>
<td></td>
</tr>
<tr>
<td>Is the pavement free of loose soil or gravel that may cause safety problems?</td>
<td></td>
</tr>
<tr>
<td>Are pavement edges free of drop-offs more than 3 in high?</td>
<td></td>
</tr>
<tr>
<td>Are shoulders firm and free of loose material?</td>
<td></td>
</tr>
<tr>
<td><strong>Road surface—pavement markings</strong></td>
<td></td>
</tr>
<tr>
<td>Is the road free of locations with pavement marking safety deficiencies?</td>
<td></td>
</tr>
<tr>
<td>Is the road free of pavement markings that are not effective for the conditions present?</td>
<td></td>
</tr>
<tr>
<td>Is the road free of pavement markings that are worn?</td>
<td></td>
</tr>
<tr>
<td>Is the road free of old pavement markings that affect the safety of the roadway?</td>
<td></td>
</tr>
<tr>
<td>Inspection Item</td>
<td>Yes or No</td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
</tr>
<tr>
<td><strong>Road surface—unpaved roads</strong></td>
<td></td>
</tr>
<tr>
<td>Is the road surface free of defects that could cause in safety problems (for example, loss of steering control)?</td>
<td></td>
</tr>
<tr>
<td>Is the road surface free of areas where water ponding or sheet flow could cause in safety problems?</td>
<td></td>
</tr>
<tr>
<td>Is the road surface free of loose gravel or fines that may cause safety problems (control, visibility, etc.)?</td>
<td></td>
</tr>
<tr>
<td>Are changes in surface type (such as where pavement ends or begins) free of drop-offs or poor transitions?</td>
<td></td>
</tr>
<tr>
<td><strong>Signing and delineation</strong></td>
<td></td>
</tr>
<tr>
<td>Are there locations where signing will improve safety?</td>
<td></td>
</tr>
<tr>
<td>Are existing signs placed where drivers can easily see them?</td>
<td></td>
</tr>
<tr>
<td>Are existing signs adequately reflective at night?</td>
<td></td>
</tr>
<tr>
<td>Are there locations with improper signing that could cause safety problems?</td>
<td></td>
</tr>
<tr>
<td>Is the road free of unnecessary signing that could cause safety problems?</td>
<td></td>
</tr>
<tr>
<td>Are signs effective for existing conditions?</td>
<td></td>
</tr>
<tr>
<td>Can signs be read at a safe distance?</td>
<td></td>
</tr>
<tr>
<td>Are signs in locations where they do not impair safe sight distance?</td>
<td></td>
</tr>
<tr>
<td>Is the road free of locations with improper or unsuitable delineation (post delineators, chevrons, object markers)?</td>
<td></td>
</tr>
<tr>
<td><strong>Intersections and approaches</strong></td>
<td></td>
</tr>
<tr>
<td>Are intersections free of sight restrictions that could create safety problems?</td>
<td></td>
</tr>
<tr>
<td>Are intersections free of abrupt elevation or surface condition changes?</td>
<td></td>
</tr>
<tr>
<td>Are advance warning signs (STOP AHEAD, YIELD AHEAD, TRAFFIC CIRCLE AHEAD or SIGNAL AHEAD) installed where drivers can’t see intersection traffic control at a safe distance ahead of the intersection?</td>
<td></td>
</tr>
<tr>
<td>On through roads, are intersection warning signs installed where drivers can’t see the intersection at safe distance ahead of the intersection?</td>
<td></td>
</tr>
<tr>
<td><strong>Other road users</strong></td>
<td></td>
</tr>
<tr>
<td>Are travel paths and crossing points for pedestrians and cyclists properly signed and/or marked?</td>
<td></td>
</tr>
<tr>
<td>If sidewalks are needed, are they present?</td>
<td></td>
</tr>
<tr>
<td>Where sidewalks are present, are they free from tripping hazards?</td>
<td></td>
</tr>
<tr>
<td>Where sidewalks are present, are curb ramps provided for disabled users? Are tactile surfaces provided to warn sight-impaired pedestrians of intersections?</td>
<td></td>
</tr>
<tr>
<td>Are bus stops safely located with adequate clearance and visibility from the traffic lane?</td>
<td></td>
</tr>
<tr>
<td>Is appropriate advance signing provided for bus stops and refuge areas?</td>
<td></td>
</tr>
<tr>
<td>Inspection Item</td>
<td>Yes or No</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>Consistency</strong></td>
<td></td>
</tr>
<tr>
<td>Is the road section free of inconsistencies that could cause safety problems?</td>
<td></td>
</tr>
<tr>
<td>Are narrow bridges, lane drops, and other reduced widths properly marked?</td>
<td></td>
</tr>
<tr>
<td>Are there any sharp curves that follow long, tangent roadway segments?</td>
<td></td>
</tr>
<tr>
<td><strong>Highway-Rail crossings</strong></td>
<td></td>
</tr>
<tr>
<td>Are railroad crossing signs used on each approach at highway-rail crossings?</td>
<td></td>
</tr>
<tr>
<td>If appropriate, are railroad signals and/or pavement markings present and in good condition?</td>
<td></td>
</tr>
<tr>
<td>Are highway-rail crossings free of vegetation and other obstructions that could potentially restrict sight distance?</td>
<td></td>
</tr>
<tr>
<td>Is the highway-rail crossing free of gouging, scrape marks, or evidence of high centering (especially lowboy trailers) on roadway approach grades and at the crossing?</td>
<td></td>
</tr>
<tr>
<td><strong>Crash history</strong></td>
<td></td>
</tr>
<tr>
<td>Are roadsides free of crash debris or collision damage to trees, guardrail, etc.?</td>
<td></td>
</tr>
<tr>
<td>Are the pavement and roadsides free of skid marks that indicate close calls?</td>
<td></td>
</tr>
<tr>
<td>Do police accident reports show a repeated pattern of similar crashes, or accidents with similar contributing factors?</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Symptoms and Countermeasures

