Better Military Traffic Engineering

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Transportation Engineering Agency

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SDDCTEA PAMPHLET 55-17

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Military Surface Deployment and Distribution Command
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CHAPTER 1 – INTRODUCTION

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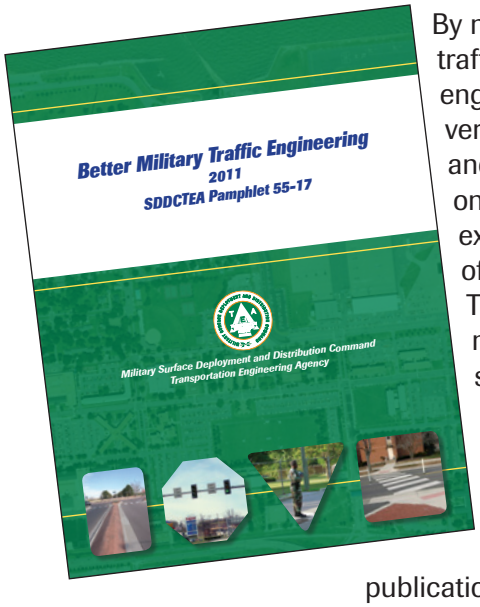
1.1. FORWARD

The *Better Military Traffic Engineering* pamphlet is intended for use by persons with responsibilities relating to traffic operations, roadway safety and/or roadway design. This pamphlet addresses the traffic engineering areas of data collection and analysis, traffic operations, and transportation planning as they should be applied on military installations.

The text emphasizes general principles of traffic engineering. Case studies and problem-solving techniques are used to illustrate the practical application of these principles as they relate to the unique conditions that exist on military installations.



By nature, traffic engineering is very complex and is built on the experience of others. Therefore, many of the standards in this text have been taken from other publications and are referenced within the text. In addition, the authors wish to acknowledge major contributions from publications of the following organizations: the American Association of State Highway and Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), and the Federal Highway Administration (FHWA).

1.2. WHO IS SDDCTEA?

The Military Surface Deployment and Distribution Command Transportation Engineering Agency, or SDDCTEA, executes the Department of Defense's (DoD) overall transportation engineering program on behalf of the military services.

SDDCTEA's mission is to improve highway safety and reduce traffic congestion on DoD installation roads and on routes providing access to installations. Our objectives are to save lives, decrease injuries, minimize lost time, and maintain readiness.

To achieve our mission and objectives, we focus our efforts into two key areas:

Training and Education – Includes the development of training and educational materials for distribution throughout the military. Materials include traffic engineering and highway safety bulletins, pamphlets, and interactive training materials. It also includes training workshops. This is an important part of training that leads to better project and master planning.

Engineering Services – Includes roadway planning, geometric design, road safety audits, traffic operations analysis, engineering guidance, and contract assistance.

1.2.1. Training and Education

As presented in Exhibit 1.1, SDDCTEA offers several forms of training and education.

Exhibit 1.1: SDDCTEA Training and Education

TRAINING AND EDUCATION PROGRAM	SUBJECT MATTER COVERED
TRAFFIC ENGINEERING AND HIGHWAY SAFETY BULLETINS Bulletins are published three to four times yearly and address a broad range of transportation and safety topics. Bulletins are available online at: http://www.tea.army.mil/pubs/dod.asp Sign up to receive bulletins at: http://www.tea.army.mil/cdrom/	Bulletin topics include: ✓ *Access Management* ✓ *Pedestrian Safety* ✓ *Parking* ✓ *Gates Revisited* ✓ *Traffic Calming* ✓ *Safety Audits* ✓ *Speed Limits* ✓ *Traffic Signs* ✓ *Roadside Safety - A Forgiving Roadside* ✓ *Traffic Engineering For Better Gates* ✓ *Highway Safety Driver-Aid Treatments* ✓ *Safety Requirements of Active Vehicle Barriers* ✓ *Sign Retroreflectivity* ✓ *Intersection Control*
PAMPHLETS SDDCTEA has produced a variety of pamphlets and manuals on transportation issues. These materials provide specific, detailed engineering guidance on key issues. Pamphlets and manuals are available online at: http://www.tea.army.mil/pubs/dod.asp	✓ *Pamphlet 55-8, Traffic Engineering Study Reference* ✓ *Pamphlet 55-10, Traffic Engineering for Better Roads* ✓ *Pamphlet 55-14, Better Traffic Engineering for Signs and Markings* ✓ *Pamphlet 55-15, Traffic and Safety Engineering for Better Entry Control Facilities* ✓ *Pamphlet 55-17, Better Military Traffic Engineering*

Exhibit 1.1: SDDCTEA Training and Education (continued)

TRAINING AND EDUCATION PROGRAM	SUBJECT MATTER COVERED
TRAFFIC ENGINEERING TRAINING & REFERENCE CD-ROM Originally released in June 2002 and updated in 2008, SDDCTEA developed the interactive multimedia CD-ROM, *Better Military Traffic Engineering* (*BMTE*) 2005, to provide the military engineering community with state-of-the-art information regarding the proper use of traffic control and safety devices on military installations. The *BMTE CD* is an instructional tool to train installation personnel, but can also be used as a reference tool. Animation and original illustrations are only part of the features available. Links are available to reference materials, Web sites, and for e-mail assistance. The *BMTE CD* is packaged inside the back cover of this pamphlet. Order additional copies online at: http://www.tea.army.mil/cdrom/	 The CD is divided into sections, each containing a different topic: ✓ *Signs* ✓ *Signals* ✓ *ECFs* ✓ *Parking* ✓ *Roadside Safety* ✓ *Intersections* The *BMTE CD* also includes several traffic calculators for reference when planning a variety of traffic engineering projects.

1.2.2. Engineering Services

KEY POINT

SDDCTEA offers on-site crash location studies at no cost to the installations.

If your installation requires a study, SDDCTEA can help you by any one of the most frequently used methods shown in Exhibit 1.2. Our focus is to deliver a quality product to the installations in a timely manner.

SDDCTEA offers on-site engineering studies

SDDCTEA's services include the following:

Safety

- ✓ Crash Location Enhancement Studies (CrashLES)
- ✓ Fatal crash analysis
- ✓ Safety audits
- ✓ Pedestrian studies
- ✓ Speed studies
- ✓ Traffic calming evaluations
- ✓ Sign retroreflectivity assessments
- ✓ Sign Management Studies

Transportation Engineering

- ✓ Traffic impact studies
- ✓ Signal warrant and operations evaluations
- ✓ Corridor evaluations
- ✓ Comprehensive transportation studies
- ✓ Roadway and intersection design/reviews
- ✓ Operational audit for traffic signal sustainability
- ✓ Parking Studies
- ✓ Desktop plan/study reviews

Force Protection and Installation Access

- ✓ Gate (ECF/ACP) studies and assessments
- ✓ Gate design
- ✓ Force protection assessments
- ✓ Access roads studies
- ✓ Active vehicle barrier location assessment and safety schemes

Exhibit 1.2: SDDCTEA Traffic Engineering Services

STUDY TYPE	COST	DURATION
FUNDED CRASH LOCATION ENHANCEMENT STUDIES (CrashLES) These studies generally involve one or more high crash locations and a safety audit. A high crash location is any location with five or more property-damage-only, three or more injury, or one or more fatal crashes in a 12-month period.	✓ FHWA funded, with no cost to the installation.	✓ The studies are typically performed in one week. ✓ A draft report, with recommendations, is provided at the end of the week along with an outbrief to installation personnel.
IN AND OUT These studies are of limited scope where the installation advises us of their most pressing problem locations. We provide recommendations to correct deficiencies, and generally include low-cost improvements that are within installation funding capabilities.	✓ The installation may be required to assist with funding.	✓ The studies are typically performed in one week. ✓ A draft report, with recommendations, is provided at the end of the week along with an outbrief to installation personnel.
COMPREHENSIVE Typically studies may address 10 to 50 intersections, as well as ECFs, access roadways, master planning issues, speed limits, pedestrian safety, and access management.	✓ The installation may pay for all or part of the study. ✓ We manage the study for the installation; to include scope of work preparation, scheduling, and technical reviews.	✓ SDDCTEA's engineer produces the pre-final and final studies over several months.

Exhibit 1.3: Additional Focus Areas

STUDY TYPE	STUDY CHARACTERISTICS
ACCESS CONTROL POINT/ENTRY CONTROL FACILITY (ACP/ECF) STUDIES	The purpose of this type of study is to assess the four priorities of an ACP or ECF consisting of: ✓ Security and Functional Requirements ✓ Safety (guards and motorists) ✓ Traffic Flow and Congestion ✓ Aesthetics
FATAL CRASH ANALYSIS	This is similar to a CrashLES study; however, it focuses on a specific fatality at a specific location. These studies are generally considered confidential and would not be distributed without permission from the installation.
SAFETY AUDITS	Safety audits involve a procedural approach to evaluating roadway safety for specific corridors. Safety audits can focus on pedestrian accommodations, traffic signals, signing and pavement markings, drainage, and roadside hazards.
PEDESTRIAN STUDIES	Pedestrian studies involve the evaluation of pedestrian facilities and related activity including crosswalks, overpasses, sidewalks, pedestrian signing, school walking routes, and Americans with Disabilities Act (ADA) requirements.
SPEED STUDIES	Speed studies usually involve the collection of speed data for the purpose of establishing appropriate speed limits on installation roadways.
TRAFFIC CALMING EVALUATIONS	This study assesses the need for and appropriate application of the use of physical measures to address speeding and excess traffic on neighborhood streets.
SIGN RETROREFLECTIVITY ASSESSMENTS	This type of study involves the inspection of installation signing to ensure that minimum retroreflectivity requirements are met for nighttime driving and to identify those signs that need replacement.
TRAFFIC IMPACT STUDIES	Traffic impact studies typically involve identifying impacts and roadway or intersection improvement needs resulting from development or an increase in population. The study involves estimating the number of additional trips to be generated by the proposed development and conducting capacity analyses to assess existing and future operations.

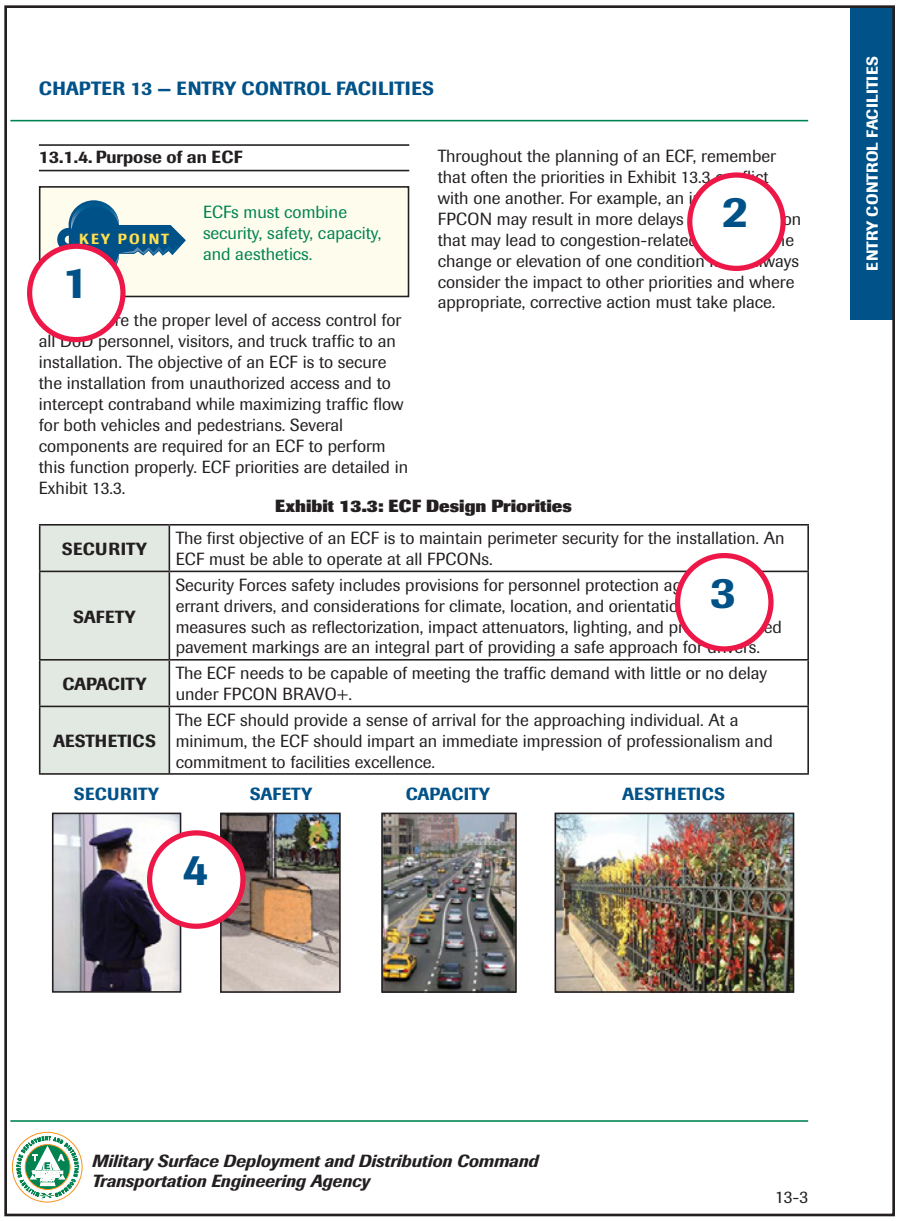
Exhibit 1.3: Additional Focus Areas (continued)

STUDY TYPE	STUDY CHARACTERISTICS
SIGNAL WARRANT AND OPERATIONS ANALYSES	This type of analysis involves conducting capacity analyses to identify operational conditions and comparing traffic volumes to the warrants set forth in the *Manual on Uniform Traffic Control Devices* (*MUTCD*) to determine if signalization should be considered. Operations analyses may include signal timing and phasing recommendations.
CORRIDOR EVALUATIONS	Corridor Evaluations involve the analysis of a group of intersections along a specific roadway corridor, and may include the identification of improvements to improve traffic flow and safety of the corridor.
ROADWAY AND INTERSECTION DESIGN REVIEWS	This service involves the review of design plans prepared by others to ensure consistency with national and local standards. This primarily involves a review of roadway geometry, but may also include a review of supporting data utilized in the design process.
INTERSECTION, ROADWAY, AND ACP/ECF DESIGNS	These designs involve advancing preliminary, conceptual designs to a final design stage so that they may be advertised for construction. They also include the development of construction specifications and cost estimates.
PARKING EVALUATIONS	Parking Evaluations include identifying existing parking shortages, projecting future parking demand, and developing conceptual parking improvement schemes.
TRAFFIC SIGNAL INSPECTIONS & OPERATIONAL AUDITS	Traffic signal inspections include an inspection of traffic signal equipment (including mast arms, signal heads, controllers, loop detectors, etc.) to determine if improvements/updates are necessary. Operational audits include the analysis of parameters such as phasing, detectors, and timing to reduce motorist delay. Measures of Effectiveness reports can be provided to convey the savings in fuel, emissions, and driver delay.

1.3. USE OF THIS DOCUMENT

There are several elements associated with the topics in this pamphlet as mentioned below:

1. **Key Point** – Represents critical information regarding the topic being discussed.
2. **Content** – Provides specific detailed theory and guidance.
3. **Tables** – Provides easy-to-use, look-up information for a particular subject.
4. **Graphics** – Illustrates the content or represents an applied condition.



CHAPTER 13 – ENTRY CONTROL FACILITIES

ENTRY CONTROL FACILITIES

13.1.4. Purpose of an ECF

KEY POINT

ECFs must combine security, safety, capacity, and aesthetics.

1

re the proper level of access control for all DoD personnel, visitors, and truck traffic to an installation. The objective of an ECF is to secure the installation from unauthorized access and to intercept contraband while maximizing traffic flow for both vehicles and pedestrians. Several components are required for an ECF to perform this function properly. ECF priorities are detailed in Exhibit 13.3.

Throughout the planning of an ECF, remember that often the priorities in Exhibit 13.3 conflict with one another. For example, an i on FPCON may result in more delays on that may lead to congestion-relate e change or elevation of one condition ways consider the impact to other priorities and where appropriate, corrective action must take place.

2

Exhibit 13.3: ECF Design Priorities

SECURITY	The first objective of an ECF is to maintain perimeter security for the installation. An ECF must be able to operate at all FPCONs.
SAFETY	Security Forces safety includes provisions for personnel protection a errant drivers, and considerations for climate, location, and orientati measures such as reflectorization, impact attenuators, lighting, and p ed pavement markings are an integral part of providing a safe approach fo ers.
CAPACITY	The ECF needs to be capable of meeting the traffic demand with little or no delay under FPCON BRAVO+.
AESTHETICS	The ECF should provide a sense of arrival for the approaching individual. At a minimum, the ECF should impart an immediate impression of professionalism and commitment to facilities excellence.

3

SECURITY SAFETY CAPACITY AESTHETICS

4

Military Surface Deployment and Distribution Command
Transportation Engineering Agency

13-3

1.4. COMMON ACRONYMS

This pamphlet uses many different acronyms throughout the document. For ease of reference, Exhibit 1.4 summarizes commonly used acronyms.

Exhibit 1.4: Commonly Used Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACP	Access Control Point
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
AIE	Automated Installation Entry
AT	Antiterrorism
ATR	Automated Traffic Recording
AVB	Active Vehicle Barrier
BMTE	*Better Military Traffic Engineering*
CCTV	Closed Circuit Television
CrashLES	Crash Location Enhancement Study
CRI	Color Rendering Index
DMS	Dynamic Message Signs (also commonly referred to as VMS, Variable Message Signs)
DoD	Department of Defense
DOT	Department of Transportation
ECF	Entry Control Facility
FC	Foot-candle
FHWA	Federal Highway Administration
FPCON	Force Protection Condition
ft	Feet
HAR	Highway Advisory Radio
HCS	*Highway Capacity Software*
HID	High Intensity Discharge
HOV	High Occupancy Vehicle
IESNA	Illuminating Engineering Society of North America
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
LOS	Level of Service
mph	Miles per hour
MUTCD	*Manual on Uniform Traffic Control Devices*
MVIS	Mobile Vehicle Inspection System
NCHRP	National Cooperative Highway Research Program
POV	Privately Owned Vehicle
OCONUS	Outside Continental United States
PT	Physical Training
RPM	Raised Pavement Marker
RSA	Roadway Safety Audit
SDDCTEA	Surface Deployment and Distribution Command Transportation Engineering Agency
TMC	Turning Movement Count
TRB	Transportation Research Board
TTC	Temporary traffic control
TTCP	Temporary Traffic Control Plan
UFC	Unified Facilities Criteria

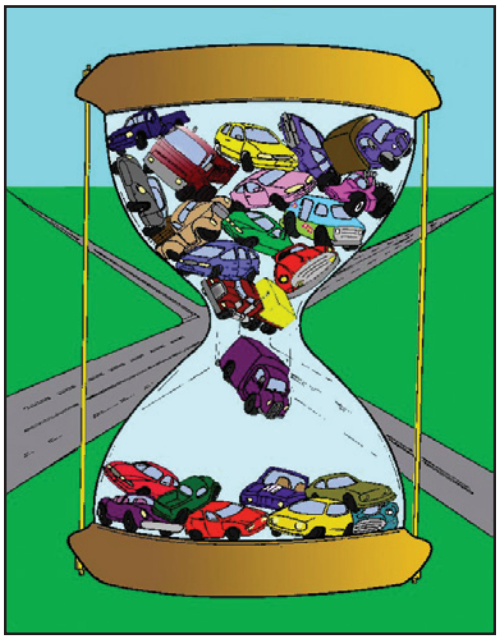
2.1. CONGESTION MITIGATION 2-1
2.2. MILITARY BASE APPLICATION 2-6
2.3. AREAS OF NEED 2-8

Basewide planning involves evaluating the overall transportation-related needs of an installation considering future changes to population and land use. Frequently, changes to population and land use occur on bases, and the resulting transportation needs are not fully considered or not considered at all. If long-term transportation needs are not considered, traffic problems will develop as missions increase, and more traffic is added to already overburdened transportation systems. Development should occur hand-in-hand with increases to the roadway network's capacity. This section will discuss how this can occur.

In addition to development, planning also includes accommodating overall areas of need that may or may not be the result of development.

2.1. CONGESTION MITIGATION

It is not uncommon for installations to experience large amounts of growth. To support existing and future demands, installations must not only identify capacity enhancements but also consider capacity management (or operations) and demand management strategies.



2.1.1. What is Congestion

Congestion is relatively easy to recognize—roads filled with cars, trucks, and buses; sidewalks filled with pedestrians. The definitions of the term congestion mention such words as "clog," "impede," and "excessive fullness."

In general, the cause of congestion is that the number of vehicles transporting travelers and goods exceeds the roadway capacity. The resulting effects are delays, increased travel time, increased costs, driver frustration, and unsafe driving practices.

There are four components of congestion:

Duration - This is the length of time during which congestion affects the travel system.

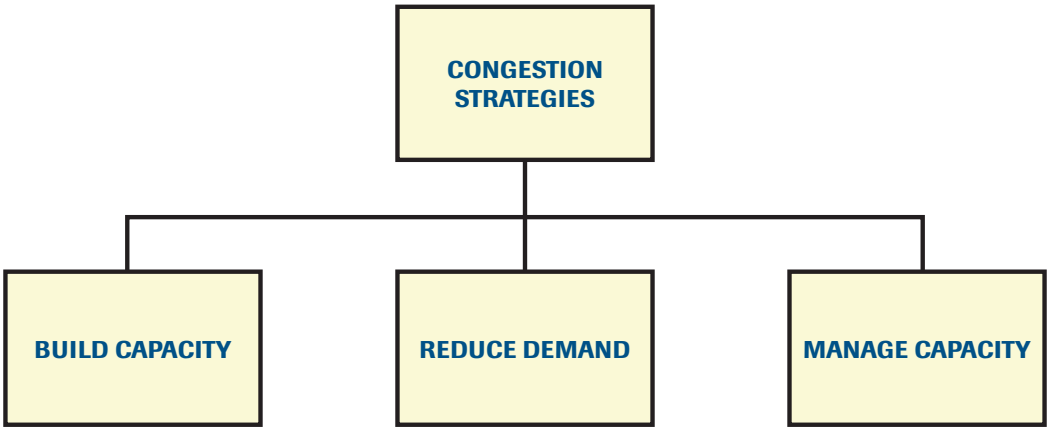
Extent - This is described by estimating the number of people or vehicles affected by congestion and by the geographic distribution of congestion.

Intensity - The severity of congestion that affects travel is a measure from an individual traveler's perspective. In concept, it is measured as the difference between the desired condition and the conditions being analyzed.

Variation - This key component describes the change in the other three elements. Recurring delay (the regular, daily delay that occurs due to high traffic volumes) is relatively stable. Delay that occurs due to incidents is more difficult to predict.

2.1.2. Causes of Congestion

Congestion is the result of several root causes, often interacting with one another.



Congested Conditions

Exhibit 2.1: Causes of Congestion

CAUSES OF CONGESTION	COMMON EXISTING CONDITIONS	COMMON FUTURE CONDITIONS WITHOUT IMPROVEMENTS
Physical Bottlenecks ("Capacity") – Capacity is the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves).	✓ Bottlenecks occur at key intersections due to a lack of turning lanes	✓ Traffic impacts have been considered in new development areas; however, basewide needs are often not fully considered. ✓ ECFs are not widened to accommodate additional growth.
Traffic Incidents – Events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents.	✓ Some crash history at key intersections and existing ECFs	✓ Crash rates generally increase without capacity and safety related improvements
Work Zones – Construction activities on the roadway that result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures.	✓ Delays on roadways in areas of work zones	✓ Additional delays expected due to construction activities.
Weather – Environmental conditions can lead to changes in driver behavior that affect traffic flow.	✓ Minor cause of congestion	✓ Minor cause of congestion

Exhibit 2.1: Causes of Congestion (continued)

CAUSES OF CONGESTION	COMMON EXISTING CONDITIONS	COMMON FUTURE CONDITIONS WITHOUT IMPROVEMENTS
Traffic Control Devices – Intermittent disruption of traffic flow by control devices such as railroad grade crossings and poorly timed signals also contribute to congestion and travel time variability.	✓ Major cause of congestion can be due to traffic signals in poor operational condition ✓ Grade crossings across busy railroad tracks can be major causes of congestion	✓ Congestion increases with no improvements
Special Events – Are a special case of demand fluctuations whereby traffic flow in the vicinity of the event will be radically different from "typical" patterns. Special events occasionally cause "surges" in traffic demand that overwhelm the system.	✓ Major cause during special events and deployments	✓ Will continue to be a major cause without improvements
Lack of Access Management – When driveways and accesses are located too frequently and closely together, the unpredictable movement of traffic into and out of these access points can slow traffic and cause congestion.	✓ Many land uses along a corridor have their own driveways. They do not share one common larger access points.	✓ Congestion increases and continues to impact traffic on the major roadway

2.1.3. Congestion Mitigation Techniques

FHWA has also identified numerous mitigation techniques associated with each category. In reality, the most successful approach may be to implement a combination of appropriate strategies from all three categories.

Capacity Enhancements can include new roadways and roadway widening for additional single-occupancy vehicle lanes (SOVCAP), but may also include minor geometric enhancements and the elimination of bottlenecks. Large-scale capacity enhancements are typically the last measures transportation professionals consider, because they are often the most expensive and can have adverse environmental impacts, such as environmental and right-of-way impacts. Large-scale capacity enhancements can also have the effect of inducing additional travel, which may result in the roadway becoming congested again in the future. However, strategic capacity enhancements can alleviate existing congestion and may accommodate some future growth if properly considered.

Operational Improvements are geared toward improving the "supply side" of the transportation system. These efforts are intended to enhance the operation of the transportation system and make it as efficient as possible. Operational Improvements include things such as intersection upgrades, access management, reversible lanes, traffic signal improvements, and Intelligent Transportation Systems. Operations represent technologies and institutional arrangements that allow transportation systems to operate more closely to their maximum design intent.

Demand Management programs attempt to address congestion at the root of the problem by reducing the number of vehicles on the road. These initiatives work to modify driver behavior by encouraging people to make fewer single-occupancy trips, travel in off-peak hours when possible, and support land use policies that reduce the demand for automobile transportation.

2.1.4. U.S. Department of Transportation Congestion Initiative

In May 2006, the U.S. Department of Transportation (U.S. DOT) announced the National Strategy to Reduce Congestion of America's Transportation Network (otherwise known as the Congestion Initiative). This initiative is focused on making meaningful and near-term reductions in congestion. Because of this initiative, the Department set a goal that calls for reducing congestion, not just reducing the rate of growth of congestion.

The Department is working to advance low-cost operational and technological improvements aimed at congestion reduction. It is encouraging and supporting state efforts to:

- ✓ Provide real-time traffic information to all users;
- ✓ Deploy incident management strategies such as the formation of roving response teams and quick clearance and "move it" laws;
- ✓ Improve traffic signal timing;
- ✓ Improve work zone safety and mobility; and
- ✓ Deploy quick fix operational and low-cost construction strategies to address congestion.[1]

[1] *Traffic Bottlenecks: A Primer – Focus on Low Cost Operational Improvements, FHWA, 2008*

2.2. MILITARY BASE APPLICATION

In the civilian world, private developers often are required to provide additional roadway capacity when they build a development in order to accommodate the additional traffic that the development would generate. Developers are required to perform whatever improvements are necessary to the external roadway network such that the amount of delay per motorist does not worsen. Depending on the size of the development, improvements are often required far offsite, as far as at least a mile away to key intersections.

In the military world, it is very common to construct facilities that generate a large amount of traffic, and make no roadway improvements. Development may only consist of the building itself, and a parking lot outside of the building. The facility will then open, and the roadways accessing it will be over capacity with no plan for improvements. Entry control facilities (ECFs) will be over capacity if the development draws additional traffic through an ECF.

When development is in the planning stage, ensure that all appropriate personnel are involved in plan reviews. This includes the following:

- ✓ Master planners
- ✓ Traffic engineers
- ✓ Security forces

Master planners should review plans for opportunities to upgrade roadways when projects occur. If a project occurs on a roadway corridor on which long-term plans exist to widen to provide more lanes, the project in the area of the building could include widening a portion of this roadway. On a smaller scale, if plans exist to upgrade sidewalks throughout the base, a project could include upgrading sidewalks in the area of the development.

Traffic engineers should review plans to ensure that projects address effects from additional traffic. This could include:

- ✓ Turn lanes at access points
- ✓ Traffic signal retiming and upgrades
- ✓ Additional traffic signals at nearby intersections
- ✓ Additional turn lanes at nearby intersections
- ✓ Additional roadways to link development to roadway networks
- ✓ Impacts to ECFs

Security forces should work with traffic engineers to ensure that additional traffic to ECFs is accommodated. This includes short-term manning at ECFs, and long-term improvements to ECFs.

It is important that traffic impacts be considered when adding development to an installation. When reviewing a plan for development, a reviewer should think of different aspects, as discussed in Exhibit 2.2.

Exhibit 2.2: Roadway Development Considerations

✓ Turn lanes at access points	• Are there left-turn lanes into the driveways so as to not delay through traffic? • Are right-turn lanes needed? • Are separate turning lanes exiting the development needed?
✓ Traffic signal retiming and upgrades	• Are nearby traffic signals going to see a change in traffic volumes, requiring retiming? • Are nearby traffic signals in need of upgrades, to detection, operations, phasing, and equipment? • Is existing traffic signal equipment sufficient to accommodate roadway widening? • Does existing traffic signal equipment need pedestrian accommodations?
✓ Additional traffic signals at nearby intersections	• Do any nearby intersections have deficient levels of service, existing or with projected traffic added to the intersection? • Are there any nearby unsignalized intersections that will warrant signalization with new development? • Are traffic signals the most appropriate form of traffic control, versus roundabouts?
✓ Additional turn lanes at nearby intersections	• Will intersections away from the development get additional turning traffic; thereby requiring turn lanes? • Will existing turn lanes need to be lengthened?
✓ Additional roadways to link development to roadway networks	• Are multiple driveways needed to alleviate traffic to and from the development? • Even if there is a driveway to an existing roadway, is there another roadway nearby that a second access can be built to, such that the traffic can be split over multiple existing roadways?
✓ Impacts to ECFs	• Are there ECFs that are currently under capacity? • Are all ECFs nearby adequately-sized to accommodate development-related traffic? • Are processing techniques appropriate for long-term conditions?

2.3. AREAS OF NEED

Accommodating overall areas of need is critical for acceptable traffic operations on base. This can include several different aspects at a master planning level. For the most part, it includes mitigation of existing traffic problems, or planning for upgrades to the transportation system hand-in-hand with upgrades to land use. In addition to vehicular traffic, consider accommodating alternate modes. When reviewing installation-wide areas of need, consider some of the following questions:

- ✓ Are there any missing roadway links that should be provided to make a continuous corridor?
- ✓ Is there a better location for an entry control facility?
- ✓ Do roadways have sidewalks if pedestrian demand is expected?
- ✓ Is there room for adding jogging trails for PT to avoid using roads for PT?
- ✓ Are bike trails provided?
- ✓ Are commissaries and PX's located close enough to employment centers to allow workers to walk to lunch?
- ✓ Is there an opportunity to make a loop-style roadway around the busier areas of a cantonment area to keep traffic in the periphery to allow for more pedestrian-friendly areas within major employment centers?
- ✓ Is development located such that access points will not impact nearby intersections?

CHAPTER 3 – TRAFFIC ENGINEERING STUDIES

3.1. PROBLEM IDENTIFICATION 3-1

3.2. TRAFFIC DATA COLLECTION 3-4

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The first step in transportation planning is to clearly identify traffic problems of the area being studied. The term "traffic problem" is defined as any situation that impairs the safe and efficient flow of traffic.

In the identification of traffic problems, relativity must be considered. Traffic problems vary across different areas of the country. For example, a five-minute delay in New York City is considered negligible, while the same delay in a remote area would be extremely frustrating to motorists. Therefore, remember that traffic problems are relative to the location being studied.

3.1. PROBLEM IDENTIFICATION

KEY POINT

Traffic engineering studies are the basis for formulating solutions to traffic problem areas.

There are two major sources of traffic-related problems on roadway networks: congestion and crashes. Congestion wastes motorists' time and money. Crashes result in property damage, injuries, and even fatalities.

Congestion

Motorists mainly dislike traffic congestion because of wasted time and the resulting increased vehicle operating costs. Excessive operating costs can be measured with a fair degree of precision.

> On a one-mile free-flowing roadway with a 30-mph speed limit, three stops of 30 seconds each will result in an increase of about 90 percent in total running costs of the car. The value of a motorist's time is far more difficult to measure. However, evidence shows that, given a choice, motorists will forfeit operating economy to save time.

Crashes

Crashes can have the most severe consequences of all traffic problems. Nationally, in 2005, there were 43,443 traffic related fatalities. Of these 25,347 were a result of road departure; 9,188 were intersection related; and 4,881 were pedestrians. These numbers indicate that there are opportunities for improvement to our roadway system which, in turn, would lower the crash rate.

Several means are available for identifying safety and operational problems on military bases. Crash analyses, roadway or intersection capacity studies, and field observation can be used in this identification process.

Crashes should be studied in an attempt to reduce the crash rate on an installation. The basic procedures in a crash study are: collection of crash data, identification of high crash locations, analysis of available data, and improvement identification. Information gained from studies of crash history may be used to identify necessary improvements that would, in turn, prevent future crashes. Crashes may be prevented by application of traffic control devices, law enforcement, driver education, and safety-oriented traffic engineering.

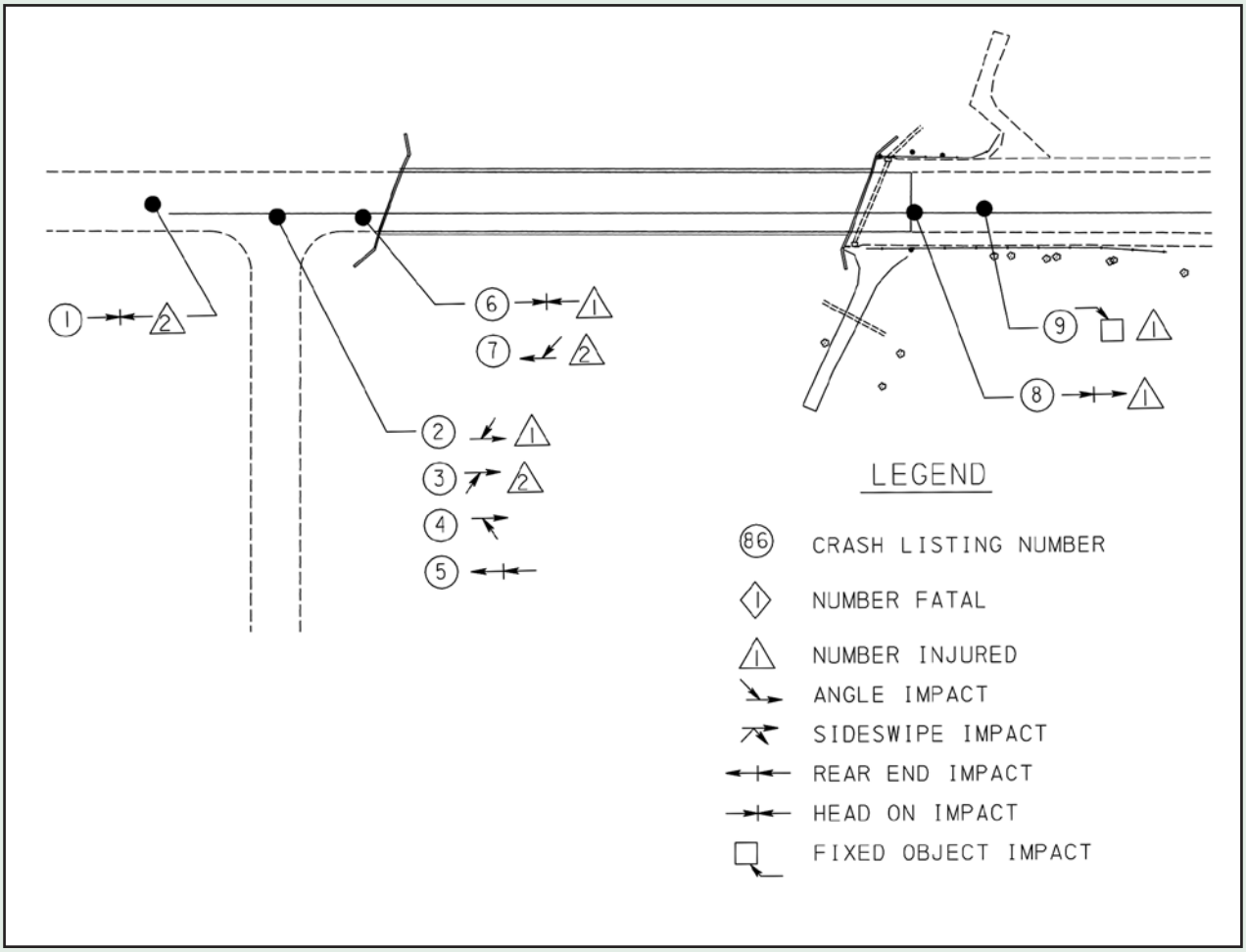
Crash reports should be collected and summarized in an orderly fashion. They are usually filed in the installation security or safety offices.

The following data should be included in the crash report:

- ✓ Location
- ✓ Day of the week, time of day, and weather conditions
- ✓ Severity
- ✓ Types of vehicles
- ✓ Collision paths of vehicles
- ✓ Probable cause

Once crash reports are obtained, they can be summarized by creating crash diagrams. As shown below, crash diagrams are graphical representations of the crash pattern at a particular location. Typically, crash diagrams are drawn using arrows to represent the movement of the vehicles involved and how the vehicles impacted each other. Crash diagrams can quickly illustrate the situation where concentrations of crashes are located.

CRASH DIAGRAM EXAMPLE



Once high crash locations are identified, the causal or contributory factors must be determined. These factors must be explored sufficiently to ensure that design features and control applications are fully evaluated for their contributory role. The procedure used to evaluate problem locations is summarized below.

- ✓ Assemble crash reports for the location under study. Typically, the most current two- to three-year period is used; however, a one-year period is acceptable if that is the only data available.
- ✓ Prepare a crash diagram, which is a not-to-scale drawing of the location showing patterns or similarities in crashes. Each crash is plotted to show direction of approach; type, severity, date, and time of crash; and weather conditions at the time of the crash.
- ✓ Prepare a condition diagram, which is a scale drawing of the location showing all physical conditions that may influence driver behavior. The drawing should show all features such as curbs, driveways, markings, traffic control devices, and so forth.
- ✓ Assemble necessary data such as traffic volumes, approach speeds, intersection delay, parking conditions, and traffic control device observance.
- ✓ Analyze problem to define primary and secondary causal contributors.

Once contributory factors are identified, a safety audit can be performed for the intersection or roadway corridor. A safety audit is a procedural approach to evaluating roadway safety. Roadway corridors are reviewed with the focus on the following:

- ✓ Pedestrian accommodations
- ✓ Signing and pavement markings
- ✓ Drainage
- ✓ Roadside hazards
- ✓ Geometric deficiencies

Safety audits focus on improving roadway safety, often through low-cost improvements

3.2. TRAFFIC DATA COLLECTION

KEY POINT

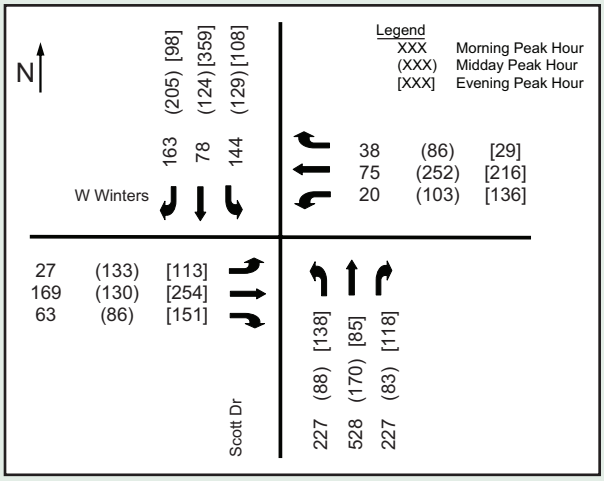
Traffic volume information is crucial to developing traffic-related improvements.

Intersection turning movement counts (TMC) are taken to obtain data on the movement of vehicles through an intersection or along a roadway. All vehicles that travel through an intersection are recorded in 15-minute increments according to their movements – either left-turn, straight, or right-turn. Electronic count boards are commonly used but, in the absence of equipment, people can manually tally vehicles. Typically, TMCs are performed in the morning peak period (0600-0900), midday peak period (1100-1300), and afternoon peak period (1500-1800). When more targeted time periods are known based on installation-specific information, the counting time periods can be reduced.

Typical turning movement counter

If the data is being summarized manually, convert it into a usable form. Add all turning volumes for each peak period studied in a 15-minute interval, and add all consecutive sets of four 15-minute intervals to obtain a peak hour volume. When the peak hour is identified, add the four 15-minute intervals separately for all intersection movements to obtain peak hour turning movements. The movements can then be summarized on a turning-movement diagram, as shown below.

TYPICAL TURNING MOVEMENT COUNT SUMMARY



More commonly, though, software is used in lieu of manually creating turning movement diagrams.

The diagram can also show pedestrian, bicycle, or other classification data as necessary.

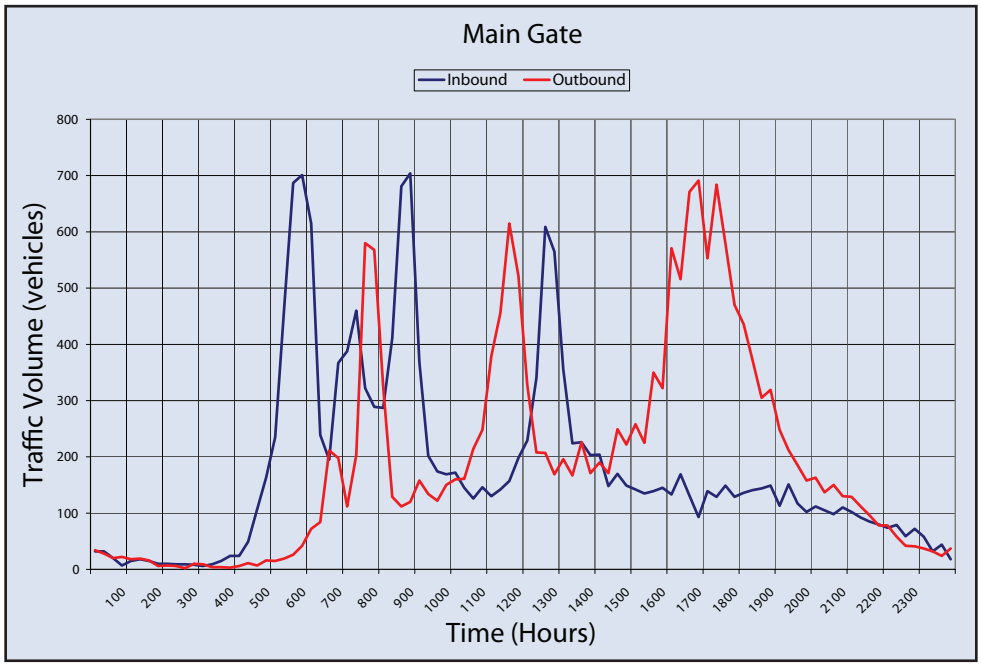
Automated traffic recording (ATR) devices are commonly used to obtain 24-hour count data. Common ATRs include tubes across the road or in-lane card counters. The total volume from a 24-hour count is commonly referred to as the average daily traffic (ADT).

Many ATRs provide other useful information such as speed and vehicle classification data. Speed data is valuable in identifying the appropriate speed limit of a roadway. Vehicle classification data is necessary in pavement design, and identifying routes that trucks may prefer to use.

Tube-style ATR

In-lane card counter

Traffic volume profiles from 24-hour ATR data help identify peak time periods. This data can be useful in several different types of applications, such as determining appropriate hours for separate traffic signal timing plans and ECF operations.



Example 24-hour traffic volume profile

3.3. FIELD ASSESSMENTS

KEY POINT

Field assessments by knowledgeable personnel are crucial to fully analyze problem areas.

Direct field observation by knowledgeable personnel is one of the most neglected techniques for problem identification. Such problems as pedestrian interference and conflicts from driveways; visibility constraints that are not necessarily shown on a condition diagram; and driver behavior patterns are usually identified only by field observation.

A field assessment was conducted to discover a safety problem at the intersection of two local residential streets. The crash pattern was such that eastbound and southbound vehicles were colliding at right angles, and the number of crashes was excessive for the low volumes on the two streets.

A review of crash diagrams immediately revealed that the probable cause of many of these crashes was the poor corner visibility at the northwest corner. However, several hours of field observation uncovered the more likely cause – extremely poor corner visibility at the southwest corner was forcing eastbound drivers to place all of their attention in that direction as they crossed the intersection, thus ignoring the southbound traffic.

Field observation is also very valuable in the study of possible geometric enhancements to improve traffic operations. For example, proper channelization can be established through the observance of actual vehicle movements. The scouring of pavement by tires often gives a good clue as to the "natural path" being followed by most drivers. These natural paths can be studied in the field or from aerial photos before geometric improvements are designed.

Field assessment

Exhibit 3.1 shows probable causes for crash patterns that can be identified through a field assessment. General countermeasures to eliminate the causes are also provided.

Exhibit 3.1: General Crash Pattern

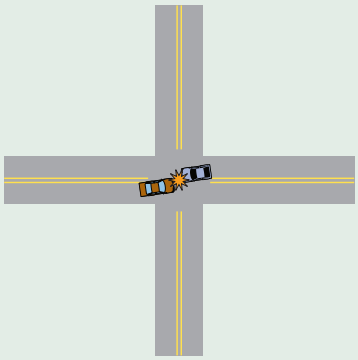
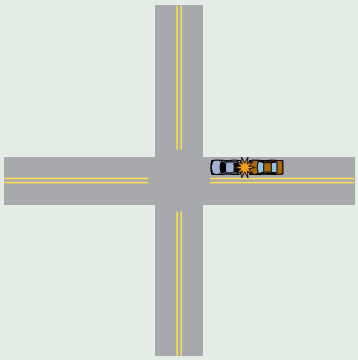
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Left-turn head-on collisions 	✓ Large volume of left turns	✓ Create one-way street ✓ Widen road ✓ Provide left-turn signal phases ✓ Prohibit left turns ✓ Reroute left-turn traffic ✓ Channelize intersection ✓ Install STOP signs (see *Manual on Uniform Traffic Control Devices [MUTCD]*) ✓ Revise signal sequence ✓ Provide turning guide lines (if there is a dual left-turn lane) ✓ Provide traffic signal if warranted by *MUTCD* ✓ Retime signals ✓ Add a roundabout
	✓ Restricted sight distance	✓ Remove obstacles ✓ Provide adequate channelization ✓ Provide special phase for left-turning traffic ✓ Provide left-turn lanes ✓ Install warning signs ✓ Reduce speed limit on approaches
	✓ Too short yellow phase	✓ Increase yellow intervals ✓ Provide all-red phase
	✓ Absence of special left-turning phase	✓ Provide special phase for left-turning traffic
	✓ Excessive speed on approaches	✓ Reduce speed limit on approaches
Rear-end collisions at unsignalized intersections 	✓ Driver not aware of intersection	✓ Install/improve warning signs
	✓ Slippery surface	✓ Overlay pavement ✓ Provide adequate drainage ✓ Groove pavement ✓ Reduce speed limit on approaches ✓ Provide Slippery When Wet signs
	✓ Large volume of turning vehicles	✓ Create left- and right-turn lanes ✓ Prohibit turns ✓ Increase curb radii
	✓ Inadequate roadway lighting	✓ Improve roadway lighting

Exhibit 3.1: General Crash Pattern (continued)

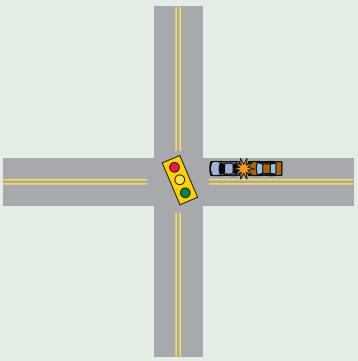
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Rear-end collisions at unsignalized intersections (continued)	✓ Excessive speed on approaches	✓ Reduce speed limit on approaches
	✓ Inadequate gaps	✓ Provide traffic signal, if warranted by *MUTCD* ✓ Provide STOP signs ✓ Add a roundabout
	✓ Crossing pedestrians	✓ Install/improve signing or marking of pedestrian crosswalks
Rear-end collisions at signalized intersections 	✓ Slippery surface	✓ Overlay pavement ✓ Provide adequate drainage ✓ Groove pavement ✓ Reduce speed limit on approaches ✓ Provide Slippery When Wet signs
	✓ Large volume of turning vehicles	✓ Create left- and right-turn lanes ✓ Prohibit turns ✓ Increase curb radii ✓ Provide special phase for left-turning traffic ✓ Add a roundabout
	✓ Poor visibility of signals	✓ Install/improve advance warning devices ✓ Install overhead signals ✓ Install 12-inch signal lenses ✓ Install visors ✓ Install backplates ✓ Relocate signals ✓ Add additional signal heads ✓ Remove obstacles ✓ Reduce speed limit on approaches
	✓ Inadequate signal timing	✓ Adjust yellow interval ✓ Provide progression through a set of signalized intersections ✓ Add all-red clearance interval
	✓ Unwarranted signals	✓ Remove signals (see *MUTCD*)
	✓ Inadequate roadway lighting	✓ Improve roadway lighting
	✓ Crossing pedestrians	✓ Install/improve signing or marking of pedestrian crosswalks ✓ Provide pedestrian WALK phase

Exhibit 3.1: General Crash Pattern (continued)

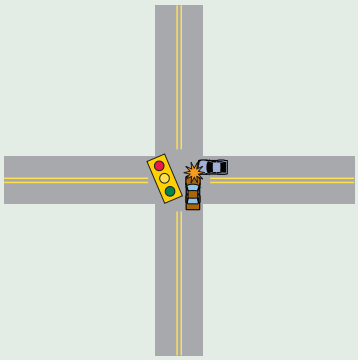
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Right-angle collisions at signalized intersections 	✓ Restricted sight distance	✓ Remove sight obstructions ✓ Restrict parking near corners ✓ Install warning signs (see *MUTCD*) ✓ Reduce speed limit on approaches ✓ Channelize intersections ✓ Install advance markings to supplement signs
	✓ Excessive speed on approaches	✓ Reduce speed limit on approaches ✓ Increase yellow interval ✓ Install rumble strips ✓ Add a roundabout
	✓ Poor visibility of signal	✓ Install advance warning devices ✓ Install 12-inch signal lenses ✓ Install overhead signal ✓ Install visors ✓ Install backplates ✓ Improve location of signal heads ✓ Add additional signal heads ✓ Add illuminated street name signs
	✓ Inadequate signal timing	✓ Adjust yellow interval ✓ Provide all-red clearance interval ✓ Install actuated signal controller ✓ Retime signals ✓ Provide progression through a set of signalized intersections
	✓ Inadequate roadway lighting	✓ Improve roadway illumination
	✓ Inadequate intersection advance warning signs	✓ Install additional intersection advance warning signs
	✓ Large intersection volume	✓ Retime signals ✓ Add traffic lane

Exhibit 3.1: General Crash Pattern (continued)

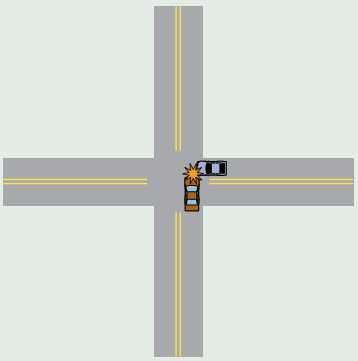
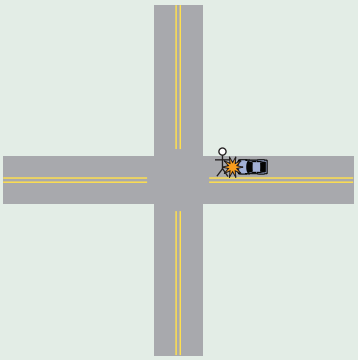
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Right-angle collisions at unsignalized intersections 	✓ Restricted sight distance	✓ Remove sight obstructions ✓ Restrict parking near corners ✓ Install STOP signs (see *MUTCD*) ✓ Install warning signs (see *MUTCD*) ✓ Reduce speed limit on approaches ✓ Install signal (see *MUTCD*) ✓ Install YIELD signs (see *MUTCD*) ✓ Channelize intersection ✓ Install advance markings to supplement signs ✓ Install limit lines ✓ Add a roundabout
	✓ Large intersection volume	✓ Install signal (see *MUTCD*) ✓ Reroute through traffic
	✓ Excessive speed on approaches	✓ Reduce speed limit on approaches ✓ Increase yellow interval ✓ Install rumble strips
	✓ Inadequate roadway lighting	✓ Improve roadway illumination
	✓ Inadequate intersection advance warning signs	✓ Install intersection advance warning signs
	✓ Inadequate traffic control devices	✓ Upgrade traffic control devices ✓ Increase enforcement
Pedestrian-vehicular collisions 	✓ Restricted sight distance	✓ Remove sign obstructions ✓ Install pedestrian crossings ✓ Install/improve pedestrian crossing signs ✓ Reroute pedestrian paths ✓ Prohibit curb parking near crosswalks
	✓ Inadequate protection for pedestrians	✓ Add pedestrian refuge islands ✓ Install pedestrian barriers
	✓ School crossings	✓ Use guards at school crossings
	✓ Inadequate signals	✓ Install pedestrian signals (see *MUTCD*)
	✓ Inadequate phasing for signal	✓ Change timing of pedestrian phase
	✓ Driver inadequately warned of frequent mid-block crossings	✓ Prohibit parking ✓ Install warning signs ✓ Lower speed limit ✓ Install pedestrian barriers

Exhibit 3.1: General Crash Pattern (continued)

CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Pedestrian-vehicular collisions (continued)	✓ Inadequate pavement markings	✓ Install thermoplastic markings ✓ Supplement markings with appropriate signing (see *MUTCD*) ✓ Upgrade pavement markings (see *MUTCD*)
	✓ Inadequate gaps at unsignalized intersections	✓ Install traffic signal, if warranted (see *MUTCD*) ✓ Install pedestrian crosswalk and signs ✓ Install pedestrian WALK-DONT WALK signals
	✓ Inadequate roadway lighting	✓ Improve road lighting
	✓ Excessive vehicle speed	✓ Reduce speed limit ✓ Install proper warning signs ✓ Install pedestrian barriers ✓ Use enforcement
Run off roadway collisions	✓ Slippery pavement	✓ Overlay existing pavement ✓ Provide adequate drainage ✓ Groove existing pavement ✓ Reduce speed limit ✓ Provide Slippery When Wet signs
	✓ Roadway design inadequate for traffic conditions	✓ Widen lanes ✓ Relocate islands ✓ Close curb lanes ✓ Install guardrails
	✓ Poor delineation	✓ Improve/install pavement markings ✓ Install roadside delineations ✓ Install advance warning signs
	✓ Inadequate roadway lighting	✓ Improve roadway lighting
	✓ Inadequate shoulders	✓ Upgrade roadway shoulders
	✓ Improper channelization	✓ Improve channelization
	✓ Inadequate pavement maintenance	✓ Perform road surface repair
	✓ Poor visibility	✓ Increase size of signs
	✓ Excessive speed on approaches	✓ Reduce speed limit

Exhibit 3.1: General Crash Pattern (continued)

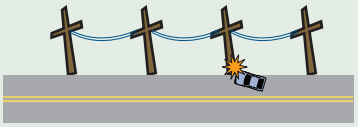
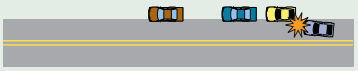
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Fixed object collisions 	✓ Obstructions in or too close to roadway	✓ Remove obstacles ✓ Install barrier curbing ✓ Install breakaway features to light poles, signposts, and so forth ✓ Protect objects with guardrail ✓ Install crash cushioning devices
	✓ Inadequate roadway lighting	✓ Improve roadway lighting
	✓ Inadequate pavement marking	✓ Install reflectorized pavement lines
	✓ Inadequate signs, delineators, and guardrails	✓ Install reflectorized paint and/or reflectors on the obstruction
	✓ Inadequate road design	✓ Provide proper superelevation ✓ Improve superelevation at curve ✓ Install appropriate warning signs and delineators
	✓ Slippery surface	✓ Improve skid resistance ✓ Provide adequate drainage ✓ Provide Slippery When Wet signs ✓ Groove existing pavement
	✓ Excessive vehicle speed	✓ Reduce speed limit ✓ Use enforcement
Collisions with parked or parking vehicles 	✓ Improper pavement markings	✓ Stripe per recommended standards
	✓ Improper parking clearance at driveways	✓ Post parking restrictions near driveways
	✓ Angle parking	✓ Convert angle parking to parallel parking
	✓ Excessive vehicle speed	✓ Reduce speed limit if justified by spot speed studies
	✓ Illegal parking	✓ Use enforcement
	✓ Improper parking	✓ Prohibit parking ✓ Create off-street parking
	✓ Large parking turnover	✓ Create one-way streets ✓ Reroute through traffic

Exhibit 3.1: General Crash Pattern (continued)

CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Sideswipe or head-on collisions	✓ Inadequate roadway design	✓ Create one-way streets and provide wider lanes
	✓ Improper road maintenance	✓ Perform necessary road surface repairs
	✓ Inadequate shoulders	✓ Improve shoulders
	✓ Excessive vehicle speed	✓ Reduce speed limit ✓ Install median devices ✓ Remove constriction such as parked vehicles
	✓ Inadequate pavement markings	✓ Install or refurnish center lines, lane lines, and pavement edge lines ✓ Install reflectorized lines and edges
	✓ Inadequate channelization	✓ Install acceleration and deceleration lanes ✓ Channelize intersection ✓ Provide turning lanes
	✓ Inadequate signing	✓ Add illuminated street name signs ✓ Add advance street name signs ✓ Install lane use control signs at the beginning of turn lanes

Exhibit 3.1: General Crash Pattern (continued)

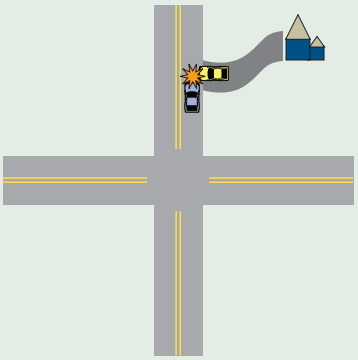
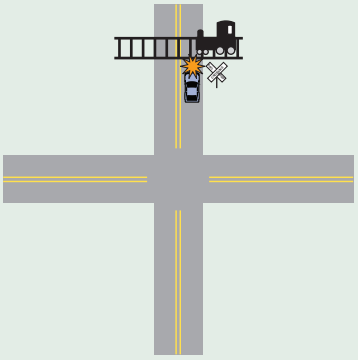
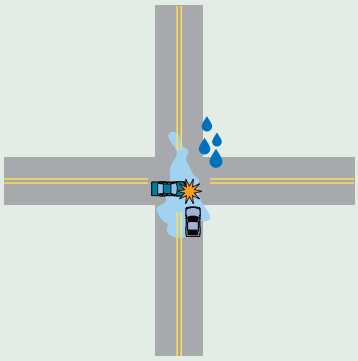
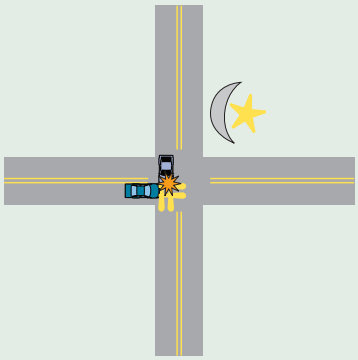
CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Driveway-related collisions 	✓ Left-turning vehicles	✓ Install median devices ✓ Install two-way left-turn lanes
	✓ Improperly located driveway	✓ Regulate minimum spacing of driveways ✓ Move driveway to side street ✓ Install curbing to define driveway location ✓ Consolidate adjacent driveways
	✓ Right-turning vehicles	✓ Provide right-turn lanes ✓ Restrict parking near driveways ✓ Widen driveways ✓ Widen through lanes ✓ Increase curb radii
	✓ Large volume of through traffic	✓ Move driveway to side street ✓ Construct a local service road ✓ Reroute through traffic
	✓ Restricted sight distance	✓ Remove sight obstructions ✓ Restrict parking near driveway ✓ Install/improve street lighting ✓ Reduce speed limit
	✓ Inadequate roadway lighting	✓ Improve roadway lighting
Train-vehicle crashes 	✓ Restricted sight distance	✓ Remove sight obstructions ✓ Reduce grade ✓ Install train-actuated signals (see *MUTCD*) ✓ Install STOP sign (see *MUTCD*) ✓ Install advance warning signs (see *MUTCD*) ✓ Install automated flashers and gates
	✓ Poor visibility	✓ Improve roadway lighting ✓ Increase size of signs
	✓ Improper traffic signal preemption timing	✓ Retime traffic signals
	✓ Excessive vehicle speeds on approaches	✓ Revise speed limit

Exhibit 3.1: General Crash Pattern (continued)

CRASH PATTERN	PROBABLE CAUSE	GENERAL COUNTERMEASURE
Train-vehicle crashes (continued)	✓ Inadequate pavement markings	✓ Install advance markings to supplement signs ✓ Install limit lines ✓ Install/improve pavement markings
	✓ Slippery surface	✓ Skidproof roadway
	✓ Improper preemption of railroad signals or gates	✓ Retime railroad signals and gates
	✓ Rough crossing surfaces	✓ Improve crossing surfaces
	✓ Sharp crossing angle	✓ Rebuild crossing with proper angle
Wet-pavement crashes 	✓ Slippery pavement	✓ Overlay existing pavement ✓ Groove existing pavement ✓ Reduce speed limit ✓ Provide Slippery When Wet signs ✓ Skidproof roadway
	✓ Inadequate drainage	✓ Provide adequate drainage
	✓ Inadequate pavement markings	✓ Upgrade pavement markings
Night crashes 	✓ Poor visibility or lighting	✓ Install/improve street lighting ✓ Install/improve delineation markings ✓ Install/improve warning signs
	✓ Poor sign quality	✓ Upgrade signing ✓ Provide illuminated signs
	✓ Inadequate channelization or delineation	✓ Install pavement markings ✓ Improve delineation markings ✓ Provide raised markers ✓ Upgrade advance warning signs

Source: MTMC, Better Military Traffic Engineering, 1987

3.4. LEVELS OF SERVICE

Level of service (LOS) is a measure of intersection performance based on the amount of delay through an intersection or roadway corridor. Levels of service are calculated using peak hour traffic volumes. When calculating LOS, traffic volumes for the morning, midday, and evening peak hours from an average day are used. Formulas for calculating LOS are provided in the *Highway Capacity Manual*. Software, such as *Synchro* and *Highway Capacity Software (HCS)*, is also available to calculate levels of service. Both of these software programs are upgraded frequently; however, the current versions as of the publication date of this pamphlet are *Synchro 7* and *HCS+ 5.5*.