This is a list of potential countermeasures to common accident problems. It is not intended to be an all-inclusive list, and not all suggested countermeasures will work in all locations.

<table>
<thead>
<tr>
<th>Safety symptom</th>
<th>Possible causes</th>
<th>Potential countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian collisions</td>
<td>Crossing street</td>
<td>Pedestrian crossing signs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrian crossing signs and crosswalks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curb extensions</td>
</tr>
<tr>
<td></td>
<td>School children</td>
<td>Crossing guards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bussing</td>
</tr>
<tr>
<td></td>
<td>Walking along streets</td>
<td>Install sidewalks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Install shoulders (rural)</td>
</tr>
<tr>
<td>Disabled access issues</td>
<td>Disabled pedestrians using street instead of sidewalk</td>
<td>Install or upgrade curb ramps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Repair sidewalks</td>
</tr>
<tr>
<td></td>
<td>Sight-impaired pedestrians not detecting intersections</td>
<td>Install tactile warning surfaces (required by law on new curb ramps, adhesive tactile warning surfaces available for existing ramps)</td>
</tr>
<tr>
<td>Head-on or opposite-direction sideswipe collisions</td>
<td>Poor passing sight distance</td>
<td>No passing zones</td>
</tr>
<tr>
<td></td>
<td>Traffic inadvertently crosses centerline</td>
<td>Centerline pavement markings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Curve delineation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Add centerline rumble strips</td>
</tr>
<tr>
<td></td>
<td>Edge drop-offs</td>
<td>Stabilize or repair paved shoulder, seal edge ruts, replace unpaved shoulder material</td>
</tr>
<tr>
<td>Rear-end collisions</td>
<td>Poor sight distance on approach to intersections</td>
<td>STOP AHEAD or YIELD AHEAD sign</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Driveway sign assembly</td>
</tr>
<tr>
<td></td>
<td>Driveway traffic</td>
<td>Turn restrictions (may move problem to next intersection)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adopt and enforce driveway geometry standards and access management plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two-way left-turn lane</td>
</tr>
<tr>
<td>Safety symptom</td>
<td>Possible causes</td>
<td>Potential countermeasures</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>--------------------------------------------------------</td>
<td>----------------------------------------------------------------</td>
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<tr>
<td>Rear-end collisions (cont.)</td>
<td>Left-turn traffic waiting in through lane to turn</td>
<td>Turn restrictions (may move problem to next intersection)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Left-turn lanes</td>
</tr>
<tr>
<td>Poor pavement friction</td>
<td>See skidding or wet weather in this table</td>
<td></td>
</tr>
<tr>
<td>Poor signal timing</td>
<td>Check signal timing for insufficient green or yellow time</td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>Improve clear zone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Edgeline stripe or rumble strips</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fill pavement edge drop-off or stabilize shoulders</td>
<td></td>
</tr>
<tr>
<td>Sharp or unexpected curves</td>
<td>Curve warning signs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chevrons, arrow signs and/or post-mounted delineators</td>
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</tr>
<tr>
<td></td>
<td>Superelevate curve</td>
<td></td>
</tr>
<tr>
<td>Poor pavement friction</td>
<td>See skidding and wet weather in this table</td>
<td></td>
</tr>
<tr>
<td>Fixed objects and critical slopes</td>
<td>Procedure for treatment of roadside hazards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reshape ditches and side slopes</td>
<td></td>
</tr>
<tr>
<td>Visibility of traffic controls</td>
<td>Check location of STOP or YIELD sign, or signal heads, move if needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Install oversized STOP or YIELD sign</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Add STOP or YIELD sign on near left corner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Add STOP AHEAD or YIELD AHEAD sign</td>