There are six LOS classifications, "A" through "F." "A" represents the best; "F" represents the worst. LOS "A" and "B" are considered to be good. LOS "C" and "D" are considered to be acceptable. LOS "E" and "F" are considered to be unacceptable. LOS is summarized in Exhibit 3.2. When designing a new intersection, designing for a LOS C or better is often desirable. LOS D or better is often considered acceptable for existing facilities.

Typically, at conventional intersections, deficient LOS can be improved by adding turning lanes or by improving traffic signal phasing and timings. Typically intersections along a corridor govern operations and LOS. When this is not the case, and if a roadway corridor has deficient LOS, it may need additional through lanes to attain acceptable LOS.

Timings
27: 761st Tank Battalion Ave & Hood Rd

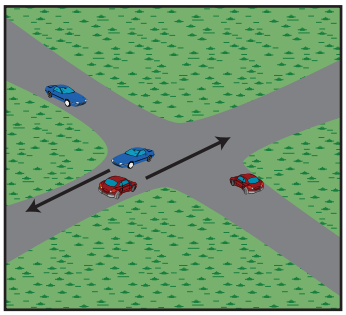
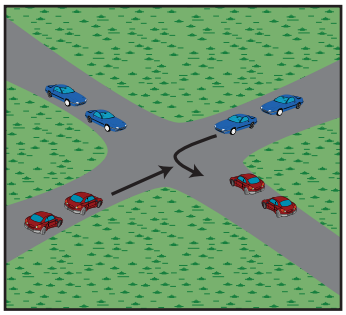
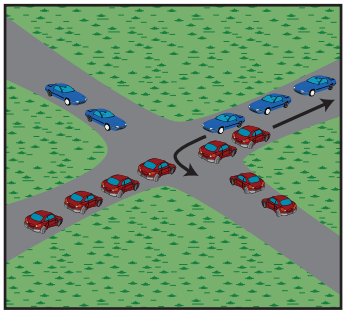
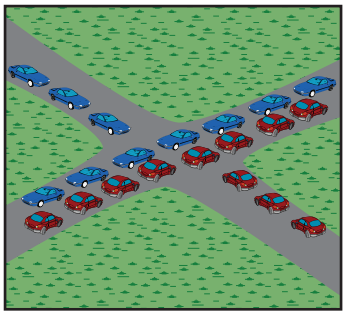
Lane Group	EBL	EBT	EBR	WBL	WBT	NBL	NBT	SBL	SBT
Lane Configurations									
Volume (vph)	192	129	88	121	106	97	911	122	882
Turn Type	pm+pt		Perm	pm+pt		pm+pt		pm+pt	
Protected Phases	3	8		7	4	1	6	5	2
Permitted Phases	8		8	4		6		2	
Detector Phase	3	8	8	7	4	1	6	5	2
Switch Phase									
Minimum Initial (s)	7.0	10.0	10.0	7.0	10.0	7.0	10.0	7.0	10.0
Minimum Split (s)	13.5	22.5	22.5	13.5	22.5	13.5	22.5	13.5	22.5
Total Split (s)	14.0	22.8	22.8	13.8	22.6	13.6	39.8	13.6	39.8
Total Split (%)	15.6%	25.3%	25.3%	15.3%	25.1%	15.1%	44.2%	15.1%	44.2%
Yellow Time (s)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
All-Red Time (s)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Lost Time Adjust (s)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Lead/Lag	Lead	Lag	Lag	Lead	Lag	Lead	Lag	Lead	Lag
Lead-Lag Optimize?									
Recall Mode	None	None	None	None	None	None	Min	None	Min
Act Effct Green (s)	25.2	15.2	15.2	24.8	15.0	44.6	35.0	45.4	37.9
Actuated g/C Ratio	0.29	0.18	0.18	0.29	0.18	0.52	0.41	0.53	0.44
v/c Ratio	0.79	0.35	0.42	0.53	0.57	0.38	0.84	0.59	0.81
Control Delay	43.1	32.7	8.2	27.3	19.0	13.9	29.5	23.6	27.2
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	43.1	32.7	8.2	27.3	19.0	13.9	29.5	23.6	27.2
LOS	D	C	A	C	B	B	C	C	C
Approach Delay		29.8			21.8		28.3		26.8
Approach LOS		C			C		C		C

Splits and Phases: 27: 761st Tank Battalion Ave & Hood Rd

Image provided courtesy of Trafficware

Example of Synchro Network

Exhibit 3.2: Level of Service Definitions

LOS	INTERSECTIONS		
	SIGNALIZED		UNSIGNALIZED
A	✓ Very low delay, average less than 10.0 seconds per vehicle (spv) ✓ Most vehicles arrive during green phase ✓ Most vehicles do not need to stop		✓ Average delays less than 10.0 spv ✓ Little or no delay to minor street traffic
B	✓ Average delay in range of 10.1-20.0 spv ✓ More vehicles stop than LOS A		✓ Average delay in range of 10.1-15.0 spv ✓ Short traffic delays to minor street traffic
C	✓ Average delay in range of 20.1-35.0 spv ✓ Number of vehicles stopping is significant ✓ Cycle failures may begin to appear		✓ Average delay in range of 15.1-25.0 spv ✓ Average traffic delays to minor street traffic
D	✓ Average delay in range of 35.1-55.0 spv ✓ Congestion more noticeable ✓ Many vehicles stop ✓ Cycle failures noticeable		✓ Average delay in range of 25.1-35.0 spv ✓ Long traffic delays to minor street traffic
E	✓ Average delay in range of 55.1-80.0 spv ✓ Cycle failures frequent		✓ Average delay in range of 35.1-50.0 spv ✓ Very long delays to minor street traffic
F	✓ Average delay in excess of 80.0 spv ✓ Delay unacceptable to most drivers ✓ Many cycle failures		✓ Average delay in excess of 50.0 spv ✓ Extreme delays with queuing ✓ Congestion affects other intersections ✓ Warrants improvement to intersection

3.5. APPLICATION

Traffic volumes provide basic traffic data and are used with other types of data to support all traffic-improvement decisions. Volumes are typically used to:

- ✓ Justify installation (or removal) of a traffic signal by comparing with traffic signal warrants.
- ✓ Determine appropriate traffic signal timing and phasing.
- ✓ Indicate the need for traffic control signs according to the requirements stated in the *MUTCD*.
- ✓ Evaluate crash data and study the relationship of turning movements with crashes and congestion.
- ✓ Compare day and night traffic volumes with their associated crash rates to determine the need for street lighting.
- ✓ Assist in the development of a street-classification system such as arterial, collector, and local streets.
- ✓ Evaluate the need for intersection or roadway corridor improvements.
- ✓ Indicate long-term growth trends for vehicle usage and for traffic volumes in general.
- ✓ Assist in establishing construction and maintenance priorities.
- ✓ Assist in establishing road pavement markings and in determining the required frequency for repainting traffic-worn lines.
- ✓ Assist in analyzing parking demands and in assessing the impact of new traffic generators on the surrounding streets.

CHAPTER 4 – GEOMETRIC DESIGN BASICS

4.1. ROADWAY FEATURES 4-1

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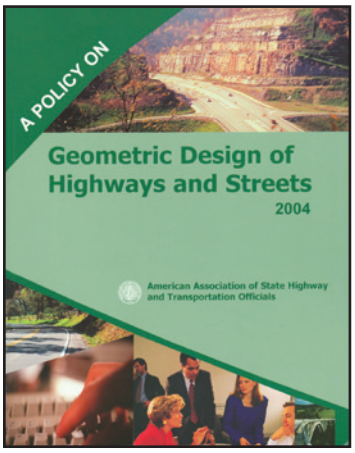
4.9. OUTSIDE CONTINENTAL UNITED STATES (OCONUS) CONSIDERATIONS 4-23

Roadway features such as design speed, roadway classification, design vehicle, land use, and traffic volumes are considered in determining the design criteria for a project. Design criteria can be divided into three categories: cross section, horizontal alignment, and vertical alignment. Additional areas of concern are intersection design, pavement design, and drainage design.



The primary "how-to" book on geometric design published by AASHTO, is titled *A Policy on Geometric Design of Highways and Streets*, commonly called the *Greenbook*. The *Greenbook* has design criteria on all areas of roadway and highway design. In addition to design criteria in the Greenbook, several state departments of transportation have also developed state-specific guidelines. There may be cases where state criteria exceeds AASHTO; therefore, it is important to verify state criteria when developing a design.

4.1. ROADWAY FEATURES

Several factors such as design speed, roadway classification, and design vehicle, influence the geometric design of a roadway. Also, the availability of land and traffic volume may impact design. This section provides basic guidance on general design features.

Design criteria provide a measure of consistency and quality when used by different engineers. Design criteria can be classified into three areas: cross section features; horizontal curvature and alignment; and vertical curvature and clearances. Many design guidelines document minimum design criteria. Whenever possible, minimum design criteria should be exceeded in order to promote safe operations and to enhance roadway operations.

4.1.1. Design Speed

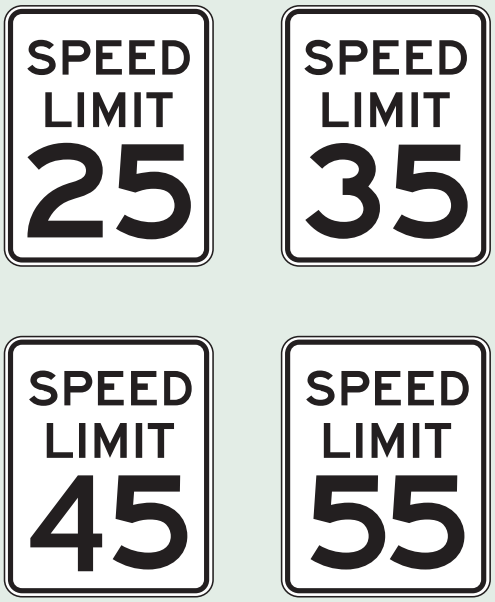
KEY POINT

Design speed is used to determine the various geometric features of a roadway.

Design speed is used to determine the various geometric features of a roadway. The design speed should be a logical speed considering the anticipated operating speed, adjacent land use, and functional classification of the roadway. AASHTO defines the design speed as the maximum safe speed that can be maintained over a specified section of roadway when conditions are so favorable that the design features of the roadway govern.

The selection of design speed should be based on the AASHTO definition of design speed. In no case should the posted speed limit exceed the design speed. In general, a good rule-of-thumb is to set the posted speed limit five miles per hour below the design speed.

VARYING FACILITY SPEEDS



4.1.2. Roadway Classification

Roadways can be classified in one of four ways: freeway, arterial, collector, and local, as shown in Exhibit 4.1.

Exhibit 4.1: Roadway Classifications

CLASSIFICATION		FEATURES	USAGE
CONTROLLED ACCESS (FREEWAY, EXPRESSWAY)		✓ Controlled access by interchanges or other grade-separated facilities ✓ No cross traffic movements provided ✓ Wide or barrier medians provided ✓ Wide shoulders and long acceleration and deceleration lanes	✓ High traffic volumes ✓ Speeds above 55 miles per hour (mph) ✓ Connect urban areas ✓ Provide efficient movement between points of origin
ARTERIAL		✓ At-grade intersections (mostly signalized) ✓ Limited access points ✓ Driveway spacing at large intervals ✓ Cross traffic movement discouraged ✓ Shoulders or curb and gutter provided	✓ High traffic volumes ✓ Speeds of 35-55 mph ✓ Provides connection to major points within an area ✓ Provides connection to controlled access
COLLECTOR		✓ At-grade intersections (mix between signalized and unsignalized intersections) ✓ Access points spaced at smaller intervals ✓ Cross traffic frequent ✓ Small shoulder or curb and gutter provided	✓ Lower traffic volumes than arterials or controlled access ✓ Speeds of 25-40 mph ✓ Connect local facilities ✓ Access abutting land uses ✓ Contribute to arterial volumes
LOCAL		✓ Narrow lanes that are sometimes unstriped ✓ At-grade intersections (mostly unsignalized) ✓ Access points spaced at irregular intervals ✓ Mostly curb and gutter provided	✓ Low traffic volumes ✓ Speeds of 25 mph ✓ Access specific land uses or developments

Source: ITE, Traffic Engineering Handbook

4.1.3. Design Vehicle

KEY POINT

The design vehicle is defined as the largest vehicle likely to use the facility with considerable frequency.

The design team must determine what design vehicle is appropriate for designing a roadway with respect to the expected roadway users. Design vehicles have critical dimensions and operating conditions such that they influence or control the design of one or more roadway elements. The design vehicle is the largest vehicle likely to use the facility with considerable frequency. The design vehicle is used to establish critical geometric features such as turning radii, lane widths, and vertical clearances.

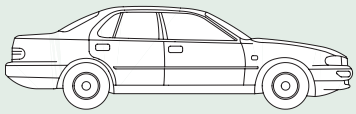
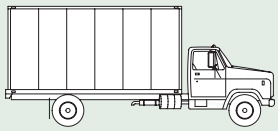
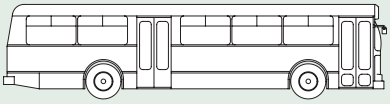
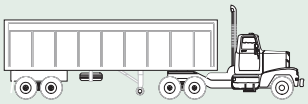
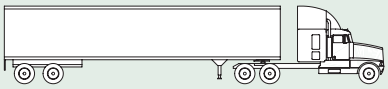
Typically, a design vehicle WB-50 should be used in areas that accommodate trucks. Consider using a WB-67 as a design vehicle where truck percentages are very high. A single unit truck (SU) or a bus (school, transit, or other) may be the appropriate design vehicle at locations where trucks are not permitted.

When using design vehicle turning templates or software programs, it is generally considered unacceptable for vehicles to overtrack into adjacent lanes. Specifically, at intersections or roadways with tight curves, the design vehicle must remain in its lane. If there is a vehicle in an adjacent lane, encroachment into the adjacent lane may result in a sideswipe crash. Generally, encroachment is minimized by widening the lane. With very tight curve radii (less than 200 feet), and larger design vehicles, the lane width may exceed 20 feet.

Exhibit 4.2 illustrates the various design vehicles and their turning radius requirements.

DESIGN VEHICLE EXAMPLES

Exhibit 4.2: Common Design Vehicles

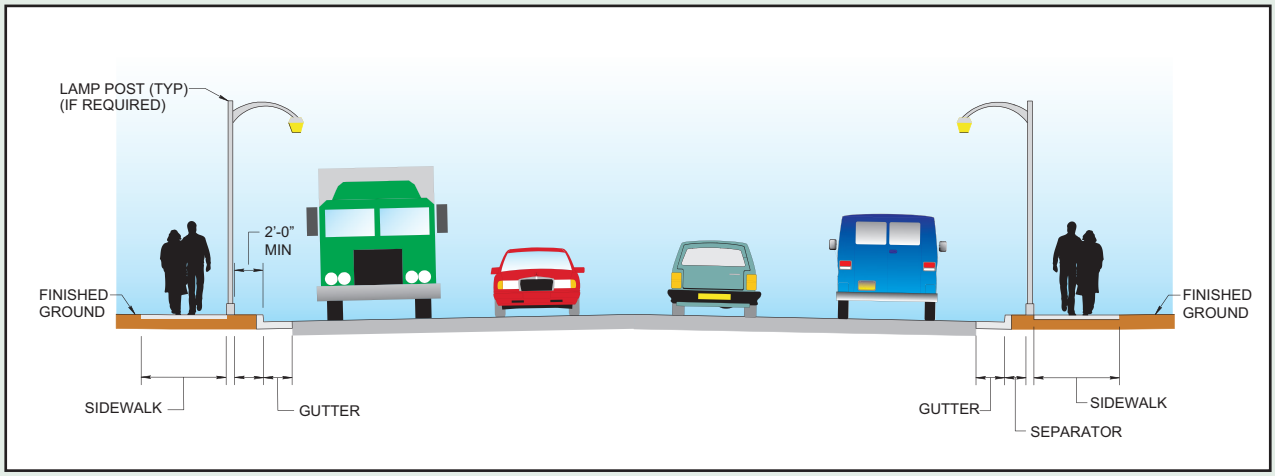
DESIGN VEHICLE	MINIMUM DESIGN TURNING RADIUS (FEET)	CENTER LINE TURNING RADIUS (FEET)	MINIMUM INSIDE RADIUS (FEET)
 Passenger Car (P)	24	21	15
 Single Unit Truck (SU)	42	38	29
 City Transit Bus (CITY-BUS) Note: Design for this vehicle also accommodates school buses.	42	38	25
 Intermediate Semitrailer (WB-50)	45	41	17
 Interstate Semitrailer (WB-67)	45	41	8
Motor Home and Boat Trailer (MH/B) Note: Design for this vehicle accommodates all AASHTO recreational vehicles.	50	46	36

Source: AASHTO, 2004 Greenbook

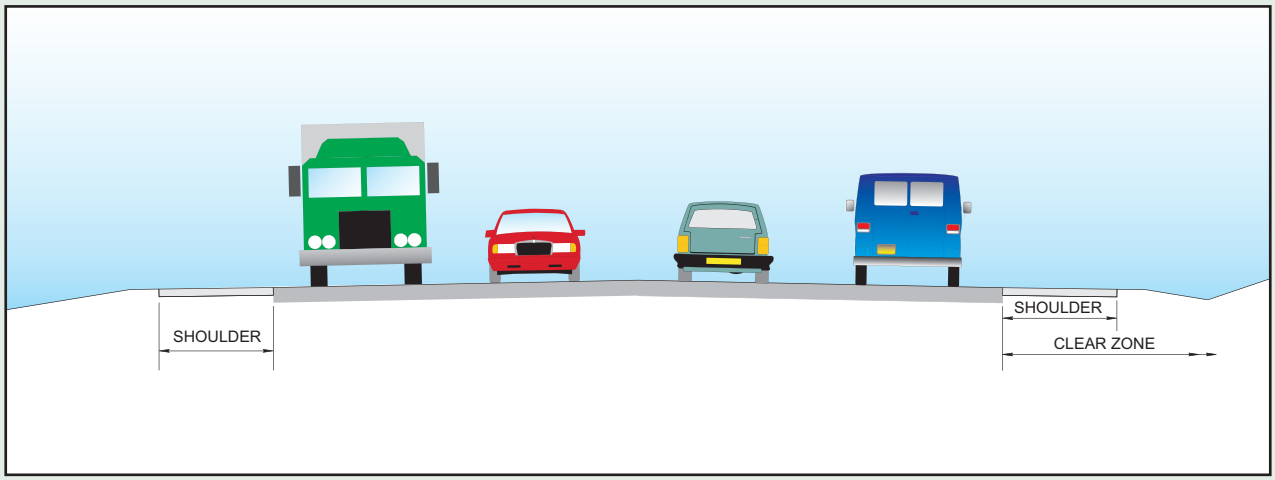
4.2. CROSS SECTIONS

The cross section of a roadway and associated features is the width available for use by vehicles, pedestrians, drainage, and other roadway features. The cross section of the travel way should channelize vehicles into a uniform pattern of movement. As a general rule, travel lanes should be at least 12 feet wide.

ROADWAY TYPICAL SECTION (URBAN)



ROADWAY TYPICAL SECTION (RURAL)



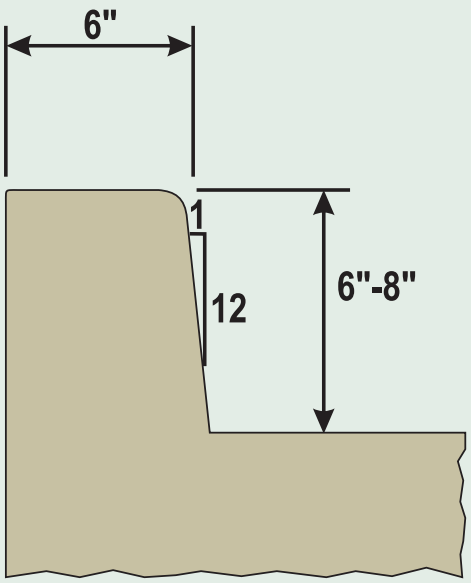
4.2.1. Curb and Gutter

KEY POINT

Combination curb and gutter sections are used to control drainage and channel it longitudinally to drainage inlets.

Gutter sections vary from 1 foot to 6 feet in width. Collector roadways typically utilize a gutter section from 1 foot to 2 feet wide. If a gutter has a different color and texture than the road surface and has a longitudinal joint, it should not be considered part of the travel lane width.

TYPICAL CURB DIMENSIONS



4.2.2. Shoulders

KEY POINT

Roadway shoulders support a variety of functions.

The shoulder is the part of the roadway immediately contiguous to the traveled way. It is intended for several functions, including:

- ✓ To provide a recoverable area outside the traveled way for drivers forced to take evasive action or experiencing temporary loss of control
- ✓ To store a disabled or parked vehicle safely out of the traveled way
- ✓ To support law enforcement activities
- ✓ To provide for certain maintenance functions
- ✓ To provide a temporary travel way during major maintenance and reconstruction
- ✓ To enable a safe travel path outside of higher speed traffic for bicycles

The shoulder width needed depends upon the type of roadway and traffic volumes. The AASHTO *Greenbook* provides specific guidance on the selection of shoulder widths. As shown in Exhibit 4.3, shoulder width varies depending on the type of roadway. As a minimum, when an uncurbed shoulder is present, all fixed objects, such as signs, fence posts, structures, and trees, should be at least 6 feet from the shoulder or 12 feet from the lane edge, whichever provides the greater clearance from the lane edge.

Shoulders should be pitched to drain away from the road surface, but not so much as to make their use hazardous. Their design should be a compromise between slope needs and drivability. Shoulder width should be consistent and continuous. Where transition is made from a shouldered roadway to a curbed, unshouldered roadway (such as entering an urban area from a rural area or an approach to an ECF), the curb should not be abruptly introduced in place of the shoulder. Rather, a transition zone, with a 10:1 minimum taper, should be used to give a driver time to react, especially at night. When a new lane is added on the right, the shoulder should continue at full width through the transition; otherwise, the new lane may appear to be a continuation of the shoulder.

Roadway shoulder

4.2.3. Clear Zone

A clear zone is the total roadside border area from the edge of the travel way that is available for safe use by errant drivers. Adequate clear zones can enhance roadway safety by providing motorists with certain levels of expectation. Clear zones are discussed more in Section 9.2.

4.2.4. Medians

KEY POINT

Medians separate opposing directions of travel.

Medians separate opposing directions of travel and can provide control for left turns. Raised median islands are often used on urban arterials. Medians typically provide green space between vertical faces, and wide medians provide a refuge area for pedestrians and left-turn traffic. When plantings are provided in a median, consult the AASHTO *Roadside Design Guide* for information on obstructions adjacent to the travel way. Additionally, plantings should not obstruct the view of turning vehicles. Typically, medians should not be less than 4 feet wide.

Exhibit 4.3: Roadway Classification Shoulder Width

ROADWAY CLASSIFICATION	AVERAGE DAILY TRAFFIC <400 VEHICLES (FEET)	AVERAGE DAILY TRAFFIC 400-1,499 VEHICLES (FEET)	AVERAGE DAILY TRAFFIC 1,500-2,000 VEHICLES (FEET)	AVERAGE DAILY TRAFFIC >2,000 VEHICLES (FEET)
ARTERIALS	4	6	6	8
COLLECTORS	2	5		
LOCAL				

Source: AASHTO, 2004 Greenbook

4.2.5. Bicycle Accommodations

Bicycles should be accommodated to the greatest extent possible in roadway design. In general, there are four major types of bicycle accommodations:

- ✓ **Shared Roadway, No Bicycle Designation:** Most bicycle travel is done on streets and highways without bicycle designations. With this type of accommodation, there are two subcategories. The street condition is fully adequate for efficient bicycle travel and additional signing and pavement markings is unneeded; or the roadway is not safe for bicycle travel and they should not be encouraged for bicycle travel. A roadway with a 4-foot minimum width shoulder is an example of the former, and a roadway with no shoulder is an example of the latter.
- ✓ **Signed, Shared Roadway:** These are designated by bike route signs. In this case, the owning agency would determine that the route is suitable for a shared route, and will be maintained in a manner consistent with the needs of bicyclists. Signing also informs motorists that bicycles are present.
- ✓ **Bike Lane:** Bike lanes are established with appropriate pavement markings and signing along roadways where there is significant bicycle demand. The intent of this is to improve conditions for bicyclists on streets. Bike lanes delineate the right of way for bicyclists and motorists. Roadway improvements should be made to accommodate the needs for bicyclists, such as eliminating potholes, using bicycle-safe inlets, and ensuring that traffic signals are responsive to bicycles.
- ✓ **Shared Use Path:** Shared paths should be provided where streets and other roadways are not adequate for bicycles, and there is adequate bicycle demand. Abandoned railroad right of way could be converted to a shared use path, or a shared use path can travel parallel to a major roadway or through a park area.

Bike Lane Example

4.3. TURNING MOVEMENTS

KEY POINT

AASHTO and *MUTCD* should be followed in design. Additionally, follow local DOT standards. There may be small differences in policy.

A decision that should be made early in the design process is which design vehicle to use. Different design vehicles have different turning radii. Turning radii influence several areas of design, including ECF, intersection, and parking lot design.

Turning Radii

Characteristics of a design vehicle include: minimum center line turning radius, out-to-out track width, wheelbase, and the path of the inner rear tire. When classifying the vehicles, AASHTO assumes the speed for determining the minimum turning radius is less than 10 mph. Exhibit 4.4 shows the AASHTO values for different design vehicle turning radii.

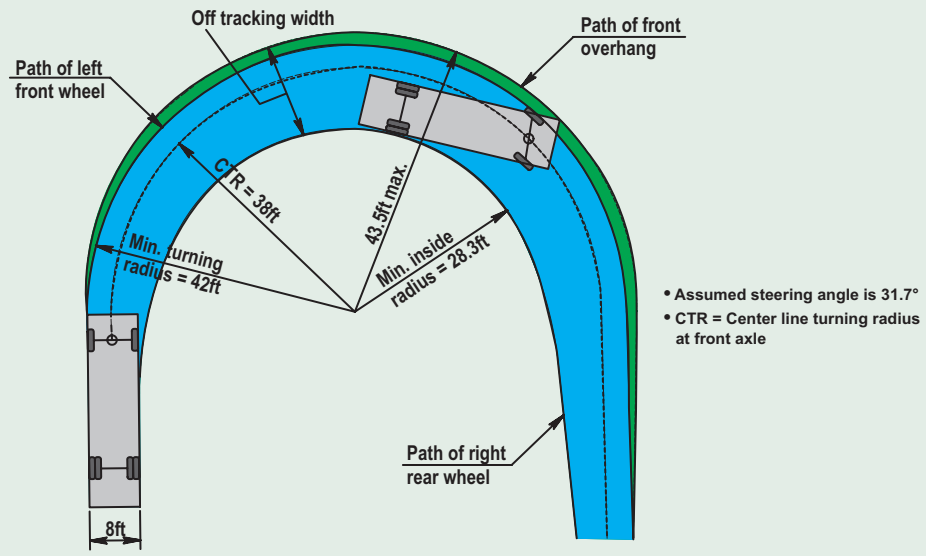
As mentioned previously, in areas where trucks are expected, use the WB-50 or WB-67 as a minimum design vehicle. At other locations, the SU or bus design vehicle should be used.

Exhibit 4.4: Design Turning Radii

DESIGN VEHICLE SERVICED	MINIMUM DESIGN TURNING RADIUS (FEET)
P (PASSENGER CAR)	24
SU (SINGLE UNIT TRUCK)	42
MH/B (MOTOR HOME WITH BOAT TRAILER)	50
WB-50 OR WB-67	45

Source: AASHTO, 2004 Greenbook

MINIMUM TURNING PATH FOR SINGLE-UNIT (SU) TRUCK DESIGN VEHICLE FROM AASHTO *GREENBOOK*



4.4. HORIZONTAL ALIGNMENTS

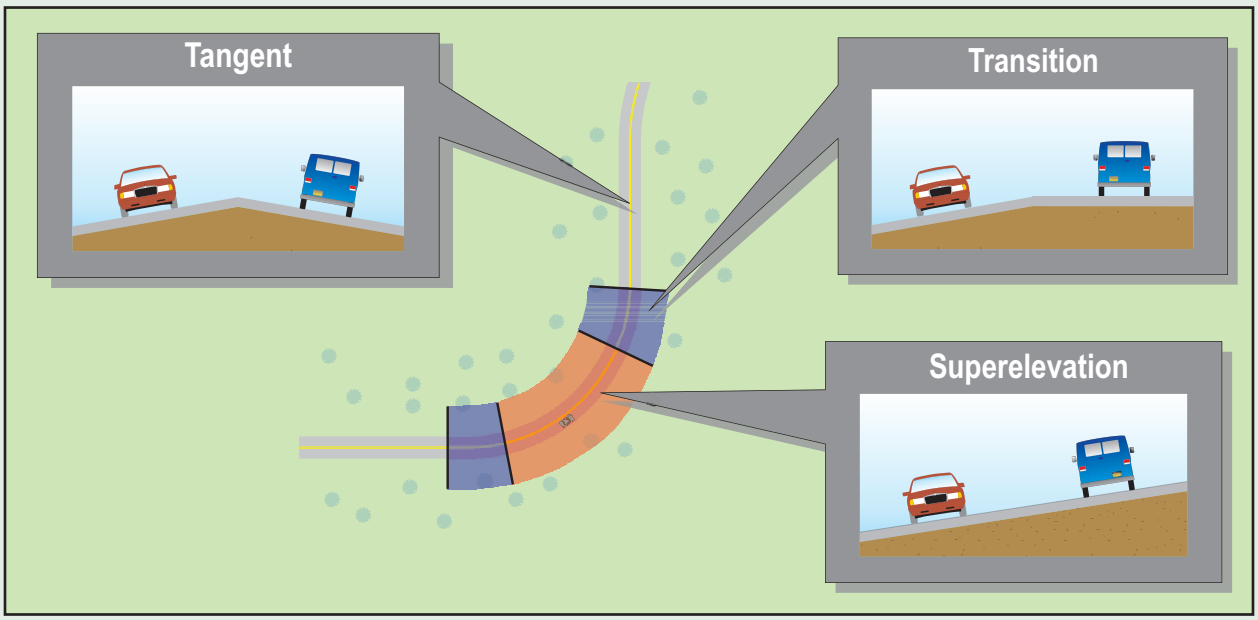
KEY POINT

At a constant speed, as the radius of curves decrease, it is necessary to bank or superelevate the curve to compensate for centripetal forces.

A horizontal alignment is comprised of curves, tangents, and curve transitions. The illustration below shows the locations of tangents, transitions, and superelevation. The goal of a horizontal alignment is to provide a roadway that is suitable in usage to the land that surrounds it, and reinforces the speed that is compatible with that land.

For curves in the roadway where the design speed exceeds 15 mph, curves should be designed based on AASHTO criteria. Curves are designed according to design speed, the surrounding areas, and the climate. The design speed determines the sharpest curve allowable. The surrounding land use dictates how much a curve can be superelevated. When designing horizontal alignment, also provide proper stopping sight distance, as discussed in Section 4.7.

TANGENT, TRANSITION, SUPERELEVATION LOCATIONS

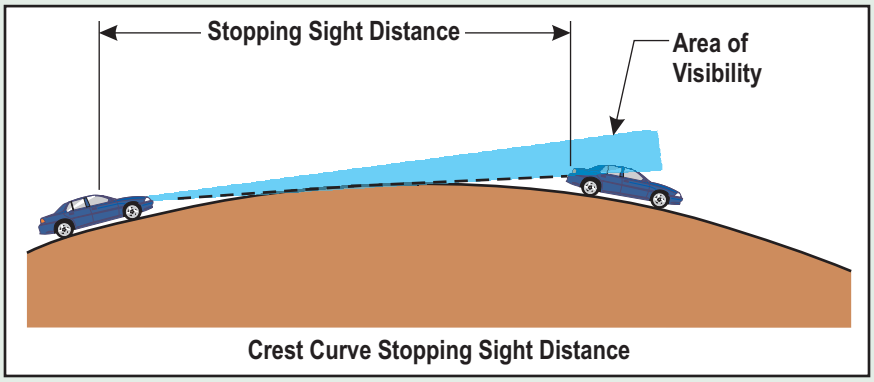


4.5. VERTICAL ALIGNMENTS

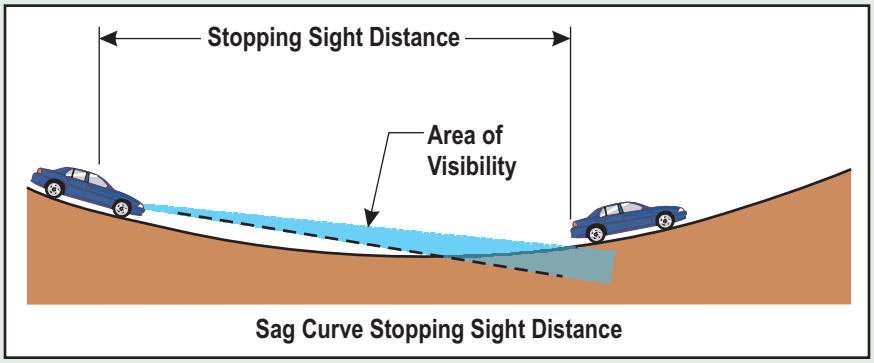
Topography greatly influences vertical alignment of roadway facilities. Vertical alignment is comprised of tangent grades and vertical curves to traverse the topography of the land. Required grades depend on the topographic characteristics. Typically, higher grades are used in mountainous terrain than would be used in level or rolling terrain. The AASHTO *Greenbook* does not set a relationship between maximum grades and design speed; however, higher grades impact traffic flow, particularly with trucks and underpowered cars.

Vertical curves are used to connect different roadway grades. Like horizontal curves, acceptable vertical curvature depends on the design speed of the roadway and the sight distance needed to identify and react to an object in the roadway. The stopping sight distances presented in Exhibit 4.7 on page 4-21 also apply when designing vertical alignment. Vertical curve rates must provide the correct stopping sight distance, which is based on the height of the vehicle's headlights rather than direct line of sight. The AASHTO *Greenbook* sets the design value for headlight height at 2.0 feet. Any object that is within the shadow zone must extend into the headlight beam to be directly illuminated. Therefore, the acceptable rate of vertical curvature varies with speed.

CREST AND SAG VERTICAL CURVES



Crest Curve Stopping Sight Distance



Sag Curve Stopping Sight Distance

4.6. INTERSECTION DESIGN CONSIDERATIONS

KEY POINT

Geometric design and traffic control are the two critical components of intersection design.

The number, type, and spacing of intersections determine to a large degree the capacity, speed, and safety of most installation roadways. Proper geometric design and traffic control are usually based on accommodating traffic demand during the three peak periods: morning, midday, and evening.

Geometric design and traffic control are the two major factors that must be coordinated in intersection design. These factors must be included in intersection design because each impacts and constrains the other. Geometric design includes number and width of lanes, median design, channelization, and curb radii, for example. Traffic control includes devices such as traffic signals and use of STOP and YIELD signs. This section covers geometric design and physical aspects of intersections. Chapter 5 discusses intersection traffic control.

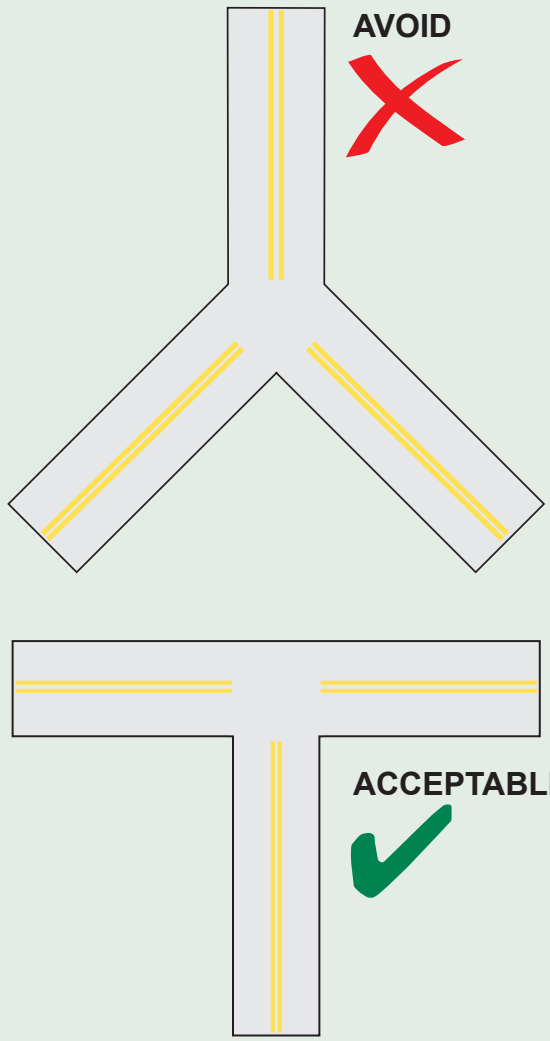
4.6.1. Intersection Types

Basic types of intersections are determined by the number of intersecting legs; that is, three-legged, four-legged, or mutli-legged. However, any one of the basic types can vary greatly in size, shape, and channelization. Once the type is established, a final geometric design can be selected simply by applying the design controls and elements discussed later.

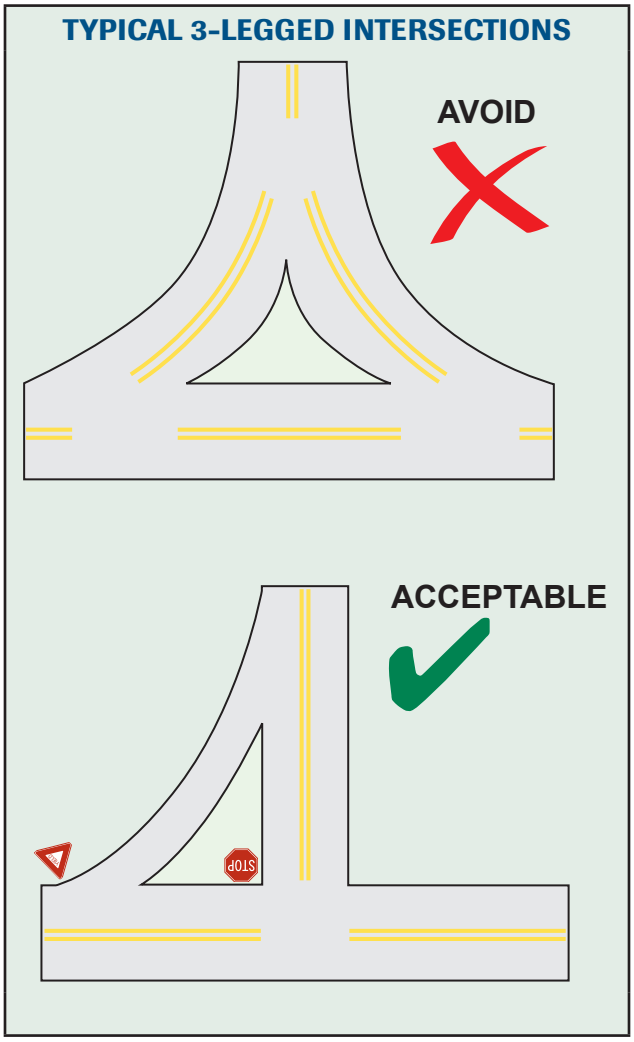
Three-Legged

Generally, this design is used to terminate one roadway. The intersection may be flared or designed with turning roadways where turning movements are hazardous or where traffic volumes warrant their use. A Y-type design, an undesirable version of the T-intersection, generally results in safety and operational problems.

TYPICAL 3-LEGGED INTERSECTIONS



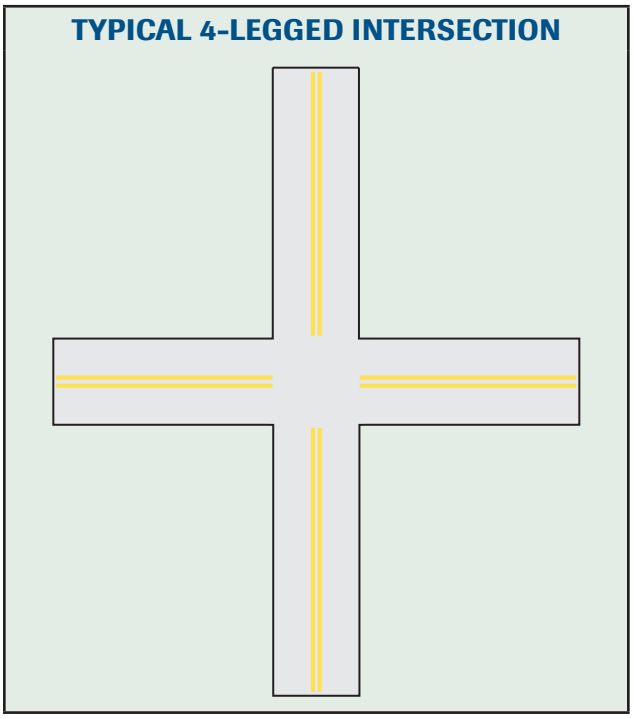
An alternative style of a three-legged intersection is one with two bidirectional turning roadways off of the major roadway which lead to the minor roadway. This type of intersection is generally not desired due to the conflict points through the intersection. It is generally desired to reconstruct these intersections to be three-leg right-angle intersections. If desired, a single-direction turning roadway could be used for right-turn traffic.

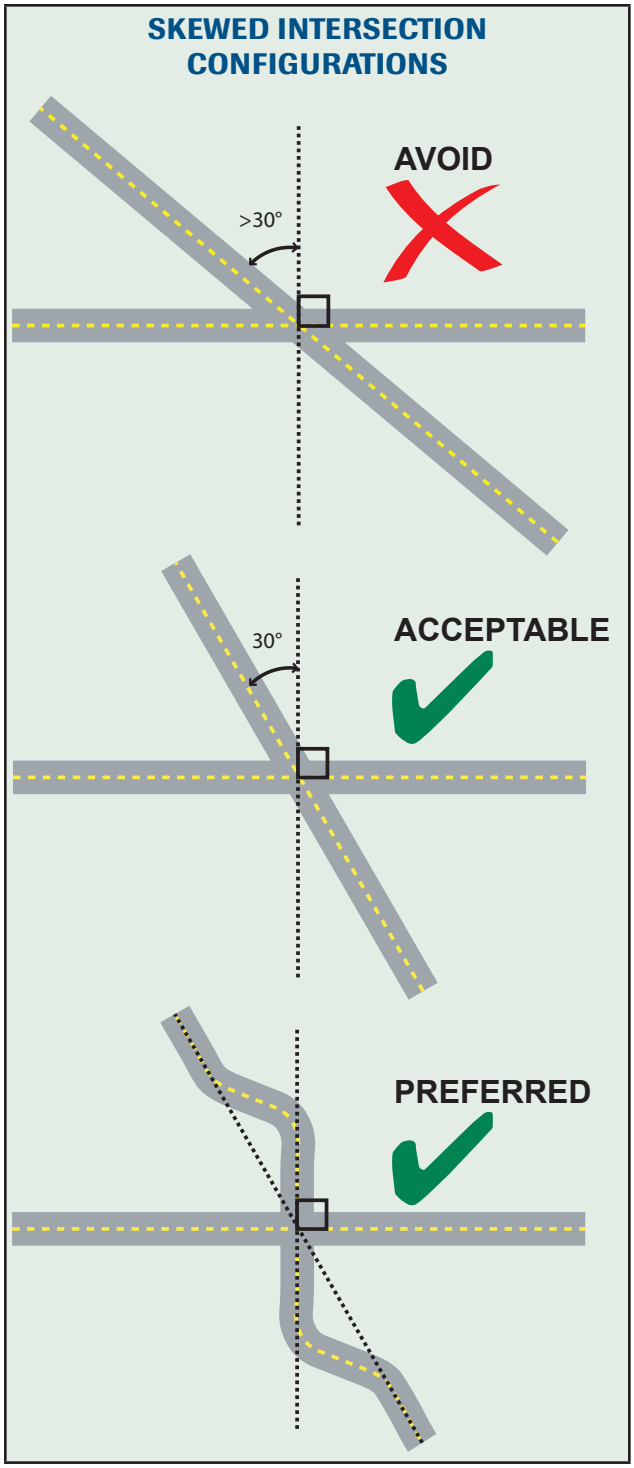


Four-Legged

A four-legged intersection is formed where two roads meet. It allows for direct crossing movements. The four-legged intersection has many variations, which are based on operating conditions. The right-angle intersection is safest and easiest for drivers to traverse. When crossroads are not perpendicular, skewed intersections result. Skewed four-legged intersections create problems with visibility, pedestrian safety, and turning angles. Where skewed intersections must be used, try to keep the angle less than 30 degrees off perpendicular, or realign to form a perpendicular intersection, as shown on page 4-14. The AASHTO *Greenbook* presents several realignment options.

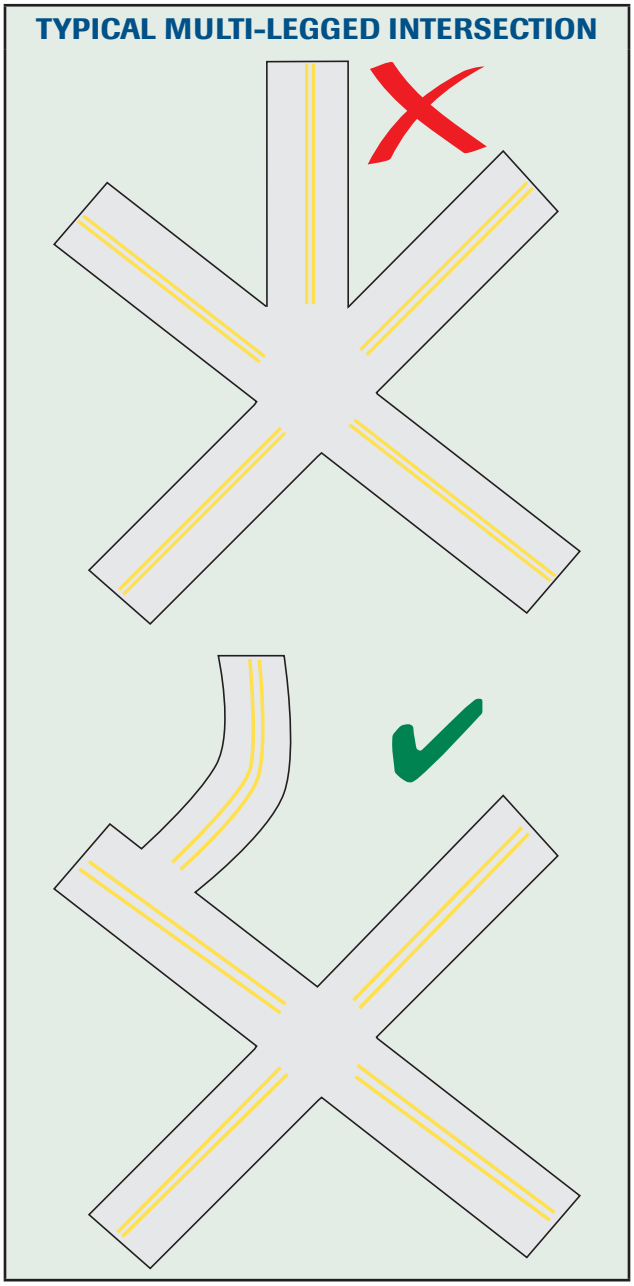
For low volume intersections, yield or stop control on two of the legs is sufficient. As volumes and turning activity increase, so does the need for traffic signal control. Chapter 5 further discusses intersection traffic control.





Multi-Legged

This type of intersection generally represents a total compromise of operational requirements. Generally, either some form of channelization and signalization should be used, or one leg of the intersection should be eliminated.



Roundabouts

Roundabouts are another type of intersection. These will be discussed in Chapter 8.

4.6.2. Lane Tapers and Transitions

A taper is a lateral shift in roadway alignment. Properly constructed tapers enhance safety and efficient use of pavement. They allow drivers to recognize a change in conditions and to react accordingly. Tapers are typically based on calculations dependent on the width of the lateral shift and the design speed. In some cases, they are referenced in ratios of length of roadway to width of change. For example, 10:1 means that 10 feet of roadway length is needed for every 1-foot of lateral shift.

In intersection applications, tapers are frequently used in adding auxiliary lanes. Auxiliary lane components include deceleration length, approach taper, bay taper, and storage length.

On high-speed roadways, it may be desirable to design turn lanes based on deceleration requirements rather than storage needs. This allows vehicles to gradually reduce their speed, thereby reducing the potential for rear-end collisions. Minimum deceleration lengths for lanes with an accompanying stop condition are 230, 330, and 550 feet for design speeds of 30, 40, and 50 mph, respectively.

Use an approach taper to transition the through-travel lanes, and to obtain the necessary width to accommodate the bay taper and storage lane. The length of the approach taper is based on speed and width of the auxiliary lane to be added.

Storage length is based upon the maximum number of vehicles that will accumulate at any one time. This length should be long enough to accommodate all turning vehicles so that traffic does not back up into through-traffic lanes. Use a minimum storage length of 100 feet if the number of left turns per hour is 60 or less. Storage lengths may need to be increased based on deceleration requirements on high-speed highways.

Bay taper length is the transition length from through-traffic lanes to adjacent auxiliary lanes. Bay taper lengths are dependent on vehicle speeds and width of auxiliary lane, although 100 feet is a common minimum.

Formulas for calculating taper lengths are shown in Exhibit 4.5.

LANE TAPERS AND TRANSITIONS

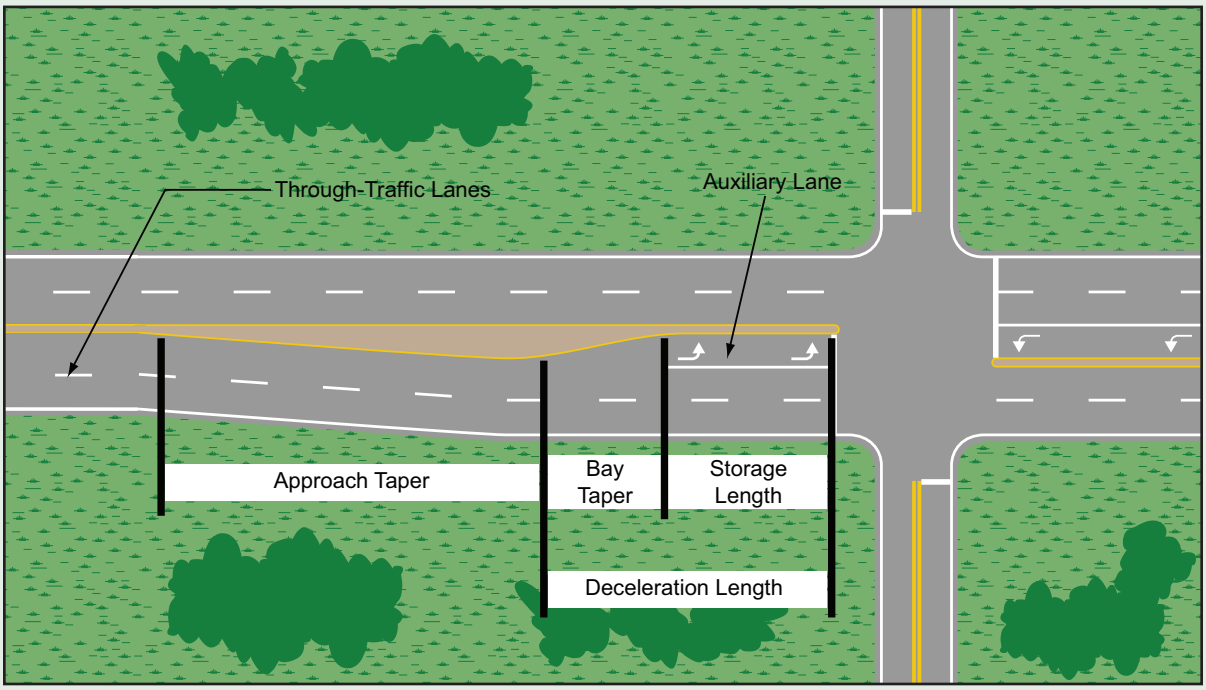
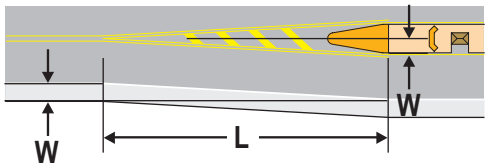
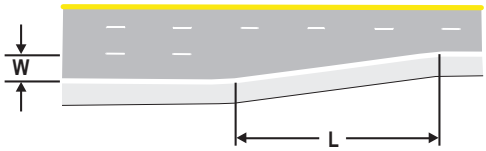
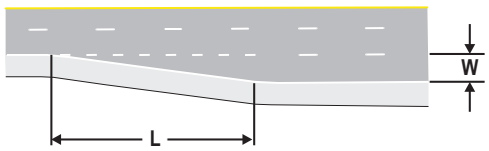
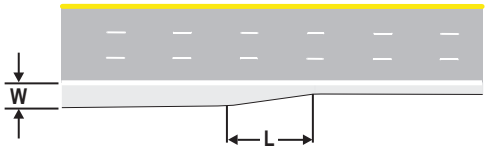


Exhibit 4.5: Transition Tapers

TYPE		CRITERIA
LANE REDIRECTED		✓ 100 feet minimum ✓ 40 mph or less use $WS^2/60$ ✓ Greater than 40 mph use W x S
LANE DROPPED		✓ 100 feet minimum ✓ 40 mph or less use $WS^2/60$ ✓ Greater than 40 mph use W x S
LANE ADDED		✓ Minimum Length WS/3 or 10:1 ratio taper, whichever is greater
SHOULDER-TO-CURB TRANSITION		✓ 10:1 minimum for a transition from a shoulder section to a curb section $L_{min} = 0.33L$, where $L=WS^2/60$ (40 mph or less) or L=WS (>40 mph)
W = Width of Lateral Shift (feet) S = Design Speed (mph) L = Length of Transition (feet)		

Source: SDDCTEA, Traffic Engineering & Highway Safety Bulletin, August 2001, Revised August 2004.

4.6.3. Islands and Channelization

KEY POINT

Traffic islands provide channelization, division, and refuge.

Channelization is the design of traffic lanes and islands in a way that will provide definite paths for vehicles to follow through an intersection. Effective channelization reduces points of conflicting traffic movements and helps to separate traffic flow.

Curbed islands can be difficult to identify at night because of glare. When curbed islands are used, lighting should be installed at the intersection or curb top delineators should be installed. When islands are used in succession along a corridor, a common geometric design should be used.

Channelizing islands are commonly delineated by the following: pavement markings or buttons; raised or outlined curbs; textured or colored pavement areas; and delineators. As shown in Exhibit 4.6, traffic islands provide channelization, division, and refuge.

Exhibit 4.6: Types of Traffic Islands

TRAFFIC ISLAND TYPE	FEATURES	GEOMETRICS	TYPICAL USAGE
CHANNELIZATION	Raised or flush	Normally triangular	When providing a free right-turn movement from one roadway to another
DIVISION	Raised or flush	Normally elongated	When a left-turn lane tapers away from the through lane
REFUGE	Raised	Triangular or elongated	When pedestrians need to cross a distance that they may not be able to complete in one signal cycle

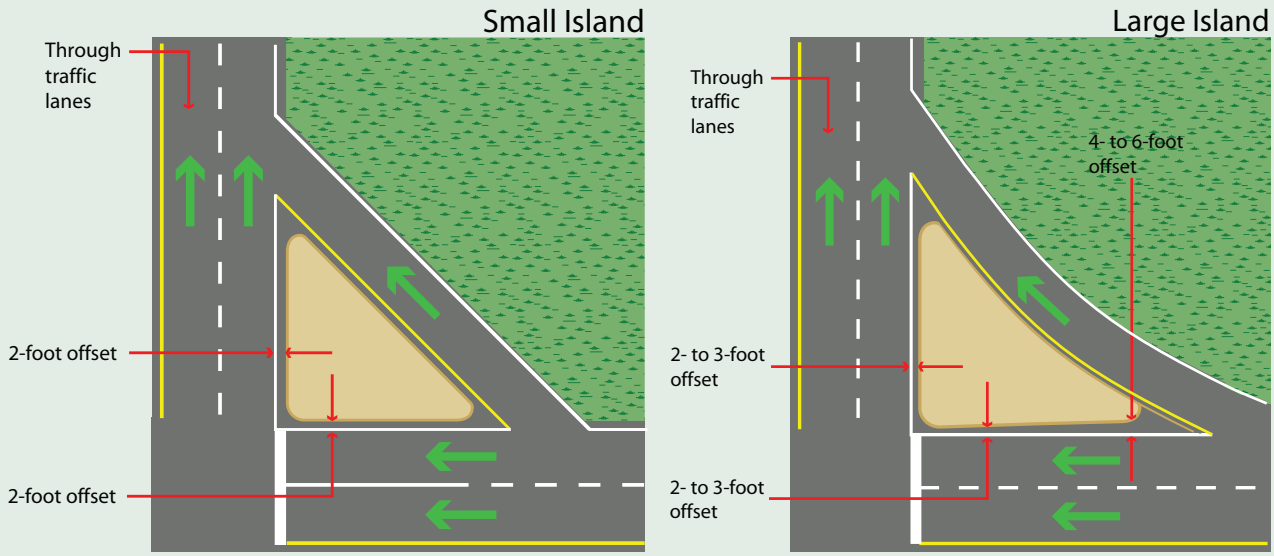
Source: ITE, Traffic Engineering Handbook

Raised islands should not be in the natural path of vehicles and should be clearly visible. Major through-traffic flow should be favored and not restricted. Avoid small islands that a vehicle could easily drive over. Islands should not be less than 75 square feet. If islands must be small, provide adequate delineation such as pavement markings around the island or object markers on the island to warn motorists; or substitute a painted island for a raised island.