<td></td>
</tr>
<tr>
<td>Visibility of the intersection when approaching it</td>
<td>Add INTERSECTION AHEAD sign</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Double arrow sign across from stem of T</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remove vegetation</td>
<td></td>
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<tr>
<td>Visibility of conflicting traffic at the intersection</td>
<td>Improve intersection sight distance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Realigned skewed intersection closer to 90°</td>
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</tr>
<tr>
<td></td>
<td>Enact and enforce corner clearance ordinance (appendix E)</td>
<td></td>
</tr>
<tr>
<td>Inappropriate intersection control</td>
<td>All-way stop, see chapter 6</td>
<td></td>
</tr>
<tr>
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<td>Traffic signal, see chapter 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modern roundabout, see chapter 6</td>
<td></td>
</tr>
<tr>
<td>Safety symptom</td>
<td>Possible causes</td>
<td>Potential countermeasures</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------</td>
<td>----------------------------------------------------------------</td>
</tr>
<tr>
<td>Nighttime collisions</td>
<td>Old traffic control devices</td>
<td>Check retroreflectivity of signs and pavement markings, replace as needed</td>
</tr>
<tr>
<td></td>
<td>Poor visibility due to darkness</td>
<td>Delineate road alignment using pavement markings, curve signs, and/or post-mounted delineators</td>
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<td></td>
<td>Street lighting</td>
</tr>
<tr>
<td>Skidding or wet weather</td>
<td>Polished pavement</td>
<td>Surface treatment or overlay, mill &amp; repave, reclaim pavement, etc. Use high-friction aggregate</td>
</tr>
<tr>
<td>accidents</td>
<td>Bleeding pavement</td>
<td>Diamond grind if Portland concrete</td>
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<tr>
<td></td>
<td></td>
<td>Reclaim or mill and replace pavement</td>
</tr>
<tr>
<td></td>
<td>Gravel or dirt on road</td>
<td>Driveway aprons</td>
</tr>
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<td></td>
<td>Insufficient or excessive cross slope</td>
<td>Gravel tire cleaning beds</td>
</tr>
<tr>
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<td>Swales or low areas between cut slope and road to divert rainwater</td>
</tr>
<tr>
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<td></td>
<td>Correct cross slope</td>
</tr>
<tr>
<td></td>
<td>Poor drainage</td>
<td>Improve drainage</td>
</tr>
<tr>
<td>Opposing left-turn collisions</td>
<td>Poor sight distance</td>
<td>Prohibit left turns (may move problem to next intersection)</td>
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<tr>
<td></td>
<td>Poor signal timing</td>
<td>Improve sight distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Retime signal, add protected left-turn phase</td>
</tr>
</tbody>
</table>
Appendix C
Sample Corner Clearance Ordinances

Use these ordinances to ensure adequate sight distances at intersections. The first one is probably easier to enforce. The second probably has more flexibility. Because the ordinances shown below are samples, you should review similar ordinances in your jurisdiction.

Example 1

- 1) § 1. Corner lot clear areas
  - a) On any corner lots, no structure, fence or planting is permitted within a “clear area” defined as:
    - i) A horizontal, triangular area described by the following three (3) points:
      - (1) Point A: the intersection of the two (2) street right-of-way lines.
      - (2) Point B: a point on one (1) of the right-of-way lines twenty (20) ft from the intersection of the right-of-way lines.
      - (3) Point C: a point on the other right-of-way line twenty (20) ft from the intersection of the right-of-way lines.
    - b) And, within this triangle: a vertical area beginning two and one-half (2 1/2) ft above the ground and extending to ten (10) ft above the ground.
      - i) Any fence or planting that extends into the clear area must be made to conform within ninety (90) days from the effective date of this chapter.