It is very important to properly sign raised channelization islands. Commonly used signs include: Divided Highway, KEEP RIGHT, and LEFT LANE MUST TURN LEFT.

Raised channelization islands should be a minimum of 2 feet from the travel lane. Larger islands can be offset 2 to 3 feet with a 4- to 6-foot taper from the inside lane approach. Islands should not reduce adjacent lane widths, as this may cause motorists to swerve to avoid hitting them.

TYPICAL ISLAND DESIGN



4.7. INTERSECTION SIGHT DISTANCE

KEY POINT

The distance required to identify, react, and stop before hitting an object in the vehicle path is the stopping sight distance.

The distance required to identify, react, and stop before hitting an object in the vehicle path is the stopping sight distance.

Providing appropriate stopping sight distance addresses the need for the driver to be able to identify and react to an obstruction in the roadway ahead. This distance is based on an assumed eye height of 3.5 feet for the driver and an object 2 feet high. As shown below, the stopping sight distance is measured along the center line of the inside travel lane. The middle ordinate is a distance from the center line of the travel lane to a chord drawn between the driver's eye and the object ahead.

Exhibit 4.7 shows calculated stopping sight distances for various design speeds. The distance is comprised of two parts: reaction time and deceleration time. The reaction time is 2.5 seconds, and the deceleration rate is 11.2 ft/sec^2. The correct stopping sight distance should be provided at all locations along a roadway; horizontal curves and intersections are especially critical.

Exhibit 4.7 also shows intersection sight distance, or the distance needed by a driver waiting at an intersection with an opportunity to enter or cross the major roadway. This applies not only for conventional intersections, but also for roundabouts.

UNOBSTRUCTED SIGHT DISTANCES THROUGH CURVES

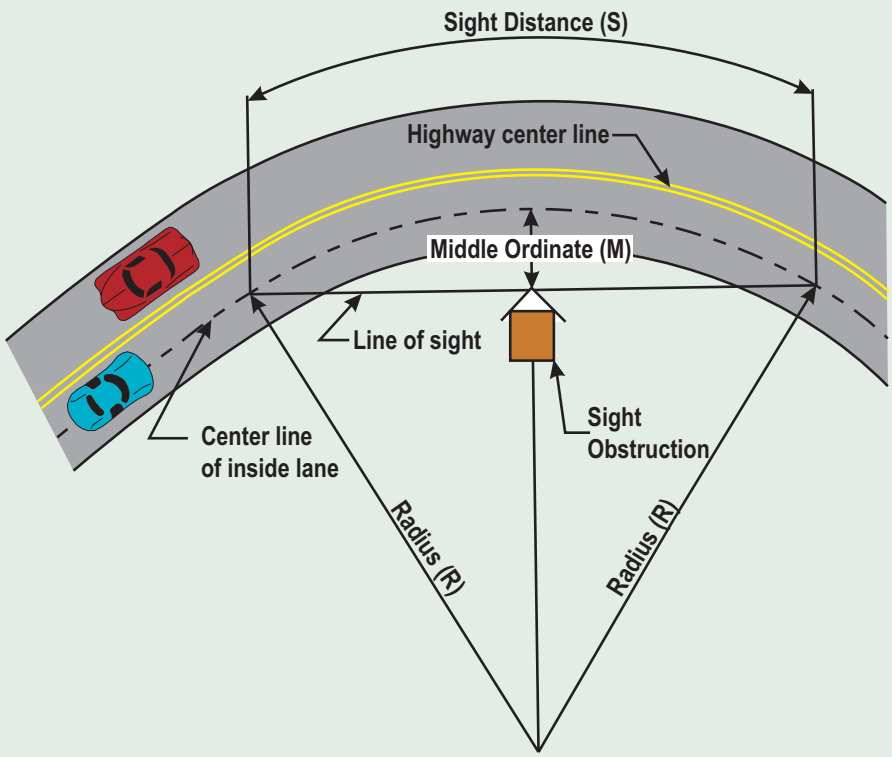
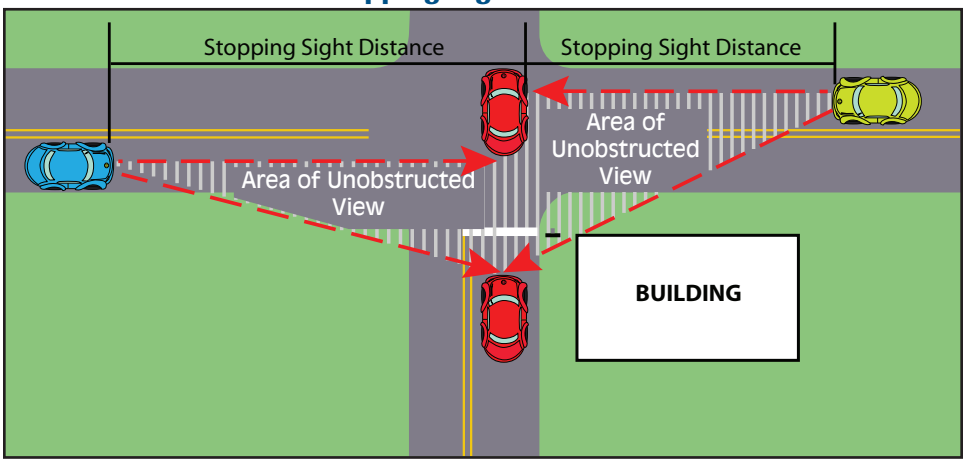
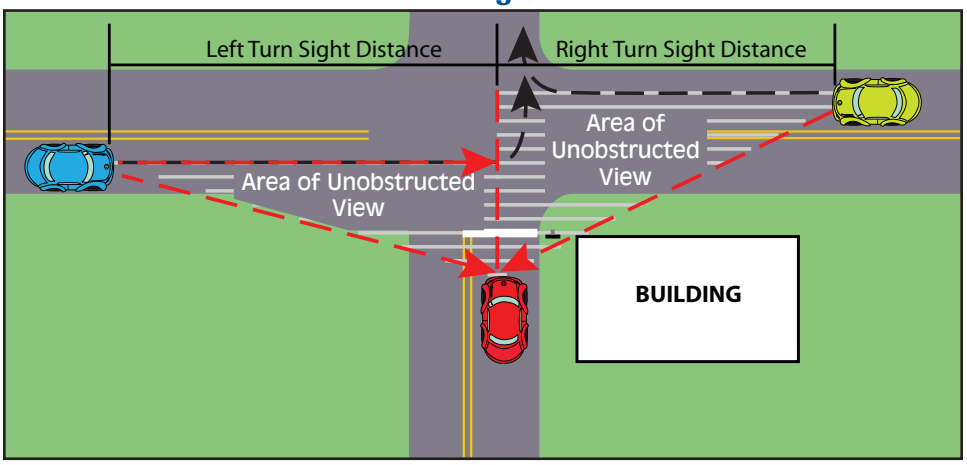


Exhibit 4.7: Minimum Sight Distance

Stopping Sight Distance



Intersection Sight Distance



STOPPING SIGHT DISTANCES (FEET)

SPEED (MPH)	LEVEL GRADE	DOWNGRADE		UPGRADE	
		3%	9%	3%	9%
30	200	205	227	200	179
40	305	315	354	289	269
50	425	446	507	405	375
60	570	598	686	538	495
70	730	771	891	690	631

INTERSECTION SIGHT DISTANCES (FEET)

SPEED (MPH)	LEFT TURNS (LEVEL GRADE)	RIGHT TURNS AND CROSSING MANEUVERS (LEVEL GRADE)
30	335	290
40	445	385
50	555	480
60	665	575
70	775	670

Source: AASHTO, 2004 Greenbook

4.8. OTHER GEOMETRIC CONSIDERATIONS

4.8.1. Pavement Design

The type of pavement used is often based on material availability, costs of materials, and design. The pavement structure varies with the type of roadway and truck volumes. An under-designed pavement surface may appear acceptable in the short-term, but will soon experience cracking, spalling, and rutting. To resist skidding:

- ✓ Provide a friction coefficient of at least 0.5.
- ✓ Evaluate annually to ensure that the minimum friction coefficient is maintained.

There are two types of pavements that are commonly used: flexible and rigid. Flexible (or bituminous) pavement is generally placed in layers with a subbase (crushed stone), a base course (hot asphalt mix), and a wearing or surface course (hot asphalt mix). The hot asphalt mix is the most common type of material used for flexible pavement; however, check what is readily available and the most economical in the area. The subbase is normally 6 to 12 inches thick, the base course is normally 4 to 6 inches thick, and the wearing course is normally 2 to 4 inches thick.

Unlike flexible pavement, rigid pavement (such as concrete) is placed in one layer over the subbase and is normally 8 to 12 inches thick. Individual services should consult their applicable guidelines and *Unified Facilities Criteria (UFC)* 3-250-0 on pavement design.

4.8.2. Drainage

Control of water is very important in roadway design. All roadways should have a sloped cross section to facilitate the quick and efficient removal of water from the roadway. In roadway design, drainage design can influence final alignment.

Drainage is important!

Roadways that have curbs and gutters adjacent to all travel lanes typically have inlets provided to capture the water from the gutter and redirect it to an acceptable location. Check your local DOT criteria for the minimum slope to be used for drainage. As the amount of water in the gutter increases, the velocity of the water increases, and the water spreads from the gutter and into the travel lane. This condition is referred to as spread.

The spacing of inlets is determined by the spread of water as it travels through the gutter. Normally, an inlet is required when the calculated spread reaches half the lane width. In other words, for a 12-foot lane, an inlet is required when the calculated spread reaches 6 feet into the lane. However, this is just a rule of thumb; the local municipalities should be consulted to determine what the acceptable spread is for the area. For more information on calculating the spread for a facility, consult AASHTO's *Highway Drainage Guidelines*.

Roadways without curb and gutter combinations often use drainage ditches with open channel flow. Ditches are graded, open channels that are typically located along the bottom of an embankment slope or at the top of a cut slope. They are generally parallel to the highway and carry runoff coming from the pavement, shoulders, and adjacent areas. They also may be used to protect the highway's boundaries from stormwater originating offsite.

The most common types of ditches are triangular, trapezoidal, and rectangular. They are often lined to control velocities and soil erosion. The trapezoidal shape is preferred due to its higher hydraulic efficiency. Triangular shapes often require less width, and can be readily maintained with a grader. Rectangular shapes are generally used in rock areas.

Section 9.3.4 has additional information on use of drainage features with respect to roadside safety.

4.9. OUTSIDE CONTINENTAL UNITED STATES (OCONUS) CONSIDERATIONS

OCONUS installations require special considerations. Generally, host country standards should be utilized for overseas designs. This generally includes traffic control devices and geometric standards. Specifically, per AR 420-1, the OCONUS installation streets and roads are to be considered an extension of the road system of the host country and shall use traffic control device standards and criteria of the host country.

Other nations generally use different signs and pavement markings. There may also be behavioral factors that may differ from Continental United States (CONUS) installations. For example, in Japan, drivers use the left side of the road. Also, many Japanese installations have significantly higher pedestrian volumes than most CONUS locations which may influence designs.

With regards to traffic law enforcement, a similar principle applies for OCONUS installations. Per 32 CFR 634, OCONUS installations must follow the applicable Status of Forces Agreement (SOFA). In this case, the law of the host nation concerning license suspension and revocation is to be followed.

Japanese STOP sign used on a Navy base

CHAPTER 5 – INTERSECTION TRAFFIC CONTROL

5.1. NO CONTROL 5-1

5.2. YIELD CONTROL 5-2

5.3. STOP CONTROL 5-4

5.4. MULTI-WAY STOP CONTROL 5-6

5.5. TRAFFIC SIGNALS, YES OR NO? 5-8

5.6. ROUNDABOUTS 5-8

5.7. CONTROL SELECTION 5-11

KEY POINT

The *MUTCD* provides warrants for traffic control devices.

One of the most common questions SDDCTEA receives is, "What is the appropriate type of intersection traffic control for a given set of conditions at an intersection?" In practice, there are six basic types of intersection traffic control:

- ✓ No control
- ✓ YIELD control
- ✓ STOP control
- ✓ Multi-way stop control
- ✓ Traffic control signals
- ✓ Roundabouts

Use the minimum appropriate level of traffic control that promotes safe and efficient traffic operations and minimizes delay while still being cost effective. The *MUTCD* provides guidelines for selecting appropriate traffic control devices.

The assessment of needed traffic control must be conducted by a qualified traffic engineer. When appropriate, installations should seek traffic engineering assistance from others, such as the state transportation agency, their county, a nearby city traffic engineering consultant, or SDDCTEA.

5.1. NO CONTROL

The most basic control type is to have no traffic control. In this case, the motorist has the basic responsibility to navigate through the intersection and to assign right-of-way among other vehicles. The absence of traffic control should be used only in very low-volume applications where sufficient sight distance is available.

Some applications for intersections with no control may include very low-volume streets in housing areas, parking areas, or low-volume driveways that intersect local or collector roadways.

How do I evaluate intersection traffic control?

5.2. YIELD CONTROL

5.2.1. Purpose and Applications

Vehicles controlled by a YIELD (R1-2) sign must slow down or stop, when necessary, to avoid interfering with conflicting traffic. YIELD signs may be warranted if engineering judgment indicates that one or more of the conditions shown in Exhibit 5.1 exist.

YIELD sign, R1-2

5.2.2. Sign Layout and Placement

Sizes of the YIELD sign vary from 30 inches by 30 inches to 60 inches by 60 inches depending on roadway classification. In most cases, the use of a 36-inch by 36-inch sign is appropriate for conventional roads. The use of a 48-inch by 48-inch sign is appropriate for an expressway. Expressways are typically divided with full to partial control of access. Conventional roads typically include all roadway classifications less than expressways.

The YIELD sign shall be installed on the right side of the roadway approach to which it applies. The YIELD sign shall be located as close as practical to the intersection it regulates, at the point where a vehicle should yield, while optimizing its visibility to the road user. When a YIELD sign is installed at an intersection and the sign visibility is restricted, a Yield Ahead (W3-2) sign shall be installed in advance of the YIELD sign.

Yield Ahead sign, W3-2

Exhibit 5.1: When to Use a YIELD Sign

	Although uncommon, when the ability to see all potentially conflicting traffic is sufficient to allow a motorist traveling at the posted speed to pass through the intersection or to stop in a reasonably safe manner.
	At a merging area where there is not adequate sight or acceleration distance.
	At a channelized right-turn lane without an adequate acceleration lane.
	At the entrance to a roundabout.
	At the second crossroad of a divided highway, where the median width at the intersection is 30 feet or greater.
	At an intersection where special problems exist and where engineering judgment indicates that the problems are susceptible to correction by the use of a YIELD sign.

5.3. STOP CONTROL

5.3.1. Purpose and Applications

KEY POINT

Stop control should never be used for speed control.

STOP (R1-1) signs should be used when vehicles are required to stop if engineering judgment indicates that one or more of the conditions shown in Exhibit 5.2 exist.

Once the decision has been made to install two-way stop control, the decision regarding the appropriate street to stop should be based on engineering analysis. In most cases, use stop control on the street carrying the lower volume of traffic. There are exceptions to this, such as when traffic volumes on both streets are balanced and visibility, pedestrian safety, or geometric conditions warrant stopping the other legs.

Stop control should never be used to reduce vehicular speeds. Stop control used in this manner breeds disrespect for STOP signs. When drivers sense that a STOP sign is unwarranted, traffic rarely comes to a full stop, and drivers tend to increase their speed between STOP signs to make up for lost time.

Proper traffic control is extremely critical. At one installation, an SDDCTEA study noted that a STOP sign was warranted in lieu of a YIELD sign; however, the $250 STOP sign was never installed. A few months later there was a fatality at this location. The Army Safety Center investigated this crash and concluded that the fatality could have been prevented if a STOP sign was in place.

5.3.2. Layout and Placement

At most military installations, STOP signs should be 30 inches or 36 inches. The 30-inch STOP sign is adequate on conventional roads, except when used at intersections with multi-lane approaches, in which case the 36-inch version may be required. At locations where a stop is unexpected, an oversized 48-inch STOP sign can be used.

STOP sign, R1-1

Exhibit 5.2: When to Use a STOP Sign

	For a street entering a through highway or street.
	At an unsignalized intersection in a signalized area.
	Where restricted view or crash records indicate a need for STOP sign control.

The STOP sign shall be installed on the right side of the roadway approach to which it applies. Locate the STOP sign as close as practical to the intersection it regulates at the point where a vehicle should stop, while optimizing its visibility to the road user. When the STOP sign is installed at the required location and the sign visibility is restricted, install a Stop Ahead (W3-1) sign in advance of the STOP sign.

See page 6-15 for appropriate advance placement distances for warning signs, such as the Stop Ahead sign.

Stop Ahead sign, W3-1

The CROSS TRAFFIC DOES NOT STOP (W4-4p) plaque may be used in combination with a STOP sign when engineering judgment indicates that conditions are present that could cause drivers to misinterpret the intersection, perhaps as a multi-way stop. Alternate messages such as TRAFFIC FROM LEFT (RIGHT) DOES NOT STOP or ONCOMING TRAFFIC DOES NOT STOP may be used on the W4-4p plaque when such messages more accurately describe the traffic controls established at the intersection.

W4-4p

5.4. MULTI-WAY STOP CONTROL

KEY POINT

Per the 2009 *MUTCD*, 2-Way and 4-Way plaques mounted with stop signs are obsolete.

5.4.1. Purpose and Application

Multi-way stop control is helpful at locations where sight distance or crash history cannot be corrected through other means. Multi-way stop control can be used where the volume of traffic on the intersecting roads is approximately equal.

Multi-way stop control

The decision to install multi-way stop control should be based on an engineering study. The criteria in Exhibit 5.3 should be considered. Multi-way STOP signs must always be supplemented with a plaque (R1-3p) so that approaching motorists are aware of the traffic control requirements on other approaches. This plaque shall have a white legend and border on a red background. The minimum size for the ALL WAY sign is 18 inches by 6 inches. This plaque should only be used if all approaches to the intersection are required to stop.

R1-3p

Exhibit 5.3: Justification for Multi-way Stop Control

TEMPORARY MEASURE	✓ Where traffic control signals are justified, the multi-way stop is an interim measure that can be installed quickly to control traffic while arrangements are being made for the installation of the traffic control signal.
CRASHES	✓ If a crash problem is present, as indicated by five or more reported crashes in a 12-month period, and susceptible to correction by a multi-way stop installation.
MINIMUM TRAFFIC VOLUMES	✓ The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 vehicles per hour for any 8 hours of an average day, and; ✓ The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches (total of both approaches) averages at least 200 units per hour for the same 8 hours, with an average delay to minor-street vehicular traffic of at least 30 seconds per vehicle during the highest hour.
HIGH SPEED CONSIDERATIONS	✓ If the 85th-percentile approach speed of the major-street traffic exceeds 40 mph, the minimum vehicular volume warrant is 70 percent of the values shown for the "minimum traffic volume" warrant.
COMBINATION WARRANT	✓ If there are four or more reported crashes in a 12-month period that are susceptible to correction by a multi-way stop installation, and the minimum vehicular volume warrant is 80 percent of the values shown for the "minimum traffic volume" warrant.
Note: For a Two-Way stop controlled intersection, no All-Way plaque is used. Because of this, four leg intersections which have three approaches stopping and one approach free violate the MUTCD.	

Source: FHWA, MUTCD

5.5. TRAFFIC SIGNALS, YES OR NO?

KEY POINT

Traffic signals must meet at least one of the nine warrants provided in the *MUTCD*.

Traffic signals assign the right-of-way between conflicting traffic flows at intersections. Traffic signals are needed when STOP sign control cannot do the job effectively. Traffic signals can also better accommodate pedestrian crossings at intersections.

Unjustified, ill-designed, improperly-operated, or poorly-maintained traffic signals may cause:

- ✓ Increased crash frequency
- ✓ Excessive delay
- ✓ Disregard of signal indications
- ✓ Circuitous travel by alternate routes

The selection and use of signals should be based on an engineering study of roadway, traffic, and other conditions. Traffic signals should not be installed unless one or more of the signal warrants are met. The *MUTCD* includes nine warrants for signals based on vehicular volume, pedestrian activities, and crash experience. The nine warrants are described in Exhibit 5.4. The chart on the following page is for informational purposes only and does not provide complete guidance. Warrants must be professionally evaluated by a qualified traffic engineer. If you have a location that you feel should be signalized, consult SDDCTEA or your state department of transportation for a detailed evaluation of an intersection.

5.6. ROUNDABOUTS

A roundabout is defined as a modified traffic circle that conforms to specific geometric design criteria that promotes driver awareness, reduced traffic speeds, and improved traffic flow. Roundabouts reduce traffic congestion by eliminating left turns. Since each approach to the roundabout is essentially an intersection with a one-way street, the driver is not delayed by traffic flow from two directions. Only right turns are allowed.

Roundabouts are advantageous because traffic is continuously flowing, versus stopping as with traffic signal or multi-way stop control. The disadvantage is that they require a higher initial cost for construction versus traffic signal or stop control. See Chapter 8 for more on roundabouts.

Roundabout Example

Exhibit 5.4: Traffic Signal Warrants

WARRANT	PURPOSE
WARRANT 1: EIGHT-HOUR VEHICULAR VOLUME	✓ The eight-hour vehicular volume warrant is intended for application where a large volume of intersecting traffic is the principal reason to consider installing a traffic control signal, or where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or conflict when entering or crossing the major street.
WARRANT 2: FOUR-HOUR VEHICULAR VOLUME	✓ The four-hour vehicular volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal.
WARRANT 3: PEAK HOUR	✓ The peak hour signal warrant is intended for use at a location where conditions are such that for a minimum of one hour of an average day, the minor-street traffic suffers undue delay when entering or crossing the major street. The warrant should be applied only in unusual cases where land uses discharge or attract a larger number of vehicles over a short time period.
WARRANT 4: PEDESTRIAN VOLUME	✓ The pedestrian volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street. ✓ Intersection MAY be a candidate if the pedestrian volume crossing the major street at an intersection or mid-block location during an average day is 100 or more for each of any four hours or 190 or more during any one hour; and in the same hour, there are fewer than 60 gaps in the traffic stream of adequate length to allow a pedestrian to cross.
WARRANT 5: SCHOOL CROSSING	✓ The school crossing signal warrant is intended for application where the fact that school children cross the major street is the principal reason to consider installing a traffic control signal. ✓ Intersection MAY be a candidate if there are a minimum of 20 students during the highest crossing hour, and there are insufficient gaps in traffic.

Exhibit 5.4: Traffic Signal Warrants (continued)

WARRANT	PURPOSE
WARRANT 6: COORDINATED SIGNAL SYSTEM	✓ The coordinated signal warrant is intended for application where the progressive movement in a coordinated signal system sometimes necessitates installing traffic control signals in order to maintain proper platooning of vehicles.
WARRANT 7: CRASH EXPERIENCE	✓ The crash experience signal warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal. ✓ Intersection MAY be a candidate if five or more reported crashes, of types susceptible to correction by a traffic control signal, have occurred within a 12-month period.
WARRANT 8: ROADWAY NETWORK	✓ Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a roadway network.
WARRANT 9: INTERSECTION NEAR A GRADE CROSSING	✓ This warrant is intended for use where the proximity between an intersection and grade crossing is the principal reason to consider installing a traffic control signal.

Source: FHWA, MUTCD

5.7. CONTROL SELECTION

SDDCTEA has developed a rule-of-thumb guide for helping highway engineers choose the appropriate traffic control. Exhibit 5.5 depicts this guide. In all cases, a qualified traffic engineer should be consulted for the final determination.

Exhibit 5.5: Type of Control to Use

A "RULE-OF-THUMB" GUIDE				
CONTROL TYPE	**YIELD CONTROL**	**STOP CONTROL**	**MULTI-WAY STOP CONTROL**	**TRAFFIC SIGNAL CONTROL**
Total entering volume per hour*	100 to 149 – likely	150 to 299 – maybe? 300 to 500 – likely	500 to 800 – maybe?	> 800 – maybe?
Total entering volume per day*	1000 to 1500 – maybe?	1500 to 2999 – maybe? 3000 to 4999 – likely	5000 to 8000 – maybe?	> 8000 – maybe?
Safe approach speed (sight distance) in mph	> 10 mph	≤ 10 mph	Blind sight distance	NA
Crashes per year (right angle)	≥ 3	≥ 3	≥ 5	≥ 5
Street classifications	✓ Local to Local ✓ Local to Collector	✓ Local to Local ✓ Local to Collector ✓ Collector to Collector ✓ Local to Major ✓ Collector to Major	✓ Collector to Collector ✓ Collector to Major ✓ Major to Major	✓ Collector to Major ✓ Major to Major
* *For speeds over 40 mph, minimum volumes need be only 70 percent of values shown.*				

Source: MTMC, Better Military Traffic Engineering, 1987

CHAPTER 6 – SIGNING AND MARKINGS

6.1. SIGNS 6-2

6.2. MARKINGS 6-22

6.3. ADDITIONAL PAVEMENT MARKINGS 6-37

KEY POINT

All traffic control devices on roads open to public travel must comply with the *MUTCD*.

A common problem on military installations is too many regulatory and warning signs. There is a misconception that extra signs "can't do any harm." In reality, extra signs create unnecessary clutter and detract from necessary traffic signs.

Other common problems include:

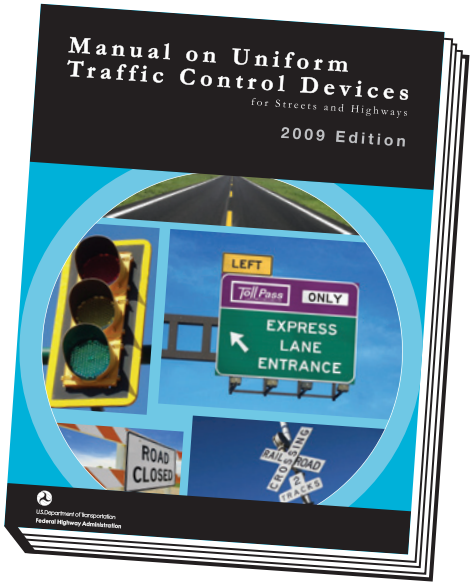
- ✓ Using non-standard, homemade-type signs, frequently with substandard size legends and without retroreflective sheeting material.
- ✓ Installing signs at a substandard height.
- ✓ Installing signs too close to other signs, or too close to a curve, turn, or intersection.
- ✓ Installing totem pole or ladder-type signs.
- ✓ Using improper colors, (e.g., brown-and-white signs).
- ✓ Allowing obsolete (non-retroreflective or non-legible) signs to remain in place.

The "how-to" book for traffic signs is Part 2 of the *MUTCD*. The primary purpose of the *MUTCD* is to improve safety and reduce driver frustration by promoting uniformity in the design and application of traffic control devices.

KEY POINT

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.

FHWA also sponsors research to improve the quality and recognition of signs, and works internationally to share ideas with other countries to promote uniformity on a global basis. This sharing of research on sign shapes, colors, symbols, and design details is very important when considering the number of international visitors.



6.1. SIGNS

Traffic signs, like other types of traffic control devices, should meet the following five basic requirements:

- ✓ Fulfill a need;
- ✓ Command attention;
- ✓ Convey a clear, simple meaning;
- ✓ Command respect from road users; and
- ✓ Allow adequate time for proper response.

6.1.1. Fulfill a Need

To determine if a sign will fulfill a need, a traffic engineering study must be conducted to collect and analyze data such as traffic volume, pedestrian volume, speed, and crash data; measure geometric features; and observe noteworthy vehicle behavior. This information is then compared to the warrants for the specific sign to determine whether the sign is appropriate.

Always base the decision to use a particular traffic sign on an engineering study or the application of engineering judgment. For this reason, a qualified engineer should make the decision whether or not to use a specific sign.

There are only three general classifications of signs, which serve the following functions:

Regulatory – gives notice of traffic laws or restrictions.

Warning – gives notice of a situation that might not be readily apparent.

Guide – shows route designations, street names, destinations, directions, distances, services, points of interest, and other geographical, recreational, or cultural information.

As illustrated in Exhibit 6.1 and 6.2, the general shape and the basic color of signs should be consistent with the type of sign.

REGULATORY

R1-1

WARNING

W1-1

GUIDE

D1-3a

Sign classification examples

Exhibit 6.1: Sign Type Basics

SIGN CATEGORY	GENERAL SHAPE	BASIC COLOR	COMMON EXCEPTIONS
REGULATORY	Rectangular	Black legend on a white background	✓ STOP (R1-1), YIELD (R1-2), and Railroad Crossbuck (R15-1) signs have a unique shape. ✓ STOP (R1-1), YIELD (R1-2), DO NOT ENTER (R5-1), and WRONG WAY (R5-1a) signs are red-and-white in color. ✓ A red circle and slash indicate prohibitions.
WARNING	Diamond	Black symbols or legend on a yellow background	✓ School (S1-1) and Advance Railroad Crossing (W10-1) signs, and the NO PASSING ZONE (W14-3) pennant, have a unique shape. ✓ Pedestrian, bicycle, and school series signs may have a fluorescent yellow-green background. ✓ Signs in construction areas have an orange background.
GUIDE	Rectangular	White legend on a green background	✓ Route (M-series) markers generally have a unique color and shape. ✓ Motorist service signs (e.g., gas, food, lodging, attractions, etc.) have a blue background.
CULTURAL INTEREST	Rectangular	White legend on a brown background	✓ This is generally the only appropriate use for this color.

Exhibit 6.2: Sign Color Examples

SIGN	SIGN CLASSIFICATION
	REGULATORY
	REGULATORY
	WARNING
	WARNING
	GUIDE
	GUIDE
	GUIDE

6.1.2. Command Attention

When developing a signing plan, it is important to use only signs that motorists understand. Therefore, use signs of the types included in the *MUTCD*. Although the *MUTCD* details the general use of traffic signs, the actual design details for the sign faces and the legend are in FHWA's *Standard Highway Signs* book.

Homemade-type signs are not only unenforceable, but they are illegal. Therefore, when there is a need for a sign not in the *MUTCD* or the state's list of approved signs, consult SDDCTEA for design assistance.

Exhibit 6.3 shows typical sizes of some common signs. Larger sizes may be warranted on roads with a speed limit greater than 45 mph, or when greater legibility or emphasis is needed. A qualified engineer should make this determination. See SDDCTEA Pamphlet 55-14 for more information on appropriate sign sizes.

Almost without exception, guide signs on military installations should have white legend on a green background. These signs generally direct drivers to the installation and to specific buildings or areas within the installation.

To further assist visitors, it is desirable to distribute easy-to-read maps at the ECF to show common visitor destinations.

Exhibit 6.3: Sizes of Common Signs

SIGN NAME AND NOMENCLATURE		SIZE, WIDTH X HEIGHT (INCHES)	
		SINGLE LANE	MULTI-LANE
STOP (R1-1)		30x30	36x36
YIELD (R1-2)		36x36x36*	48x48x48*
Speed Limit (R2-1)		24x30	30x36
Turn Prohibition (R3-series)		24x24	36x36
DO NOT PASS (R4-1)		24x30	24x30
DO NOT ENTER (R5-1)		30x30	36x36
WRONG WAY (R5-1a)		36x24	42x30
ONE WAY (R6-1)		36x12	54x18
No Parking (R7-series)		12x18	12x18

Exhibit 6.3: Sizes of Common Signs (continued)

SIGN NAME AND NOMENCLATURE		SIZE, WIDTH X HEIGHT (INCHES)	
		SINGLE LANE	MULTI-LANE
NO TURN ON RED (R10-11, R10-11a)		24x30	36x48
Turn (W1-1)/Curve (W1-2)		30x30	36x36
Chevron (W1-8)		18x24	18x24
Intersection (W2-series)		30x30	30x30
Stop/Yield/Signal Ahead (W3-series)		36x36	30x30
Railroad Advance Warning (W10-1)		36 DIA	36 DIA
Advisory Speed (W13-1)		18x18	18x18
NO PASSING ZONE (W14-3 pennant)		48x48x36*	48x48x36
Destination (D1-, D2-series)		6-inch legend	6-inch legend

**Length of each side*

Recommended size is that which is most commonly occurring on military bases. See the MUTCD *for sizes needed on expressway and freeway conditions.*

Guide signs that are outside of the installation are generally a cooperative effort with the state or local government entity that owns the road. For installations with two or more ECFs, it is desirable to develop a comprehensive guide sign plan to direct traffic to the appropriate ECF. Signs approaching the installation can inform drivers of the various ECF locations. Where appropriate, signs should detail:

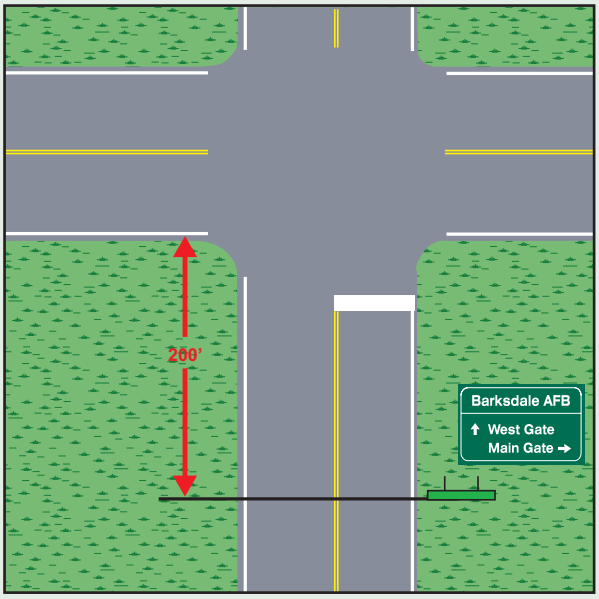
- ✓ Location
- ✓ Gate name
- ✓ Usage type (visitors, decal POVs, trucks)
- ✓ Any limited hours of operation

Signs on public highways approaching the installation should generally use a minimum 8-inch white legend on a green background. To improve legibility, use title case (i.e., uppercase and lowercase) legends for all destinations.

In addition to having the proper sign face (e.g., layout, legend, dimensions, color, etc.), signs need to be retroreflective so that the sign is visible at night under headlamp illumination. To accomplish this, sign shops apply a "retroreflective sheeting material" over the entire sign.

In addition, any white legend (i.e., letters, numerals, arrows, symbols, and borders) also needs to be retroreflective. See Section 6.1.6.2 for more information on sign retroreflectivity. Additionally, Pamphlet 55-14 contains a comprehensive discussion of sign retroreflectivity.

PREFERRED GUIDE SIGN LOCATION



The *MUTCD* assigns a unique nomenclature to all common types of traffic signs. All states use the nomenclature in the *MUTCD*, but each state also has some additional traffic signs that they have approved for unique applications, and for which they have assigned their own nomenclature. The first letter in sign nomenclature conforms to the following:

- ✓ Regulatory signs – R.
- ✓ Warning signs – W, except school signs start with the letter S.
- ✓ Guide signs – a variety of letters, but most commonly D, G, I, or M.

Sign names used in this pamphlet may look awkward because some are in all capital letters while others are in title case. This mix of styles is common because the *MUTCD* and most other sign manuals generally use the following practice:

- ✓ All uppercase legends (capitals) for sign names when the sign name and the sign legend message are the same (e.g., STOP, YIELD, and DO NOT ENTER signs).
- ✓ Title case for symbol signs and when the sign name and sign message are not the same (e.g., Speed Limit, Turn, and Intersection signs).

When ordering signs:

- ✓ Only order from a reputable sign shop – if in doubt, discuss with the appropriate state Department of Transportation.
- ✓ Specify aluminum sign blanks since they are more durable than most other sign blank materials.
- ✓ Specify Type III, Type IV, or higher type retroreflective sheeting material for post mounted signs.
- ✓ Type VII, VIII, IX, or X material for white legend and border only overhead signs.

In order to command attention, it is also important to place signs where other signs, parked cars, buildings, or vegetation will not obscure them. Signs should be placed on the right side of the road unless the *MUTCD* defines a different location. For example, No Left Turn, DO NOT ENTER, NO PASSING ZONE, Keep Right, and Chevron signs are frequently installed at other locations.

Each sign should be individually mounted unless one sign supplements another (e.g., an ALL WAY plaque and a STOP sign), or unless guide signs must be grouped. The *MUTCD* also encourages some back-to-back installations, (e.g., DO NOT ENTER sign on the back of a STOP or YIELD sign).

Typical heights and lateral locations of signs are illustrated in the diagrams on pages 6-10 and 6-11. Use a minimum 7-foot mounting height if curb and gutter exists, parking is allowed, or pedestrians walk near the signs.

However, there is an exception to the normal height requirement — the In-Street Pedestrian Crossing (R1-6 and R1-6a) signs rest directly on the roadway. These "in-street" signs generally reduce speeds because they narrow the travel lane.

These signs create an extra object that can be hit, potentially inflicting injury to pedestrians and damage to vehicles. Therefore:

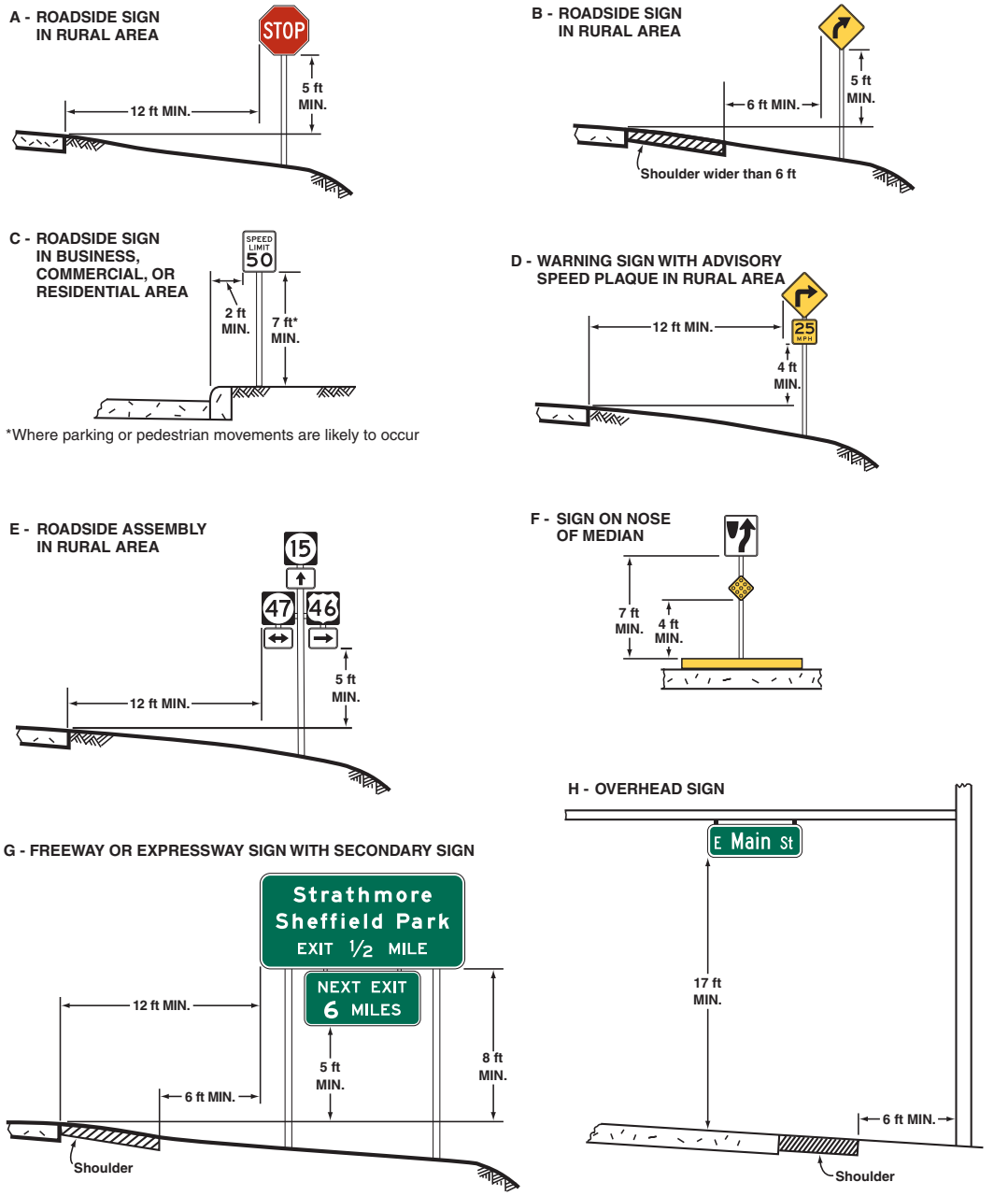
- ✓ Use these signs only on roadways with a speed limit of 35 mph or less, and with lanes that are at least 10 feet wide.
- ✓ Use only at marked mid-block crosswalks or marked crosswalks at non-signalized intersections.
- ✓ Use the appropriate sign (R1-6 or R1-6a) to correspond to the requirements of the applicable state vehicle code.
- ✓ Place the sign near the crosswalk, either on the center line or a lane line pavement marking.

R1-6

R1-6a

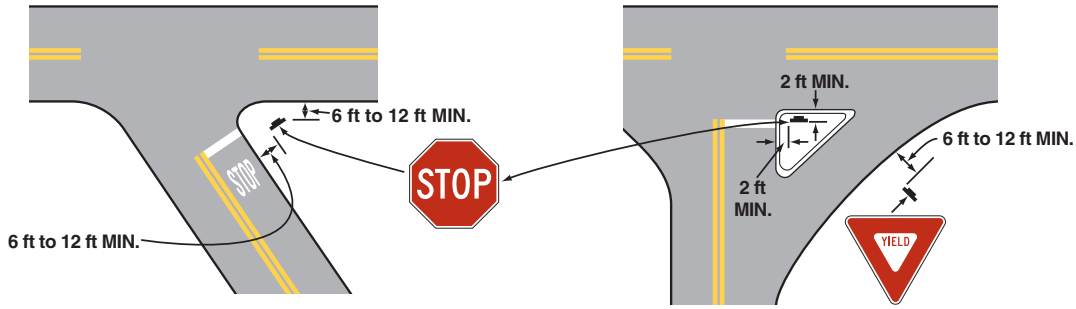
Sometimes it is desirable to install signs above the roadway. For example, overhead lane-use signs should be used approaching intersections when there are three or more lanes in one direction, when a through lane drops as a turn lane, or when a single lane can serve multiple movements. When used, overhead signs should be a minimum of 17 feet above the roadway surface.

HEIGHTS AND LATERAL LOCATION OF SIGNS



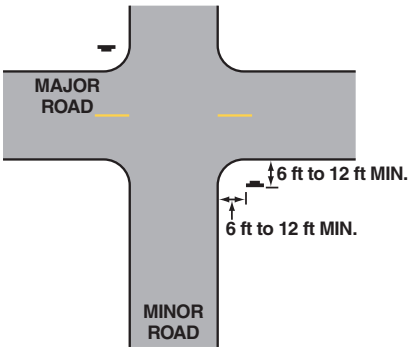
Note:
See *MUTCD* Section 2A.19 for reduced lateral offset distances that may be used in areas where lateral offsets are limited, and in business, commercial, or residential areas where sidewalk width is limited or where existing poles are close to the curb.

HEIGHTS AND LATERAL LOCATION OF SIGNS

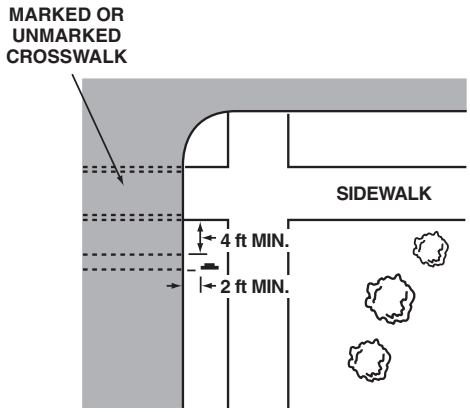


A - ACUTE ANGLE INTERSECTION

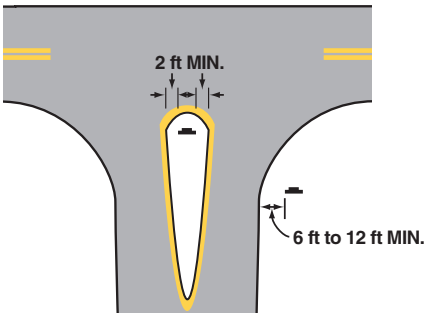
B - CHANNELIZED INTERSECTION



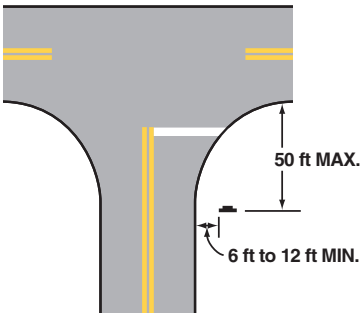
C - MINOR CROSSROAD



D - URBAN INTERSECTION



E - DIVISIONAL ISLAND



F - WIDE THROAT INTERSECTION

Note: Lateral offset is a minimum of 6 feet measured from the edge of the shoulder, or 12 feet measured from the edge of the traveled way. See page 6-10 for lower minimums that may be used in urban areas, or where lateral offset space is limited.

6.1.3. Convey a Clear, Simple Meaning

KEY POINT

Whenever possible, use symbol signs instead of legend messages because they are legible from greater distances, and because they help non-English-speaking people understand the message.

Many military installations still use ladder-type signs for guide signing. These sign assemblies typically contain more information than can be processed by passing motorists. Therefore, it is important to limit the number of destinations at any location to a maximum of three, and to install a second sign assembly at a separate location if there are more than three destinations.

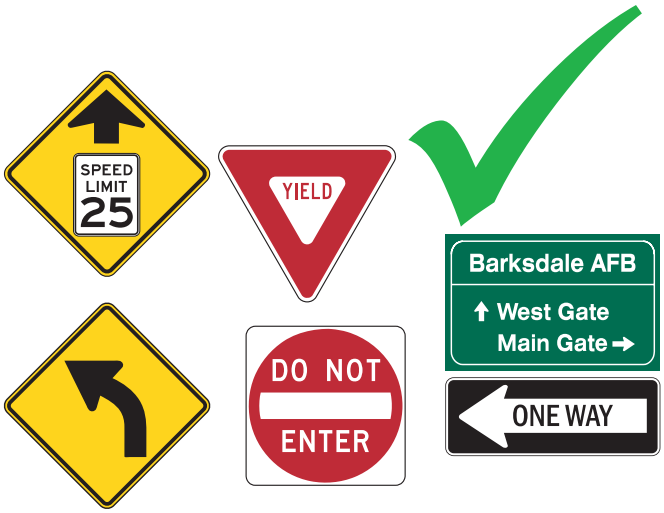
The images below provide some examples of good and bad signs.

The current "rule-of-thumb" is that signs are legible from a distance of 40 feet for every one inch in the legend height. This means that a sign with 6-inch legend should be legible from a distance of about 240 feet.

The legibility of symbol signs depends on the size and detail of the symbol. Fortunately, most symbol signs use bold symbols (e.g., Stop Ahead, Intersection, Curve, Turn, Pedestrian, etc.) and are legible from distances greater than 240 feet.

The *MUTCD* allows the use of title case (i.e., uppercase/lowercase) legends for all destinations and street names. Since drivers can read title case legends at a greater distance than legends using all capitals, new signs should use title case legends whenever permitted.

GOOD



BAD

6.1.4. Command Respect

KEY POINT

For proper respect, all signs must be legible, visible, and placed correctly.

To command respect, sign messages must be realistic. For example, excessively low speed limits, unnecessary STOP signs, an overabundance of signs, and lack of maintenance, cause drivers to lose respect for all signs.

Signs require regular maintenance such as tightening fasteners, realigning posts, cleaning sign faces, and removing vegetation around the post and in front of the sign. In addition, damaged signs and sign posts should be immediately repaired and, if necessary, replaced.

Signs also deteriorate over time; therefore, replace all signs every 10 to 12 years (if existing signs have Type I or Type II retroreflective sheeting, replace after 7 years). An effective sign inventory system can help to maintain a complete and accurate accounting of the locations, types, and conditions of installed traffic signs as discussed in the *Sign Retroreflectivity* safety bulletin.

Exhibit 6.4 shows additional requirements of signs to command proper respect.

Exhibit 6.4: Sign Requirements

REQUIREMENTS	EXAMPLES
BE LEGIBLE	✓ Use symbol messages when available ✓ Use minimum 6-inch high lettering (except for signs like No Parking signs) ✓ Use the proper type legend from FHWA's *Standard Highway Signs* book
BE VISIBLE	✓ Space signs at intervals of at least 150 feet from other signs ✓ Orient signs to face approaching traffic ✓ Clear obstructions and roadside features such as vegetation and utility poles ✓ Require Type III retroreflective sheeting on new signs ✓ Replace or repair damaged or misaligned signs ✓ Replace signs at least every 10 or 12 years
BE PLACED CORRECTLY	✓ Use proper lateral offset distance from the edge of the road ✓ Install signs at the proper height above the roadway surface ✓ Use an approved breakaway or yielding signpost and install in accordance with the manufacturer's recommendations ✓ Use overhead lane use signs for three or more lanes in one direction, or when a single lane can serve multiple movements

6.1.5. Allow Adequate Time for Proper Response

Signs should usually be spaced a minimum of 150 or 200 feet from other signs so that drivers have adequate time to read a sign before being confronted with another sign. This concept of trying not to overload the driver with too much information is sometimes referred to as "sign spreading."

When installing a regulatory sign, such as a Speed Limit (R2-1) or Weight Limit (R12-1) sign, military installations should install a sign at the location where the restriction physically begins. In addition, military installations may need to install a warning sign in advance of the regulatory sign to allow drivers ample time to make necessary adjustments.

The placement of warning signs must allow these drivers sufficient time to see the sign, understand the intent, identify the potential hazard, decide what action must be taken, and then perform any necessary maneuver. Exhibit 6.5 (Table 2C-4 of the *MUTCD*) provides minimum recommended sign placement distances for warning signs.

When using the table on page 6-15, note that Condition A is only for those situations where motorists may have to change lanes in heavy traffic.

Applicable signs using Condition A include:

- ✓ Merge (W4-1)
- ✓ Lane Reduction Transition (W4-2L, W4-2R)
- ✓ Entering Roadway Merge (W4-5)
- ✓ RIGHT LANE ENDS (W9-1)

The advance placement distances for Condition B, shown in Exhibit 6.5, are typically much smaller than the historical values used by traffic engineers. However, remember that these are minimum advance distances.

For Stop Ahead, Yield Ahead, Signal Ahead and Intersection Warning signs, use the advance distance for the "0 mph" advisory speed because some drivers may wish to turn at the intersection or may need to stop due to other stopped or turning traffic. For example, the minimum advance distance for a warning sign for a potential stop condition is 175 feet on a 45-mph roadway.

WARNING DISTANCES

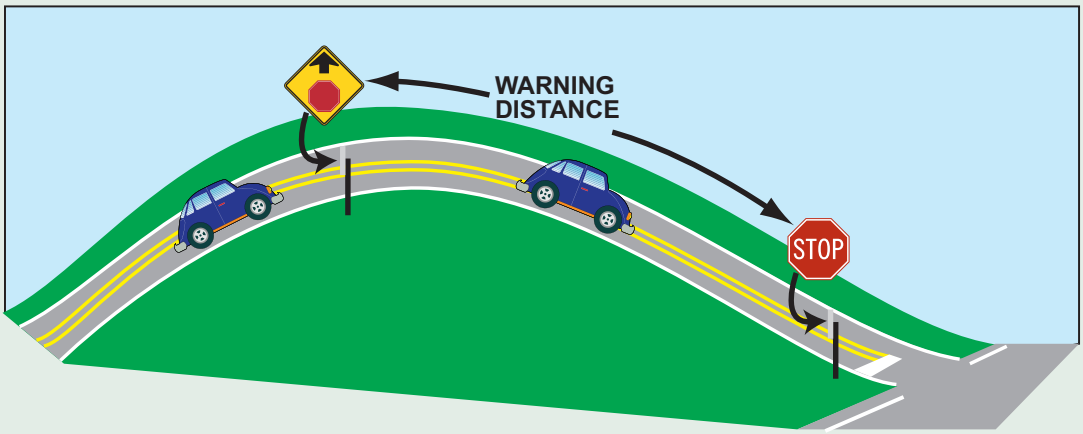


Exhibit 6.5: Guidelines for Advance Placement of Warning Signs

Posted or 85th-Percentile Speed	Advance Placement Distance[1]								
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0[3]	10[4]	20[4]	30[4]	40[4]	50[4]	60[4]	70[4]
20 mph	225 ft	100 ft[6]	N/A[5]						
25 mph	325 ft	100 ft[6]	N/A[5]	N/A[5]					
30 mph	460 ft	100 ft[6]	N/A[5]	N/A[5]					
35 mph	565 ft	100 ft[6]	N/A[5]	N/A[5]	N/A[5]				
40 mph	670 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]				
45 mph	775 ft	175 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]			
50 mph	885 ft	250 ft	200 ft	175 ft	125 ft	100 ft[6]			
55 mph	990 ft	325 ft	275 ft	225 ft	200 ft	125 ft	N/A[5]		
60 mph	1,100 ft	400 ft	350 ft	325 ft	275 ft	200 ft	100 ft[6]		
65 mph	1,200 ft	475 ft	450 ft	400 ft	350 ft	275 ft	200 ft	100 ft[6]	
70 mph	1,250 ft	550 ft	525 ft	500 ft	450 ft	375 ft	275 ft	150 ft	
75 mph	1,350 ft	650 ft	625 ft	600 ft	550 ft	475 ft	375 ft	250 ft	100 ft[6]

Notes:

1. The distances are adjusted for a sign legibility distance of 180 feet for Condition A. The distances for Condition B have been adjusted for a sign legibility distance of 250 feet, which is appropriate for an alignment warning symbol sign. For Conditions A and B, warning signs with less than 6-inch legend or more than four words, a minimum of 100 feet should be added to the advance placement distance to provide adequate legibility of the warning sign.
2. Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge and Right Lane Ends. The distances are determined by providing the driver a PRT of 14.0 to 14.5 seconds for vehicle maneuvers (2004 AASHTO *Greenbook*, Exhibit 3-3, Decision Sight Distance, Avoidance Maneuver E) minus the legibility distance of 180 feet for the appropriate sign.
3. Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, Signal Ahead, and Intersection Warning signs. The distances are based on the 2004 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT of 2.5 seconds, a deceleration rate of 11.2 feet/second^2, minus the sign legibility distance of 180 feet.
4. Typical conditions are locations where the road user must decrease speed to maneuver through the warned condition. Typical signs are Turn, Curve, Reverse Turn, or Reverse Curve. The distance is determined by providing a 2.5 second PRT, a vehicle deceleration rate of 10 feet/second^2, minus the sign legibility distance of 250 feet.
5. No suggested distances are provided for these speeds, as the placement location is dependent on site conditions and other signing. However, the alignment warning sign should be installed in advance of the curve and at least 100 feet from any other signs.
6. The minimum advance placement distance is listed as 100 feet to provide adequate spacing between signs.

Source: FHWA, MUTCD

6.1.6. Other Considerations

6.1.6.1. Sign Posts

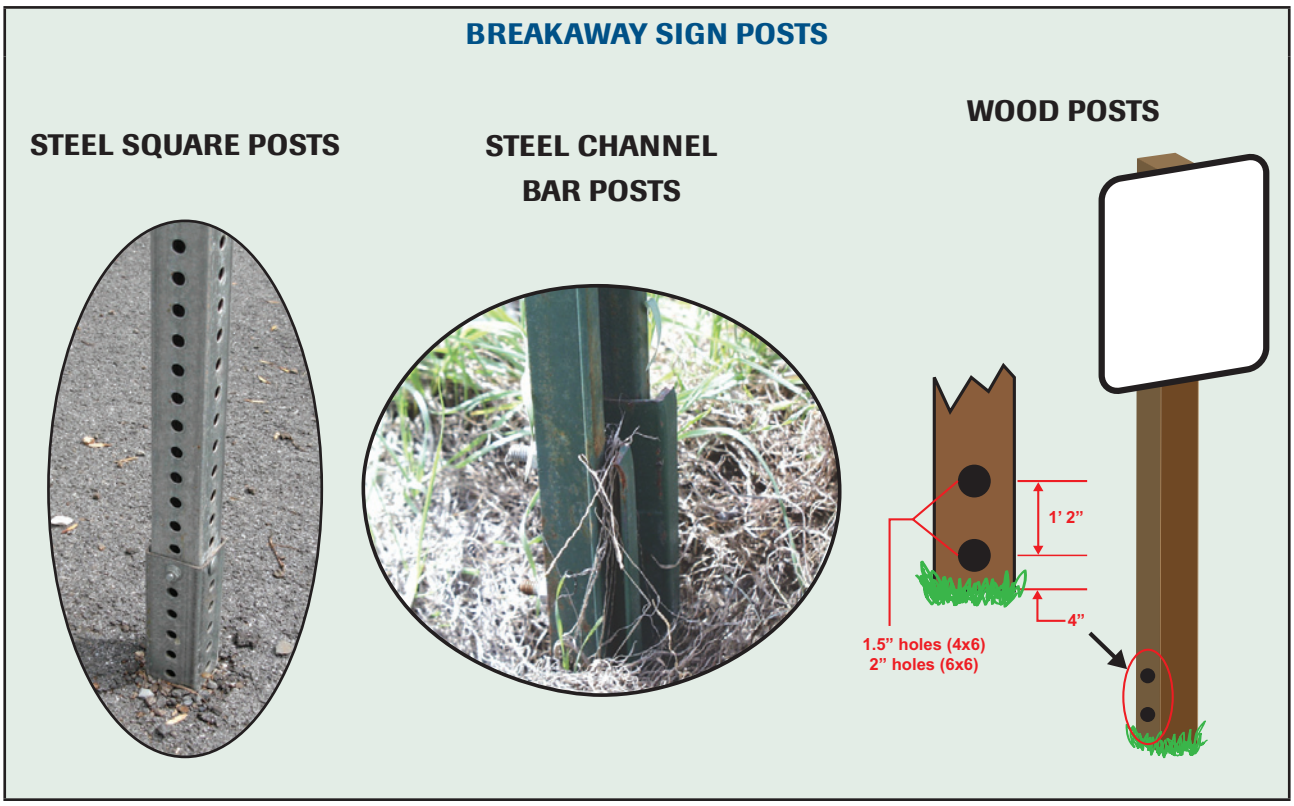
To reduce potential injuries and vehicle damage, all sign posts must be of an approved breakaway or yielding design as approved by FHWA. The most common types of approved sign posts are:

- ✓ Steel square posts where the upper part nests inside a slightly larger anchor post.
- ✓ Steel channel bar posts with a bolted connection at ground level.
- ✓ Wood posts, typically with two drilled holes to create a "shear plane" for the post to break if impacted by a vehicle.

Generally, a maximum of two of these posts can be used, and signs with areas greater than about 20 square feet generally require larger, more sophisticated sign support systems. Before ordering steel sign posts, require the manufacturer or distributor to provide the following:

- ✓ Certification that the sign post is approved by FHWA, and that the maximum allowable number of breakaway sign posts within 7 feet from the roadway edge is not exceeded.
- ✓ Documentation showing the maximum sign area that the sign post will support in your locale (the design wind speeds and soil conditions vary).
- ✓ Proper installation instructions.