- 2) § 2. Driveway clear areas
  - a) On any lot, no structures, fence, or planting is permitted within a driveway clear area, defined as:
    - i) A horizontal, triangular area described by the following three (3) points:
      - (1) Point A: the intersection of the center of the driveway and the street right-of-way line.
      - (2) Point B: a point on the driveway ten (10) ft from this intersection.
      - (3) Point C: a point on the street right-of-way line ten (10) ft from this intersection.
    - b) And, within this triangle: a vertical area beginning two and one-half (2 1/2) ft above the ground and extending to ten (10) ft above the ground.
      - i) Any fence or planting that extends into the clear area must be made to conform within ninety (90) days from the effective date of this chapter.

Example 2:

Required sight distance. Intersections shall be so planned and graded that a clear view exists across the corner property from a vehicle 75 ft from the center of the intersection on one street to another vehicle the same distance from the intersection on the other street and 100 ft in the case of a major street. A corresponding sight distance shall be observed on curves on all major streets, and up to this line of sight, the subdivider shall permit no obstruction to view.
Glossary

85th Percentile Speed. The speed at or below which 85 percent of motorists drive on a given roadway during free-flow conditions.

AASHTO. American Association of State Highway and Transportation Officials, an association of transportation departments in the 50 States, the District of Columbia, and Puerto Rico.

ADT (Average Daily Traffic). The number of vehicles using a road on an average day. AADT is Annualized Average Daily Traffic. AADT corrects for seasonal changes in traffic volumes to provide a year-round average.

Clear zone. The area available to a vehicle that goes off the road. It is the area free of obstacles or dangerous slopes, which gives drivers an opportunity to recover control before hitting anything.

Clear zone width. The distance from the edge of the travel way to the nearest roadside hazards. It includes the shoulders. Plan on providing wider clear zone width on high-speed and high-volume roads. If the road is on top of a fill slope, more should be provided. If the roadside slopes upward, less clear zone is needed.

• Desired clear zone width. The width recommended in national standards, based on speed, volume, curvature, and roadside slopes.
• Design clear zone width. What agency designers actually decide to provide when designing a road project. It considers cost, right-of-way, etc. It also represents a commitment to maintain a clear area at least this wide.

Collision diagram. A graphic display used to indicate accident patterns at an intersection or on a roadway segment. The diagram typically shows collision type, location, date, time of day, weather conditions, and other geometric design features. Use a legend to clearly show the various collision types such as rear-end, sideswipe, or head-on crashes.

Condition diagram. A graphic display of a roadway or intersection showing the location of curves, traffic control devices, fixed objects, and other geometric features.

Corner angle. The included angle between two roadways or a road and a driveway. It should be between 75 and 105 degrees. Angles close to 90 degrees are safest.
**Critical slope.** A slope parallel to the road steeper than 3:1. There is a good chance that a vehicle on a critical slope will roll over. Shield critical slopes higher than 5 ft with guardrail or add fill to make the slope traversable or recoverable.

**Decision sight distance.** Distance required for a driver to recognize unexpected information or a condition in the roadway or its surroundings, recognize the condition or threat, select an appropriate speed and path, and complete the maneuver safely and efficiently.

**Expectancy.** How drivers expect the road ahead of them to be. Drivers base expectancy on the road they have just driven and their lifelong driving experience. Conditions that fail to meet expectancy often cause driver error.

**Fixed object.** A roadside object such as trees, utility poles, boulders, etc. that is massive enough to injure vehicle occupants.

**Functional class.** A way of classifying roads based on the role they play in the transportation network:

- **Local roads** primarily provide access to adjacent land. Through traffic is usually a small percentage of total traffic.
- **Collectors** provide access to neighborhoods and carry traffic from local neighborhood road networks to arterials. They also provide access to adjacent properties.
- **Arterials** carry large traffic volumes. They usually serve traffic traveling regionally. Intersections are generally at-grade, but driveway access to neighboring properties may be restricted.
- **Freeways** primarily carry through traffic. Junctions with other roads occur at interchanges. Driveways are not allowed. Interstate highways are freeways.

**Geometry or Geometrics.** Collective term for alignment, lane widths, curve radius, etc.

**Jurisdiction.** A Federal, State, regional, local, or tribal government agency having legal authority.

**Low-volume road.** A road with an ADT of less than 400 vehicles per day.

**MPO (Metropolitan Planning Organization).** An urbanized area with a population of 50,000 or more.

**Opportunity cost.** The other choices you give up when selecting one alternative over others. In other words, what you could have done instead.

**Recoverable slope.** A slope parallel to the road that is flatter than 4:1. If the clear zone is wide enough, a driver on a critical slope may be able to regain control and return the vehicle to the roadway.

**Retroreflective.** A property of material that reflects light back roughly in the direction it came from, rather than the equal and opposite angle. It is used on traffic control devices to reflect the light from vehicle headlights back to the driver’s eyes.