Wood posts should be pressure-treated Yellow Pine or Douglas Fir lumber. Except for the 4"x4" size, wood posts require two holes drilled through the posts on the vertical center line of the post.



6.1.6.2. What is Retroreflection?

Most objects reflect light. The most common type of reflection is "diffuse reflection" where light scatters after striking rough surfaces such as trees, clothing, and carpet. Only a very small amount of the diffused light reflects back toward the light source.

Another type of reflection is "mirror reflection" that occurs when light strikes smooth or glossy surfaces, and the light reflects off the surface at an equal but opposite angle. Mirror reflection frequently occurs at night on wet roads when the headlights of approaching vehicles create extensive glare. Sign faces also produce some mirror reflection due to their glossy surfaces, and for this reason, it is a good practice to rotate signs away from the driver (see Section 2.1.11 of SDDCTEA Pamphlet 55-14 for more information).

In contrast, "retroreflection" is the unique ability of a surface to reflect light back toward the light source even when the surface is not perpendicular to the light source; and "retroreflectivity" is the measure of this unique property.

The three types of reflection are illustrated in Exhibit 6.6.

Retroreflective Sheeting Materials

To make signs retroreflective, sign shops apply retroreflective sheeting to the face of each sign, which incorporates either microscopic glass beads or microscopic cube-corner reflectors (frequently called "microprismatic material") behind a smooth translucent pigmented surface layer. If the manufacturers could make perfectly shaped glass beads or cube-corner reflectors, all light from a vehicle's headlights would return directly back to the headlights. Although we do not have perfectly shaped glass beads or reflectors, drivers do see more reflected light when their eyes are closer to the headlights. As illustrated in Exhibit 6.7, the angle formed between the headlights, the sign, and the driver's eyes is the observation angle, and the smaller the angle the higher the retroreflection.

Exhibit 6.6: Types of Reflection

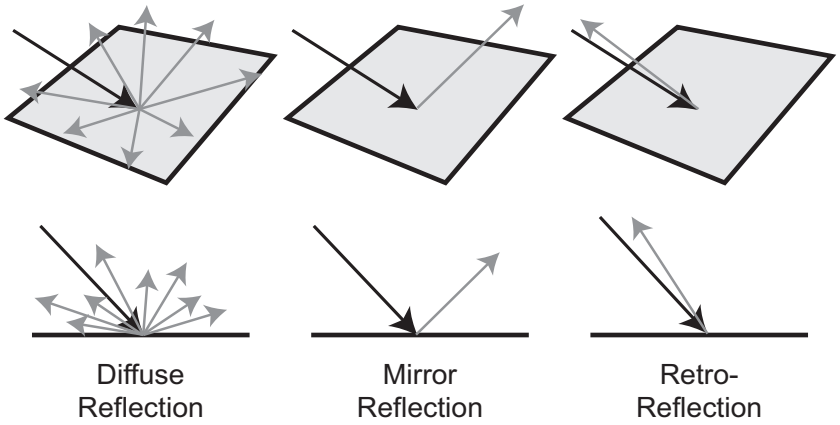
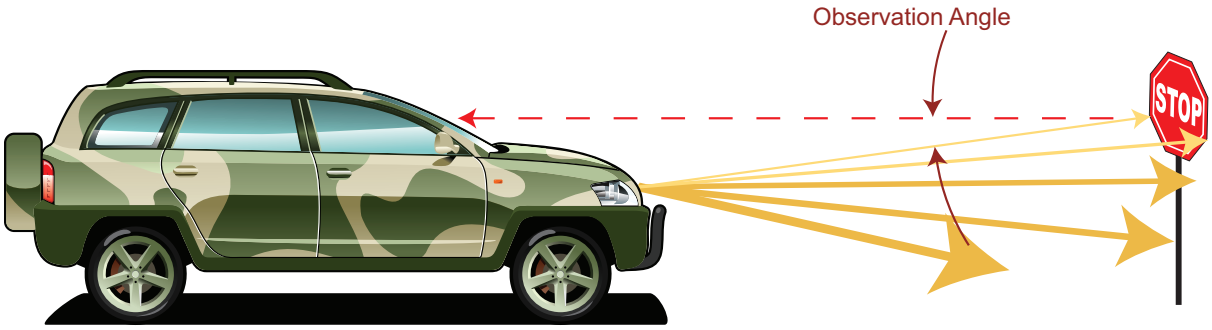


Exhibit 6.7: Graphic Illustration of the Observation Angle



Retroreflective materials are also more efficient when the light source is approximately perpendicular to the sign face; therefore, it is important to have signs oriented toward approaching traffic.

Some traffic signs may look almost new during the day but are completely ineffective at night. This nighttime visibility problem is usually a function of the type and age of the retroreflective material. For example, the STOP sign on page 6-19 looks almost new during the day, but it is not retroreflective because the sign shop used a non-retroreflective sheeting material (the sign shop also used a non-standard lettering font). Therefore, these problems illustrate the importance of:

- ✓ obtaining all signs from a reputable sign shop; and
- ✓ performing nighttime inspections of the signs.

Factors that Affect a Driver's Ability to "Read" Signs at Night

Of the following eight items, military installations can only help drivers by modifying Items 5, 6, 7, and 8:

1. The driver's night vision and acuity.
2. Intensity and light distribution of the headlights.
3. Location of driver's eyes with respect to the headlights.
4. Frost, dew, or snow on the sign face; or rain, snow, fog, smoke, etc., between the vehicle and the sign.
5. Obstructions in the line-of-sight between the driver and the sign.
6. Size and readability of the sign.
7. Locations, mounting height, and orientation of the sign in relation to the vehicle's headlights.
8. Type and age of the retroreflective sheeting material.

An Unacceptable, Non-retroreflective Sign

Making Retroreflective Signs

Signs are made retroreflective by applying white or colored retroreflective sheeting on the sign blank. Sign messages for mass-produced signs are typically silk-screened directly on the sheeting. All non-black inks need to be a transparent type and applied on white sheeting so that the screened color is both retroreflective and the proper color.

One-of-a-kind signs are typically made with cutout, pressure-sensitive legend (i.e., letters, symbols, numbers, and arrows). Non-black cutout legends and borders need to be made from retroreflective sheeting material.

Measuring Retroreflectivity

Retroreflectivity is measured with a retroreflectometer. Hand-held instruments for use in the field cost about $12,000 and measure the retroreflectivity value at preset angles to simulate what drivers see. Many units also capture GPS coordinates which can be downloaded into an inventory or asset management database.

However, using a portable retroreflectometer is more difficult than it may seem because signs are normally on posts and either the retroreflectometer needs to be supported by an extension pole and accurately held against the sign face, or the user must climb on a ladder.

Measuring Retroreflectivity

In addition, researchers typically suggest taking about three readings on signs, at least those signs that are nearing the end of their useful life, since retroreflectivity sometimes varies at different locations on a sign face. And to make matters worse, the unit must also be precisely centered on white legends on signs such as STOP signs and guide signs. Therefore, up to six readings are sometimes recommended, making the process both challenging and time-consuming. Taking retroreflectivity readings on signs installed over the road on mast arms or sign structures is another problem.

Retroreflectivity readings are normally defined as the value RA measured in candelas per lux per square meter (cd/lx/m2). The RA value deteriorates over time, but materials of even the same type and color do not always deteriorate uniformly.

Therefore, it is desirable to provide a safety factor when scheduling replacement signs as illustrated in Exhibit 6.8.

Exhibit 6.8: The Decline of Retroreflectivity over Time

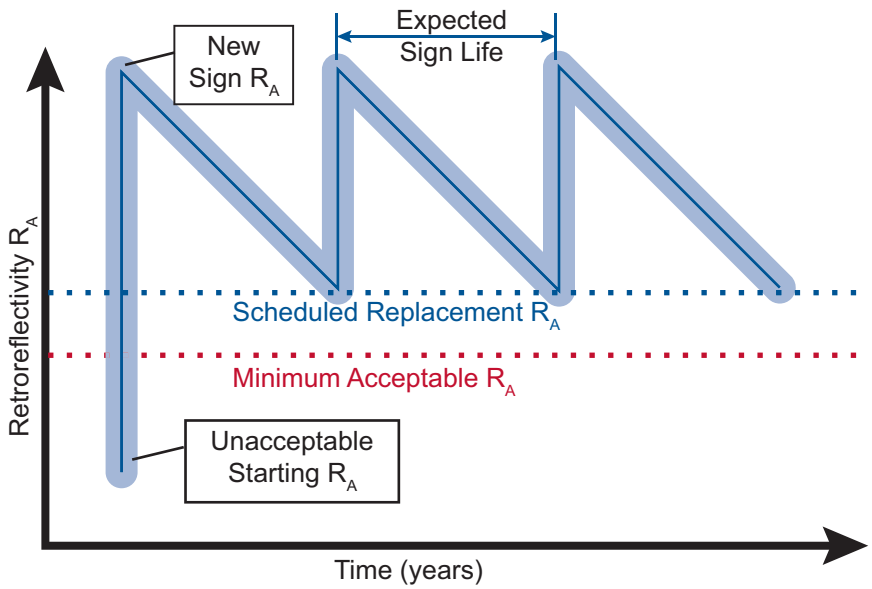


Exhibit 6.9: *MUTCD* Retroreflectivity Requirements

SECTION NO.	SECTION TITLE	SPECIAL PROVISION	COMPLIANCE DATE
2A.08	Minimum Retroreflectivity Levels	Implementation and continued use of an assessment of management method that is designed to maintain traffic sign retroreflectivity at or above the established minimum levels.	01/22/2112
2A.08	Minimum Retroreflectivity Levels	Replacement of regulatory, warning, and post-mounted guide (except street name) signs that are identified using the assessment or management method as failing to meet the established minimum levels.	01/22/2015
2A.08	Minimum Retroreflectivity Levels	Replacement of street name signs and overhead guide signs that are identified using the assessment or management method as failing to meet the established minimum levels.	01/22/2018

Retroreflectivity Requirements

Per the *MUTCD*, the dates shown in Exhibit 6.9 are required target dates relating to sign retroreflectivity. For all cases, Engineering Grade sheeting (Type I and Type II) do not meet the minimum retroreflectivity levels. These are easily recognizable since they have a uniform appearance similar to an automotive paint. Other better materials have a pattern of hexagons, diamonds, or other similar shapes that are approximately 1/8 of an inch wide. See SDDCTEA Pamphlet 55-14 for more information on specific sheeting types.

6.1.6.3. Attention-Getting Devices

When engineering judgment indicates that there is a need to draw additional attention to a regulatory or warning sign, there are several methods to accomplish this. First, it is permissible to attach a single flashing light to the top of the sign. However, the cost of running commercial power to a sign or replacing batteries is significant.

Section 2A.08 of the *MUTCD* allows the use of small light emitting diodes (LEDs) along the sign border or to supplement a symbol or word message of a regulatory, warning, or guide sign. To date, the effectiveness of these lights has not been studied and the relatively high cost per installation indicates that it may be beneficial to consider other measures.

Image provided courtesy of Traffic And Parking Control Co., Inc. TAPCO (www.tapconet.com)

Sign supplemented by LEDs

For regulatory and warning signs, Section 2A.21 of the *MUTCD* allows strips of retroreflective sheeting material on the front side of sign posts to draw attention to signs. When used, the strips must be a minimum of 2 inches wide, and applied from the bottom of the sign to within 2 feet of the bottom of the post. The color of a retroreflective strip must match the background color of the sign.

Plastic retroreflective sleeves are commercially available from several sources, and sign crews can generally use self-tapping screws to attach them to the posts. Depending on the type of sign post, a similar effect can be obtained by applying a strip of pressure-sensitive retroreflective sheeting directly to the posts.

These retroreflective strips are very effective at night, perhaps because they help define the physical location of the sign instead of allowing the sign to just float in the air. During daylight hours, the colored strips are also somewhat effective as an attention-getting device. Since these strips are relatively inexpensive and require no batteries or electricity, they currently are the recommended attention-getting device.

Retroreflective strips in use on a sign post

6.2. MARKINGS

KEY POINTS

Pavement markings and other types of delineation are economical ways to increase safety.

Pavement markings, like signs, should be placed in accordance with the *MUTCD* standards. Markings provide continuous guidance and work with signs to provide information to the motorist. Unlike other traffic control devices, pavement markings are visible to drivers without requiring them to take their eyes off the roadway.

Pavement markings typically consist of waterborne paints and thermoplastic tape. Inlaid blocks, bricks, and metal strips should not be used as pavement markings.

Typical pavement markings

Pavement markings may be categorized into two primary groups:

- ✓ Longitudinal markings help facilitate vehicle guidance and location
- ✓ Transverse markings provide warning and regulatory information to the motorist

Both types of pavement markings provide vital information to the vehicle operator. Therefore, they must be uniform in design, position, and application.

6.2.1. Longitudinal Markings

KEY POINT

The primary role of longitudinal pavement markings is to provide continuous guidance.

Longitudinal markings are the primary source of information for positioning vehicles on the roadway. It is important that markings be uniform so they can be recognized and understood instantly by all drivers. The *MUTCD* provides the basic principles to which all pavement markings should adhere.

Proper installation and maintenance of pavement markings is important since longitudinal construction joints can sometimes be falsely interpreted as pavement markings. When markings become worn, drivers tend to follow these joints, particularly in adverse weather or at night.

Dimensions of longitudinal pavement markings generally vary by state. In general, longitudinal markings should have a minimum width of 4 inches, although wider lines are helpful both day and night. Double solid yellow and white lines should typically have a 4- or 6-inch space between them. Broken yellow and white lines should have a 10-foot line and a 30-foot skip. Dotted lines should have 2-foot line and a 4-foot skip. Examples of pavement marking dimensions are shown in the illustration below.

Exhibit 6.10 shows dimensions and spacing for longitudinal pavement markings. Warrants for the use of pavement markings are contained in the *MUTCD*. Exhibit 6.11 outlines the *MUTCD* warrants for center lines and edge lines.

Exhibit 6.10: Dimensions and Spacing

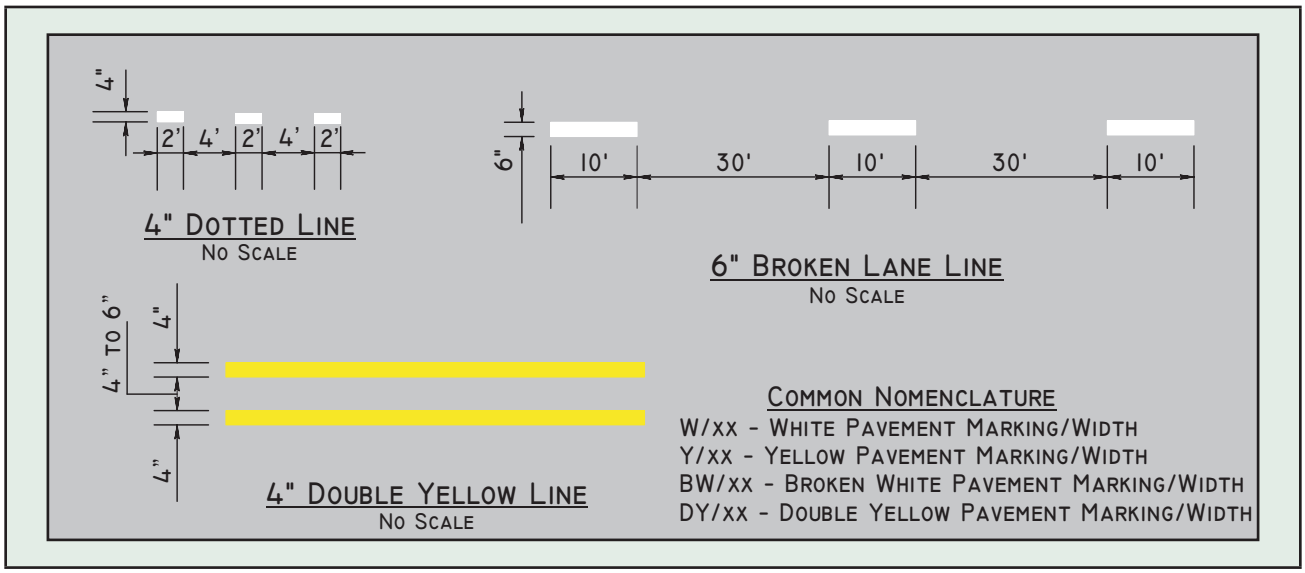
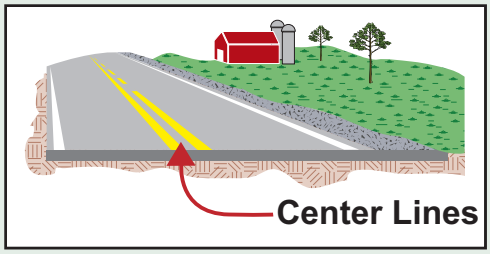
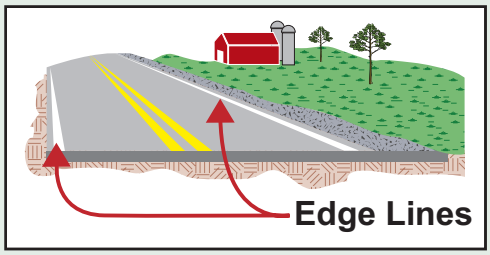


Exhibit 6.11: Primary Longitudinal Pavement Markings

SOLID YELLOW LINE	The solid yellow line indicates a no-passing zone applying to traffic with the solid line to its immediate left. Used alone, a single solid yellow line is only used to define the median of a freeway or divided roadway, or left edge of a one-way roadway. It is not to be used as a centerline on a bidirectional roadway.
DOUBLE SOLID YELLOW LINE	A double solid yellow line divides lanes of traffic flow in opposing directions where passing is prohibited in both directions.
BROKEN YELLOW LINES	A broken yellow line defines the center of a two-lane, two-way roadway where passing is permitted in both directions.
COMBINATION SINGLE SOLID/BROKEN YELLOW LINE	This combination is used when passing is permitted in one direction (adjacent the broken yellow), and prohibited in the other (adjacent the single solid).
BROKEN WHITE LINES	A broken white line is used to delineate lanes for travel in the same directions. Lane changing is permitted.
SOLID WHITE LINE	A solid white line is used to mark the right edge of the roadway, and to mark lanes for travel in the same direction where lane changing is discouraged. Its normal application is as a lane line on multilane approaches to intersections and, particularly, to delineate left- and right-turn lanes.
DOUBLE SOLID WHITE LINE	The double solid white line is used for travel in the same direction, but crossing the double line is prohibited. For example, the double solid white line may be used on a bridge to prevent lane changing.
DOTTED LINES	The dotted line delineates the extension of pavement markings through an intersection or interchange area. It should be the same width and color as the line it extends.

Source: FHWA, MUTCD

Exhibit 6.12: Warrants for Pavement Markings

TYPE, PURPOSE, AND APPLICATION	*MUTCD* CRITERIA	BENEFITS
CENTER LINES  ✓ Provides separation of traffic traveling in opposite directions ✓ Provides delineation of separation	Standards: ✓ Mandatory for all paved urban arterials and collectors with a travel way width of 20 feet or more and an ADT of 6,000 or more ✓ Mandatory for all paved two-way streets or highways that have three or more traffic lanes Guidance: ✓ Should be placed on all urban arterials and collectors with a travel way of 20 feet or more and ADT of 4,000 or more ✓ Should be placed on all paved rural arterials with a travel way width of 18 feet or more and an ADT of 3,000 or more ✓ Should be placed on other paved areas and travel ways less than 16 feet wide as a traffic engineering assessment indicates	✓ 30% reduction in head-on crashes
EDGE LINES  ✓ Provides an edge of pavement guide for drivers ✓ May result in lower speeds since travel lanes appear narrower	Standard: ✓ Mandatory for freeways, expressways and paved rural arterials with travel way widths of 20 feet or more and an ADT of 6,000 or more Guidance: ✓ Should be placed on all rural arterials and collectors with a travel way of 20 feet or more and an ADT of 3,000 or more Options: ✓ May be placed where center lines are not present ✓ May be used to minimize driving on shoulders	✓ 11 to 25% reduction in run-off-the-road crashes

Source: FHWA, MUTCD

6.2.2. Raised Pavement Markers

Raised Pavement Markers (RPMs) can be used to increase the visibility of pavement markings. They should be the same color as the pavement markings they supplement (except on divided roadways, where the backside facing wrong-way traffic may be red).

RPMs can be used in snow zones, but it is necessary to specify a more expensive snowplowable model that is partially embedded into the road surface. To protect the retroreflective surfaces, these special RPMs have metal rails on both sides of the unit to lift the snowplow blade up and over the retroreflectors.

Raised pavement markers

6.2.3. Transverse Markings

KEY POINT

Transverse markings generally indicate that drivers need to take immediate action.

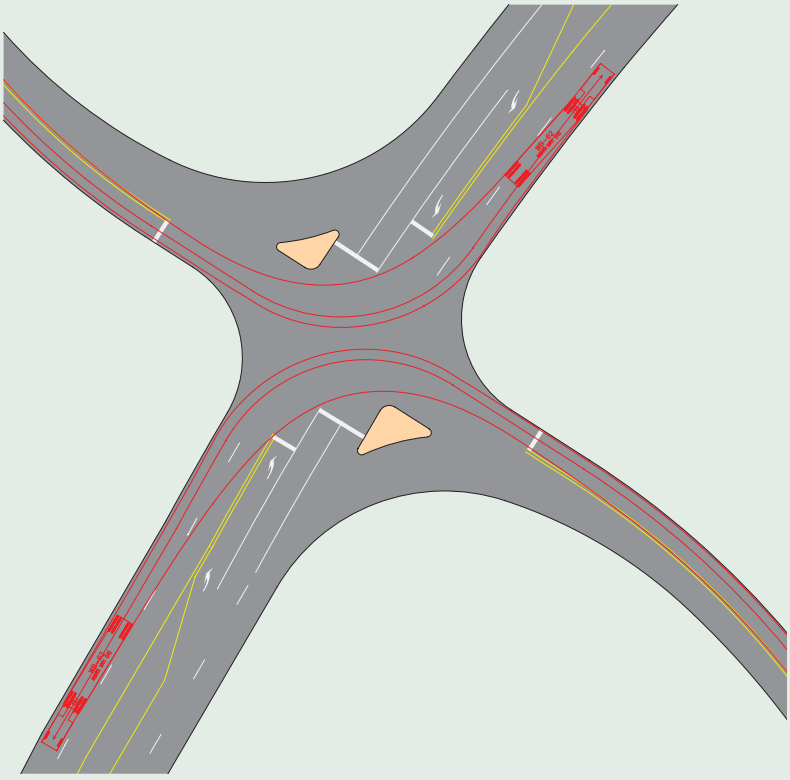
Transverse markings may indicate a command to stop at an intersection, to advise caution for pedestrians in a crosswalk, or to advise against travel within boundaries defined by crosshatching or painted islands. Several types of transverse markings include:

- ✓ Stop lines and yield lines
- ✓ Word and symbol markings
- ✓ Crosshatch lines
- ✓ Crosswalks

6.2.3.1. Stop and Yield Lines

Stop lines supplement STOP signs and traffic signals. When used, the location of the stop line is determined primarily by the geometry of the intersection, road width, sight distance, and the design-vehicle turn radius. This is illustrated in the figure below. The stopping point should be positioned on the approach leg such that it will not conflict with vehicles turning left from the cross street. Stop lines for left turn lanes sometimes need to be pushed ahead of those for the through lanes. This can be evaluated by turning templates of the design vehicle, as shown below.

STOP LINE PLACEMENT

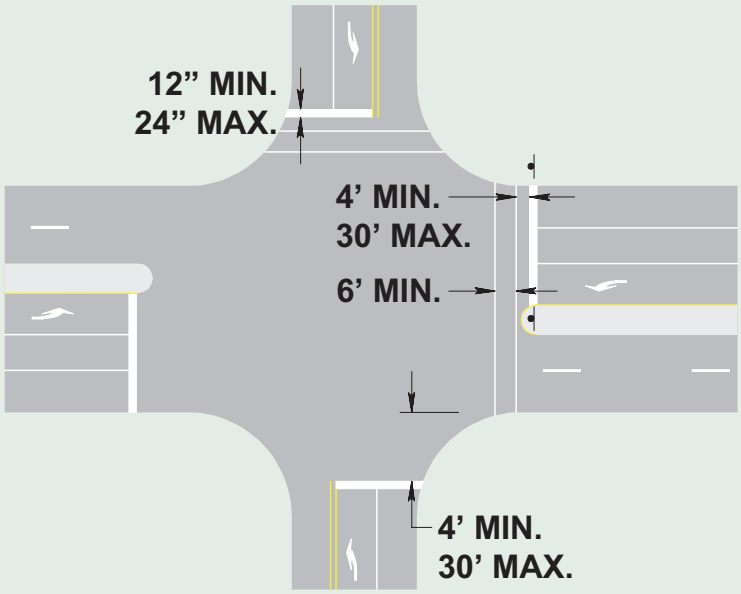


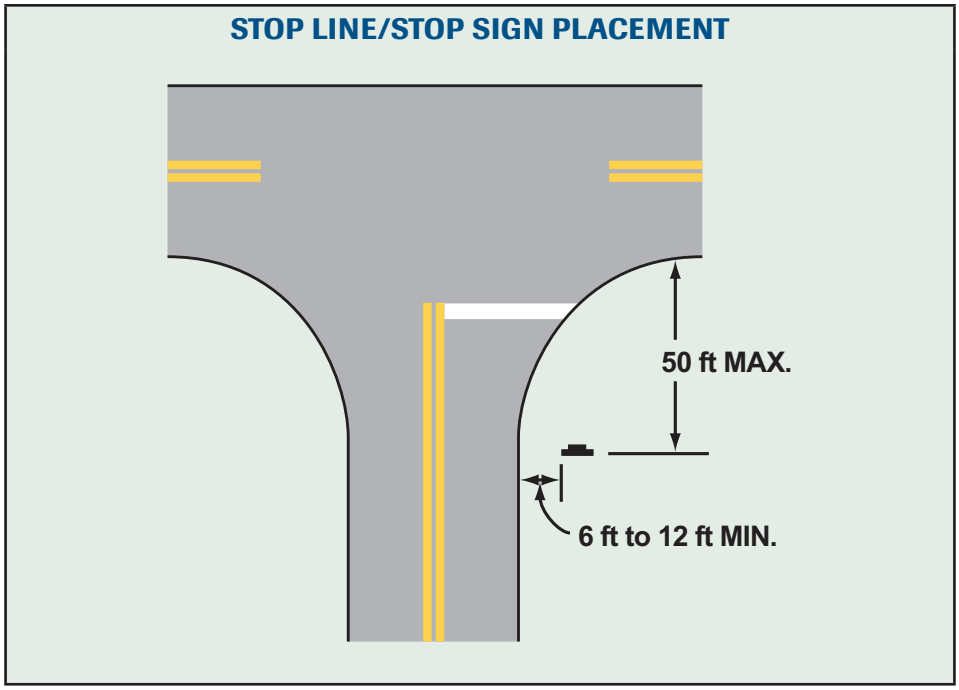
Although stop lines are not necessary at all stop locations, they should be provided where crosswalks are present, and at signalized intersections. The stop line should be marked only across the approach lanes in which traffic is required to stop. The line may be parallel with the intersecting roadway or crosswalk.

Locate the stop line at the desired stopping point, but in no case less than 4 feet or more than 30 feet from the edge of the intersecting roadway, travelway, or crosswalk. The location of the stop line is independent of the location of the STOP sign. The STOP sign should be no greater than 50 feet from the edge of pavement of the intersecting roadway.

The stop line is retroreflective white and is no less than 12 nor more than 24 inches wide. The width depends on the speed of the roadway and/or the presence of hazardous conditions.

STOP LINE PLACEMENT




STOP LINE/STOP SIGN PLACEMENT
50 ft MAX.
6 ft to 12 ft MIN.

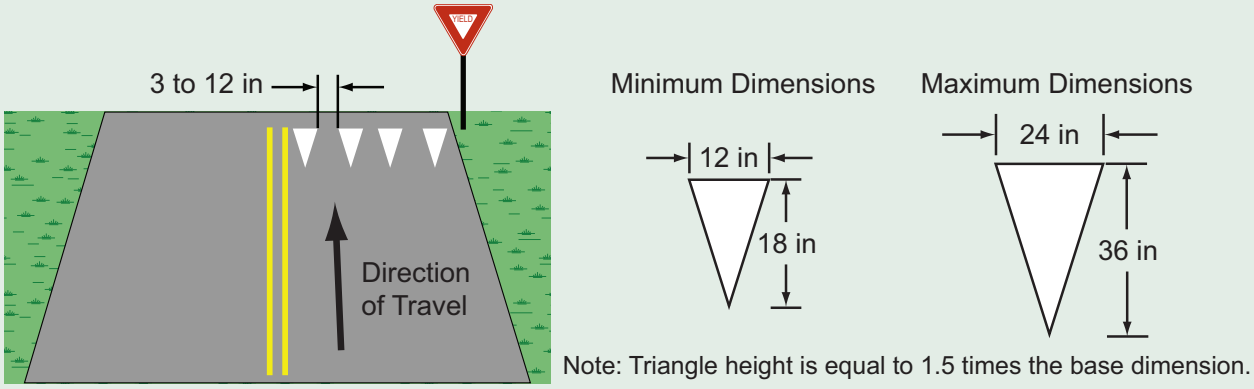
Similarly, yield lines supplement YIELD signs. Determining their location is similar to determining the location of stop lines. When used, yield lines consist of a row of solid white isosceles triangles pointing toward approaching vehicles extending across lanes to indicate the point at which drivers are to yield. Yield line placement examples are shown in the figure below. The individual triangles should have a base of 12 to 24 inches, and a height equal to 1.5 times the base. The space between the triangles should be 3 to 12 inches.

A common mistake is placing stop or yield lines too far away from the intersecting road where drivers do not have a clear view of traffic on the crossing road. As a result, drivers sometimes enter the intersection without proper clearance because they had inadequate sight distance.

Therefore, it is very important to check sight distance to both the left and the right before finalizing the location of a stop or yield line. Keep in mind that a driver's eyes will typically be about 10 feet behind the line and at an elevation about 3.5 feet above the pavement.