**Roadside hazard.** Conditions near the road that present a danger to vehicles leaving the road. Common hazards include:

- Fixed objects like trees, buildings, or guardrail.
- Spearing hazards that could crash into the passenger compartment.
- Slopes steep enough to launch a vehicle into the air or roll it over.
**Road safety audit.** A formal examination by an independent team of trained specialists of an existing road or a future road or traffic project. The team assesses the safety of a roadway project and prepares a report that identifies potential safety problems.

**Rural and urban areas.** Urban areas are designated by a jurisdiction having a population greater than 5,000. Urban areas are those with a population greater than 50,000. Rural areas are those outside an urban boundary.

**Superelevation.** Banking of a curve

**Tort Liability.** A wrongful act that results in an injury to a person’s property for which the injured party is entitled to compensation.

**Traffic study.** An investigation that gathers information on traffic flow or safety and uses it to solve a traffic problem. Always document information gathered, techniques used, and decisions made during traffic studies for future use.

**Traversable slope.** A slope steeper than a recoverable slope, but not as steep as critical slope. A vehicle on a traversable slope probably will not overturn, but it is unlikely that the driver will be able to return to the road. The vehicle will probably continue down to the bottom of the slope.
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or Keri Shoemaker
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Fax: (802) 654-2555
E-mail: hlambert@smcvt.edu
Web: http://personalweb.smcvt.edu/vermontlocalroads/welcome.htm
Primary contact: Henry R. Lambert

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Fax: (434) 293-1429
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Web: http://www.vtrc.net/vtttc/
Primary contact: Russ Neyman

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Olympia, WA 98504-7390

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Fax: (360) 705-6858
E-mail: wst2center@wsdot.wa.gov
Web: http://www.wsdot.wa.gov/TA/T2Center/T2hp.htm
Primary contact: Lawrence Schofield, P.E.

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Fax: (304) 293-7109
E-mail: mblanken@wvu.edu
Web: http://www.cemr.wvu.edu/~wwwtt
Primary contact: Mike Blankenship

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Primary contact: Dan Moreno

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Primary contact: Bernard D. Alkire

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Fax: (509) 359-7485
E-mail: rrolland@ewu.edu
Web: http://www.cbpa.ewu.edu/~LTAP/
Primary contact: Richard Rolland
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<tr>
<th>ACRONYMS</th>
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<tbody>
<tr>
<td>AASHTO</td>
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<td>Americans With Disabilities Act</td>
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<td>ADT</td>
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<td>ATSSA</td>
<td>American Transportation Safety Services Association</td>
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<td>BIA</td>
<td>Bureau of Indian Affairs</td>
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<td>CFR</td>
<td>Code of Federal Regulations</td>
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<td>FHWA</td>
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<td>AASHTO publication, <em>A Policy on Geometric Design of Highways and Streets</em></td>
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<td>MADD</td>
<td>Mothers Against Drunk Driving</td>
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<td>MPO</td>
<td>Metropolitan Planning Organization</td>
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<td>MUTCD</td>
<td>Manual on Uniform Traffic Control Devices</td>
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<td>National Cooperative Highway Research Program</td>
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<td>SMS</td>
<td>Safety Management System</td>
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<td>M VMT</td>
<td>Millions of Vehicle Miles Traveled</td>
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<td>TEA-21</td>
<td>Transportation Equity Act for the 21st Century</td>
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## SI* (Modern Metric) Conversion Factors

### Approximate Conversions to SI Units

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>WHEN YOU KNOW</th>
<th>MULTIPLY BY</th>
<th>TO FIND</th>
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**NOTE:** Volumes greater than 1000 L shall be shown in m³

| **MASS**                                      |             |             |            |        |
| oz     | ounces              | 28.35       | grams      | g       |
| lb     | pounds              | 0.454       | kilograms  | kg      |
| T      | short tons (2000 lb) | 0.907       | megagrams (or "metric ton") | Mg (or "t") |

**TEMPERATURE (exact degrees)**

| oF    | Fahrenheit             | 5 (F-32)/9 or (F-32)/1.8 | Celsius        | oC     |
### SI* (MODERN METRIC) CONVERSION FACTORS

#### APPROXIMATE CONVERSIONS TO SI UNITS

<table>
<thead>
<tr>
<th>SYMBOL</th>
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<th>TO FIND</th>
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#### TEMPERATURE (exact degrees)

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<th>Unit</th>
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<td>Celsius</td>
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<tr>
<td>°F</td>
<td>Fahrenheit</td>
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*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.*