Stop and yield lines should be used before midblock crosswalks. Different states have different rules regarding stopping versus yielding to pedestrians in midblock crosswalks. Prior to marking a midblock crosswalk, be sure to check your state's law regarding which is appropriate to your installation.

TYPICAL YIELD LINE PLACEMENT



Note: Triangle height is equal to 1.5 times the base dimension.

6.2.3.2. Word and Symbol Markings

Pavement word and symbol markings may be used for guiding, warning, or regulating traffic. They are generally used at intersections for lane assignment, or on roadways when special situations exist where additional guidance to the motorist is required. In such cases, they should be limited to no more than three lines of information and shall be white with retroreflective properties.

Although multiple lane approaches to intersections may be marked with lane-use arrows, it can often be difficult for motorists to determine which lane to use at an intersection. This can become more difficult at nighttime, in wet conditions, and when pavement markings become worn. To supplement pavement markings, lane-use control signs should be installed on multiple lane approaches. The *MUTCD* provides guidelines for the installation of these signs.

6.2.3.3. Crosshatch Lines

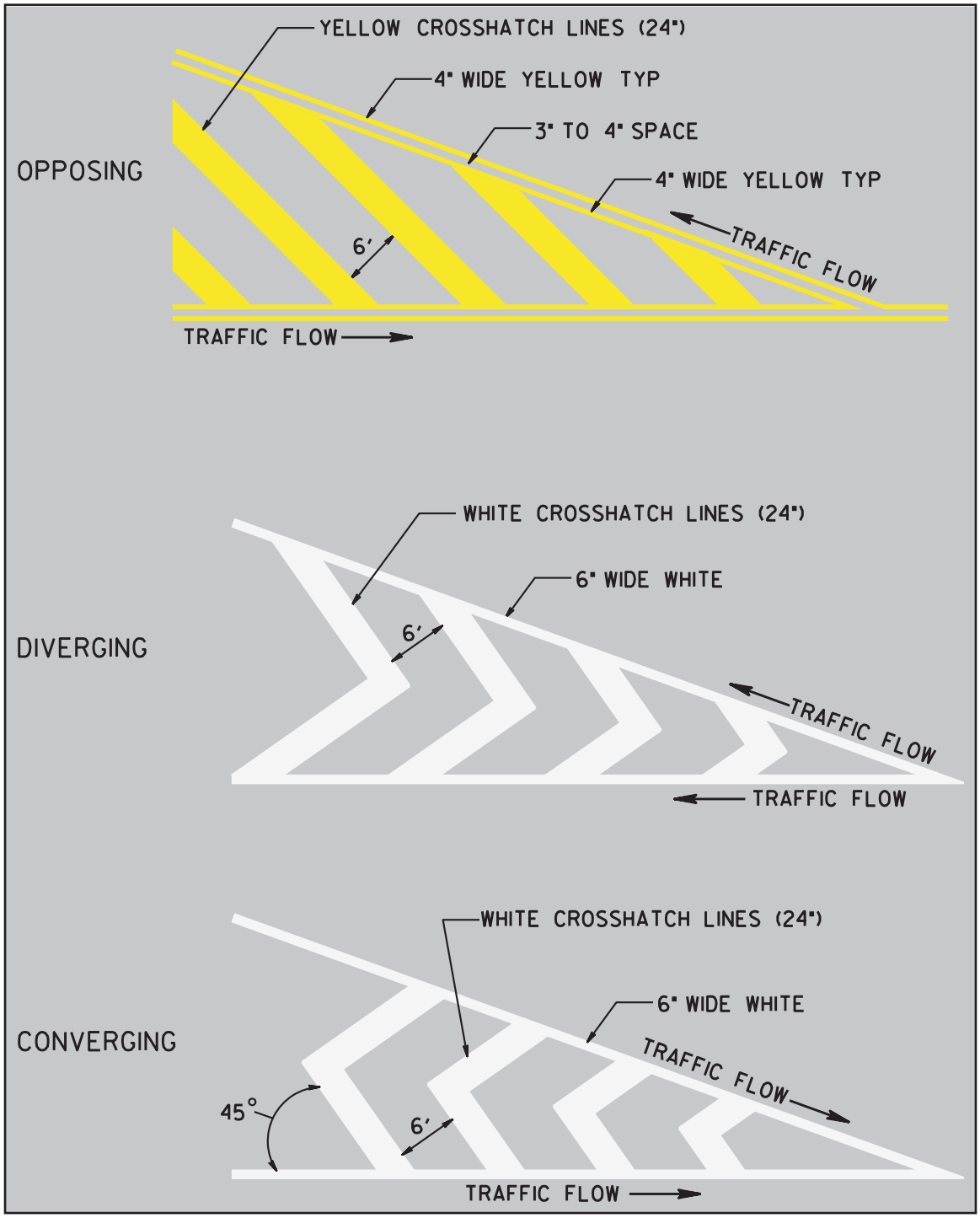
Crosshatch lines indicate an area, within defined boundaries, over which vehicular traffic should not travel. To attract attention, crosshatch lines provide an alternating light and dark contrast pattern. Also, these lines guide motorists past an area they should not enter. Crosshatch lines may be used in conjunction with divisional and channelizing islands, on approaches to obstructions, and paved shoulders. However, prudent use of these lines is recommended. Crosshatch lines should be sloped in the direction of traffic flow. Within a particular area they may all slant in one direction, or, if traffic passes on more than one side, they may slope in various directions. Where islands are small and traffic flows in several directions, it may be infeasible to slope all crosshatch lines in the direction of traffic flow. In such cases, the slope should favor the major flow of traffic. Crosshatching design is shown in Exhibit 6.13.

Crosshatch lines are commonly used in the following locations:

- ✓ Wide medians (yellow lines)
- ✓ Channelization islands at intersections (white or yellow lines)
- ✓ Shoulders (white lines)
- ✓ ECF areas, around ID check islands (white or yellow lines)

Typical median crosshatching

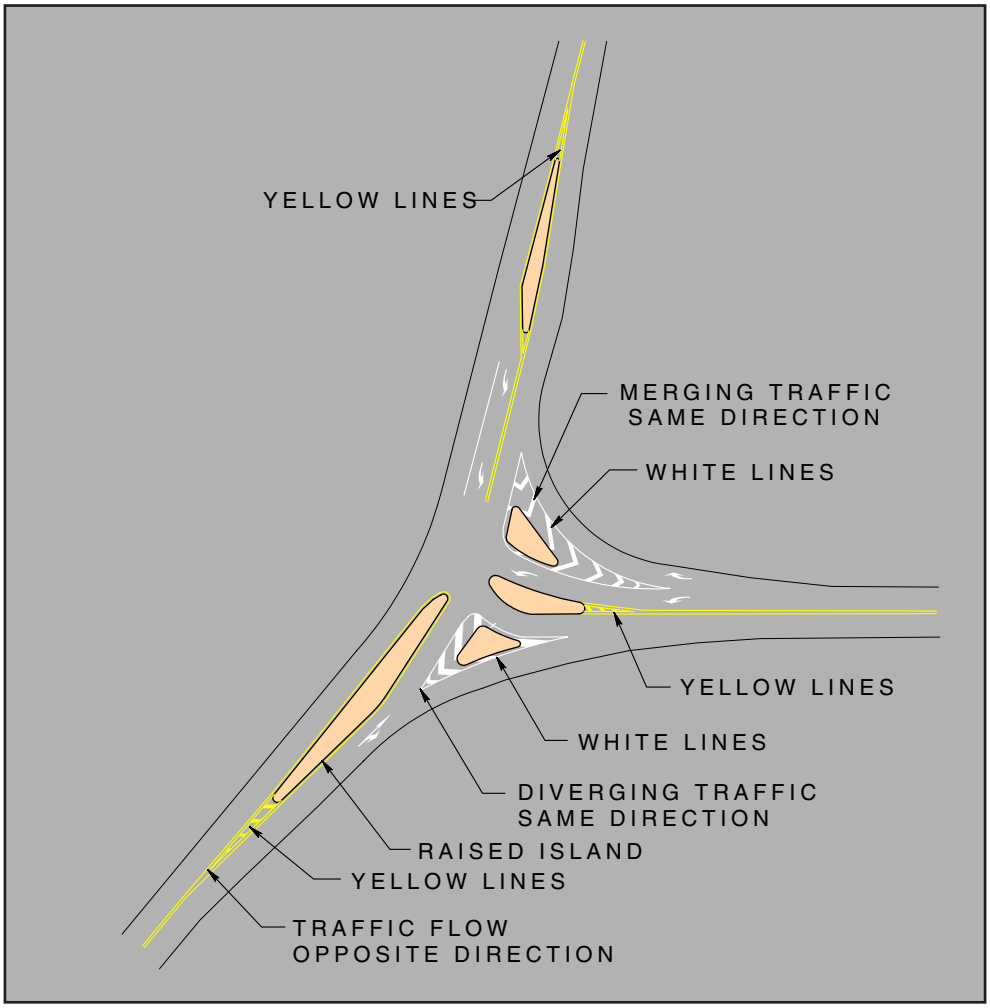
Exhibit 6.13: Typical Crosshatching



6.2.3.4. Painted Islands

Islands may be formed with pavement markings to channelize traffic. Where travel in the same direction is permitted on both sides, an 8-inch-wide or double solid white line should be used. Where islands separate travel in opposite directions, double yellow lines should be used. For added emphasis, painted crosshatching may be placed within the island, in which case the crosshatch markings should be the same color as the lines that outline the island. Exhibit 6.14 shows the use of painted islands.

Exhibit 6.14: Painted Islands



6.2.3.5. Crosswalks

When crosswalk lines are used, they should be solid white lines and should not be less than 6 inches nor greater than 24 inches in width (OPTION 1 below). For added visibility, the area of the crosswalk may be marked with white diagonal lines at a 45-degree angle to the line of the crosswalk (OPTION 2 below) or with white longitudinal lines parallel to traffic flow (OPTION 3 below).

If used, the diagonal or longitudinal lines should be 12 to 24 inches wide and spaced 12 to 60 inches apart.

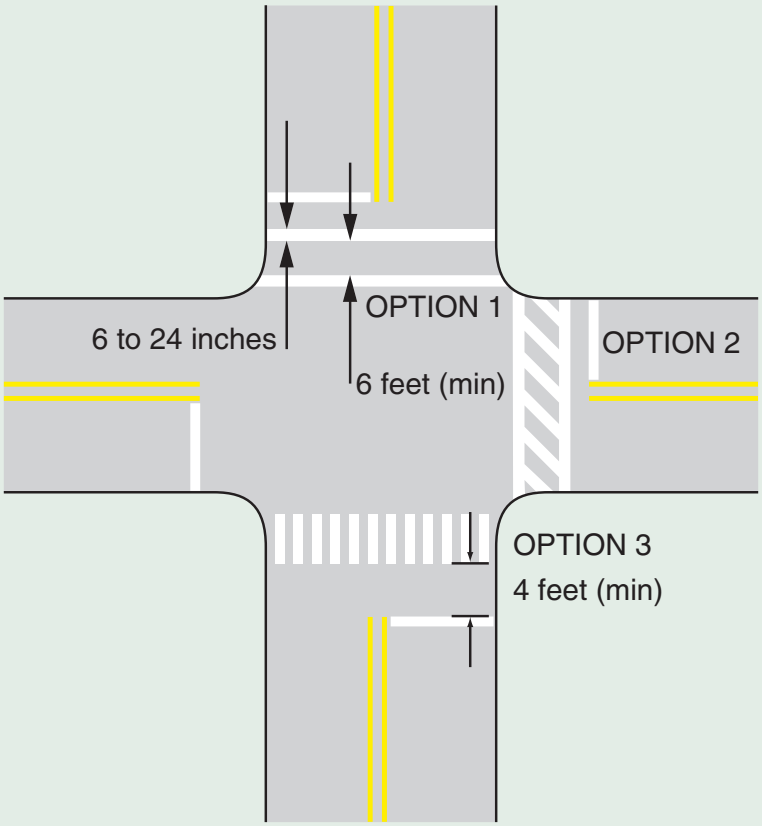
These types of markings may be used at locations where:

- ✓ Substantial numbers of pedestrians cross without any other traffic control device.
- ✓ Physical conditions are such that added visibility of the crosswalk is desired.
- ✓ A pedestrian crosswalk might not be expected.

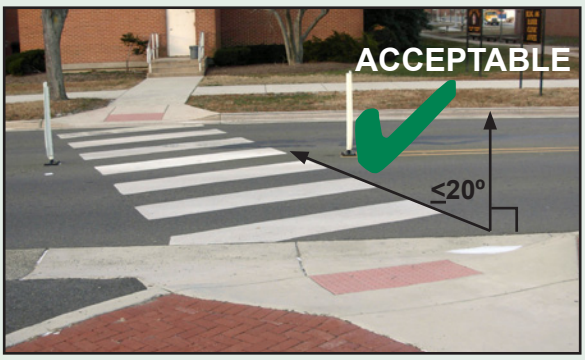
Crosswalks should be at least 6 feet wide, with wider crosswalks where pedestrian demand is high.

Crosswalks which are not perpendicular to the roadway they cross should be avoided. With a perpendicular crosswalk, the time that a pedestrian is in the roadway exposed to traffic is minimized. If the crosswalk is not perpendicular to the roadway, it should not be greater than 20 degrees off of perpendicular to the roadway.

CROSSWALK MARKING OPTIONS



SKEWED CROSSWALK CONFIGURATIONS



6.2.4. Applying Pavement Markings

The most common pavement marking material is waterborne paint, which is really a latex paint. During the past few years, there were significant improvements in the quality and durability of waterborne paint; and in most cases, the better paints will last at least 2 years.

Waterborne paints are generally applied at a wet thickness of 15 mils (i.e., 0.015 inch), which translates to one gallon of paint for every 321 linear feet of 4-inch wide line. These paints will generally dry within about 2 minutes.

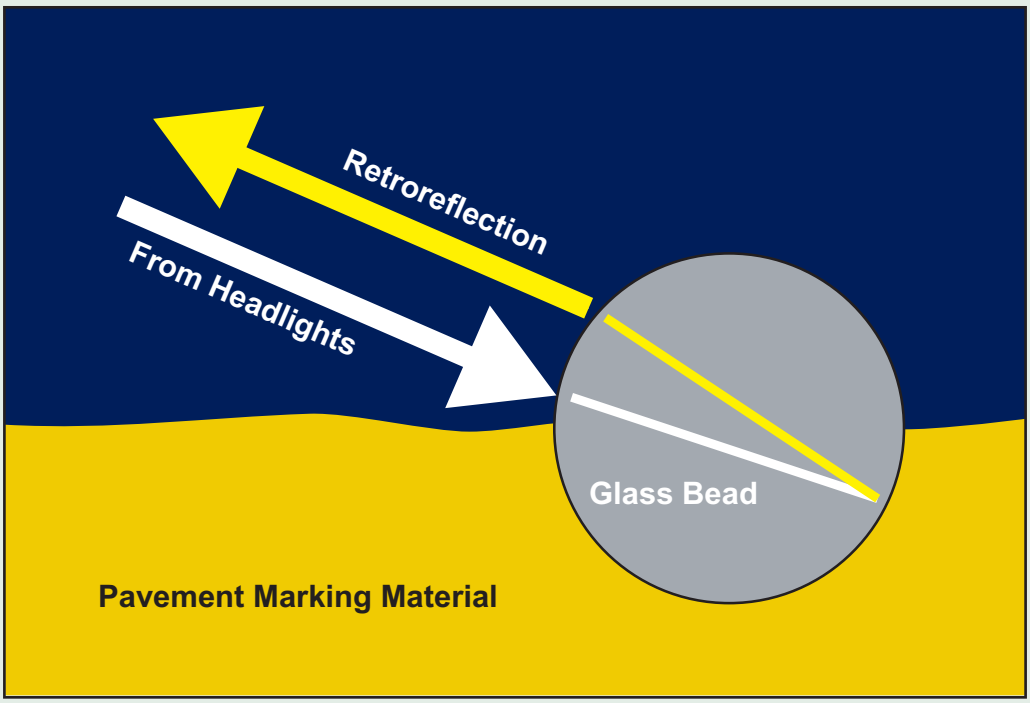
Pavement markings need to be retroreflective, since non-retroreflective markings are useless at night.

Almost without exception, all pavement-marking materials rely on round glass beads embedded into the surface of the pavement marking material to make them retroreflective. When a vehicle's headlights illuminate a glass bead, the light:

- ✓ Refracts or bends as it enters the bead;
- ✓ Reflects off the backside of the bead if this part of the bead is embedded in the pavement marking material;
- ✓ Refracts again as it leaves the glass bead; and
- ✓ Returns to the general vicinity of the headlights and driver.

It is essential that the proper type and quantity of glass beads are added to the paint before it solidifies. Specify at least seven pounds of glass beads for every gallon of paint. Pavement markings should be inspected annually to ensure they are in acceptable condition.

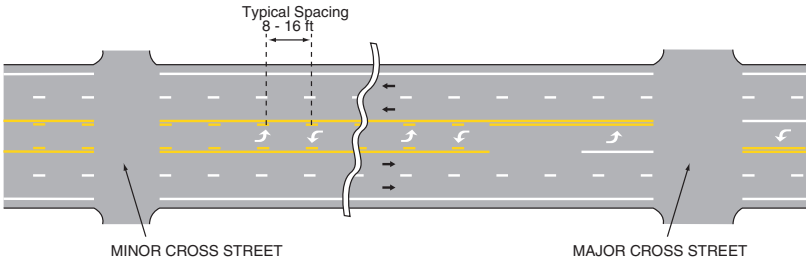
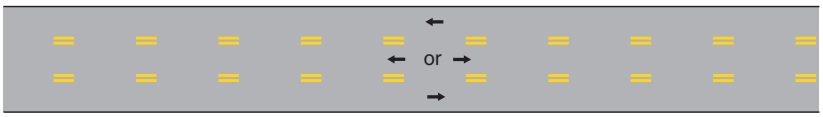
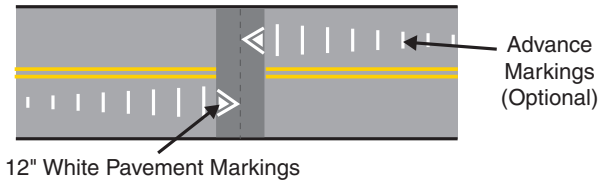
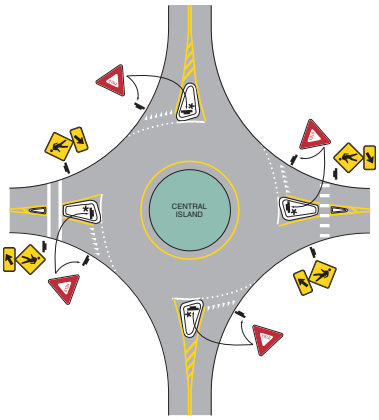
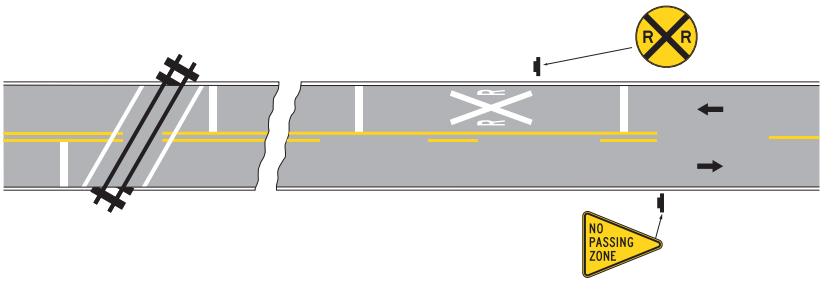
PAVEMENT MARKING RETROREFLECTIVITY



6.3. ADDITIONAL PAVEMENT MARKINGS

The *MUTCD* includes guidance for some other less common markings, as shown in Exhibit 6.15.

Exhibit 6.15: Additional Types of Pavement Markings

TWO-WAY LEFT-TURN LANES	
REVERSIBLE LANES	
SPEED HUMPS	
ROUNDABOUTS	
HIGHWAY-RAIL GRADE CROSSINGS	

CHAPTER 7 – TRAFFIC SIGNALS AND ITS

7.1. TRAFFIC SIGNALS: THE BASICS. 7-1

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7.1. TRAFFIC SIGNALS: THE BASICS

Traffic signals are a valuable tool in assigning right-of-way at intersections where, without such control there would be excessive delay or safety concerns.

As a result, there are more than 300,000 traffic signals nationwide. However, traffic signals themselves can significantly worsen traffic congestion and create safety concerns if they are not designed, maintained, and operated properly.

- ✓ Five percent of traffic congestion can be attributed to traffic signals.
- ✓ Traffic signal congestion costs approximately $10,000 in delay and fuel costs per intersection per year.
- ✓ Six percent of all fatal crashes occur at signalized intersections.

Traffic signals are needed when STOP sign control cannot do the job effectively. STOP signs do not work well when there is a high volume of traffic or it is difficult for vehicles on the side roads to safely pull out. Signals can also be used to make it safer for pedestrians to cross the street, and for emergency vehicles to enter the roadway.

Prior to being installed, traffic signals must meet at least one of the nine traffic signal warrants presented in Exhibit 5.4 and the *MUTCD*. When warranted and properly designed, a traffic signal helps to:

- ✓ Reduce crashes.
- ✓ Improve traffic movement.
- ✓ Allow other vehicles and pedestrians to cross a heavy traffic stream.
- ✓ Control traffic better than non-automated methods.

Unjustified, ill-designed, improperly operated, or poorly maintained traffic signals may cause:

- ✓ Increased crash frequency.
- ✓ Excessive delay.
- ✓ Disregard of signal indications.
- ✓ Circuitous travel by alternate routes.

Typical traffic signal head

7.1.1. Basic Design Guidelines

The *MUTCD* sets basic guidelines for the design and construction of traffic signal installations. Furthermore, many state DOTs have specific guidance regarding the design and implementation of traffic signals. The design of traffic signals requires the expertise of a qualified traffic engineer. Exhibit 7.1 illustrates some basic design concepts.

Exhibit 7.1: Basic Traffic Signal Design Guidelines

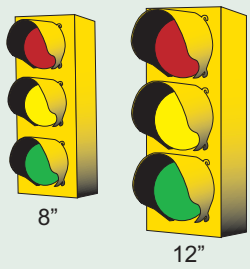
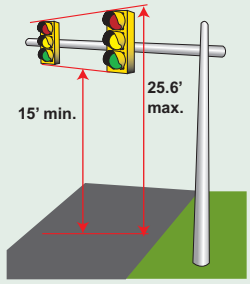
DESIGN ELEMENT	DESIGN CONSIDERATION/GUIDANCE
LENS SIZE  	✓ There are two nominal sizes for signal lenses: 8-inch and 12-inch. ✓ SDDCTEA recommends using 12-inch lenses in most cases, and always: • Where arrow signal indications are used • When intersection approach speeds exceed 40 mph • Where signals are over 120 feet from the stop line • For approaches where signals might be unexpected or sight distance is limited • For locations where there is a significant percentage of elderly drivers.
SIGNAL DISPLAY REQUIREMENTS 	✓ A minimum of two signal faces for the major traffic movement must be continuously visible on an approach to a signalized intersection. ✓ Provide adequate sight distance of the signal display. The sight distance varies with approach speed, as shown below. ✓ Locate signals between 40 and 180 feet from the stop bar. ✓ Required signal faces for any one approach must be mounted no less than 8 feet apart, measured horizontally perpendicular to the approach and between the centers of the signal faces.
SIGNAL MOUNTING HEIGHT  	✓ The bottom of the signal housing and any related attachments to a vehicular signal face located over a roadway shall be at least 15 feet above the pavement. ✓ The top of the signal housing of a vehicular signal face located over a roadway shall not be more than 25.6 feet above the pavement.

Exhibit 7.1: Basic Traffic Signal Design Guidelines (continued)

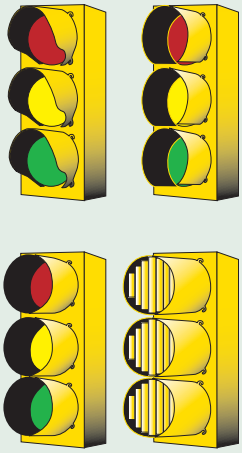
DESIGN ELEMENT	DESIGN CONSIDERATION/GUIDANCE
BACKPLATES 	✓ Provide backplates on signal heads to improve their visibility by making the head stand out from the surroundings. ✓ Backplates also help to prevent confusion due to advertising signs and the rising or setting of the sun. ✓ A yellow retroreflective strip can be placed on the backplate for additional visibility.
LATERAL PLACEMENT OF SUPPORTS 	✓ Where speeds are less than 40 mph, signal poles should be placed at least 2 feet (but preferably more) beyond the edge of vertical curb or at least 2 feet (but preferably more) beyond the usable shoulder if no curb exists. ✓ Generally, if no curb exists and where speeds exceed 40 mph, poles should be more than 10 feet from the edge of the roadway.
VISOR TYPE Cut-away Tunnel  Full Circle Louvered	✓ Equip all signal faces with visors to reduce reflected glare from the sun or other light, and to direct the signal indication to the approaching traffic. ✓ Cut-away visors are the most commonly used type. ✓ Full circle, tunnel, and louvered type visors further reduce the possibility of signal indications being seen by opposing traffic.

Exhibit 7.1: Basic Traffic Signal Design Guidelines (continued)

CONTROLLER CABINET	✓ A controller cabinet is used to store the equipment used to operate a traffic signal. ✓ Locate it as far from the roadway as practical. ✓ It should not be placed where it would be hazardous to pedestrians, joggers, or bicyclists, or where it blocks the view of motorists. ✓ Position it so that a person working on the cabinet will have a clear view of all intersection approaches.
OPTICALLY PROGRAMMED SIGNAL FACES	✓ Use optically programmed signal faces when signal faces may be able to be viewed from another approach or adjacent intersection. ✓ Optically programmed signal faces limit visibility of signal faces to the area for which they are intended.

7.1.2. Signal Display and Design Configuration

Generally, provide the same number of overhead signal faces as approach lanes with a minimum of two. See Exhibit 7.2 for recommended number of signal faces per approach.

A traffic signal installation's effectiveness depends largely on the ease with which the signal heads can be seen and recognized. For this reason, certain standards have been developed to place signal faces within the motorist's cone of vision, and within a desirable mounting height and location within the intersection.

Signal heads may be mounted on posts or poles at the sides of the roadway or on raised islands in the roadway. They also may be suspended from span wires or mast arms over the roadway. The use of tether wire with span wire mountings reduces the movement of signal heads due to wind. Post-mounted signals are not recommended for use as the primary control of left-turn and through-traffic movements due to visibility issues.

The *MUTCD* requires that at least one signal face (but preferably two) be located within a cone of 20 degrees to the left or to the right of the "center of the approach lanes extended." Signals should be located between 40 and 120 feet from the stop bar. When a 12-inch signal face is used, signals can be installed up to 180 feet from the stop bar without installation of a near-side supplemental signal face.

Required distances are illustrated in Exhibit 7.3.

Exhibit 7.2: Recommended Minimum Number of Primary Signal Faces[1]

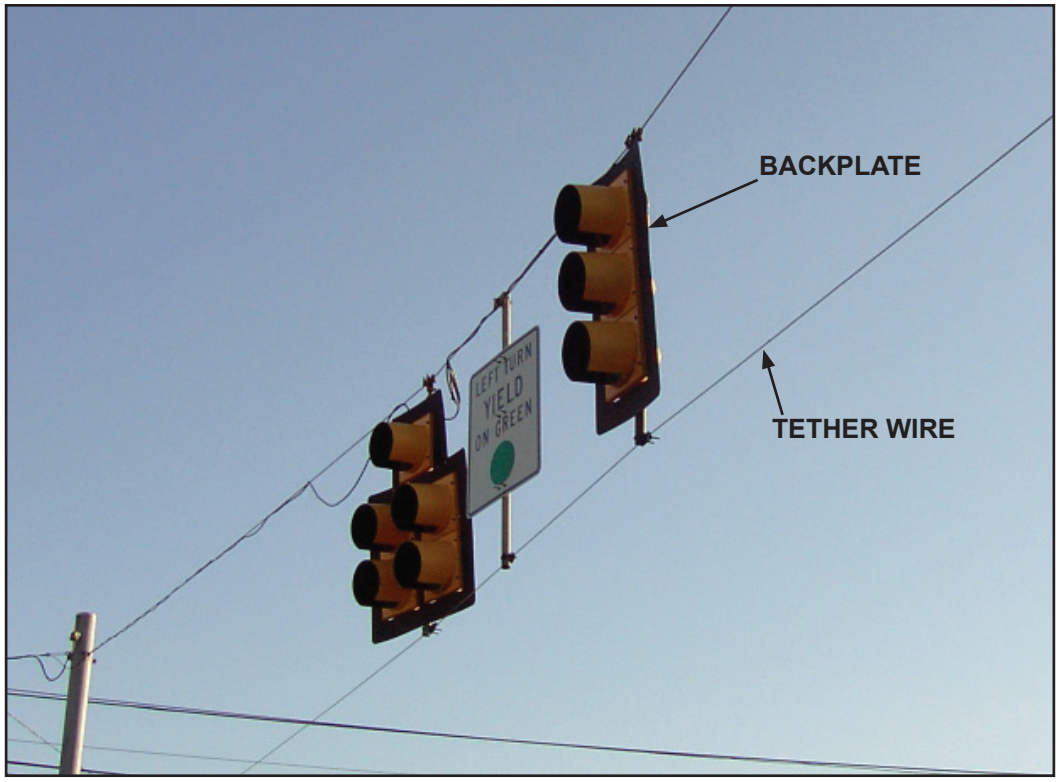
NUMBER OF THROUGH LANES ON APPROACH	TOTAL NUMBER OF PRIMARY THROUGH SIGNAL FACES FOR APPROACH[2]	MINIMUM NUMBER OF OVERHEAD-MOUNTED PRIMARY THROUGH SIGNAL FACES FOR APPROACH
1	2	1
2	2	1
3	3	2[3]
4 or more	4 or more	3[3]

Notes:

[1] This table applies for through traffic on approaches with posted, statutory, or 85th-percentile speed of 45 mph or higher.

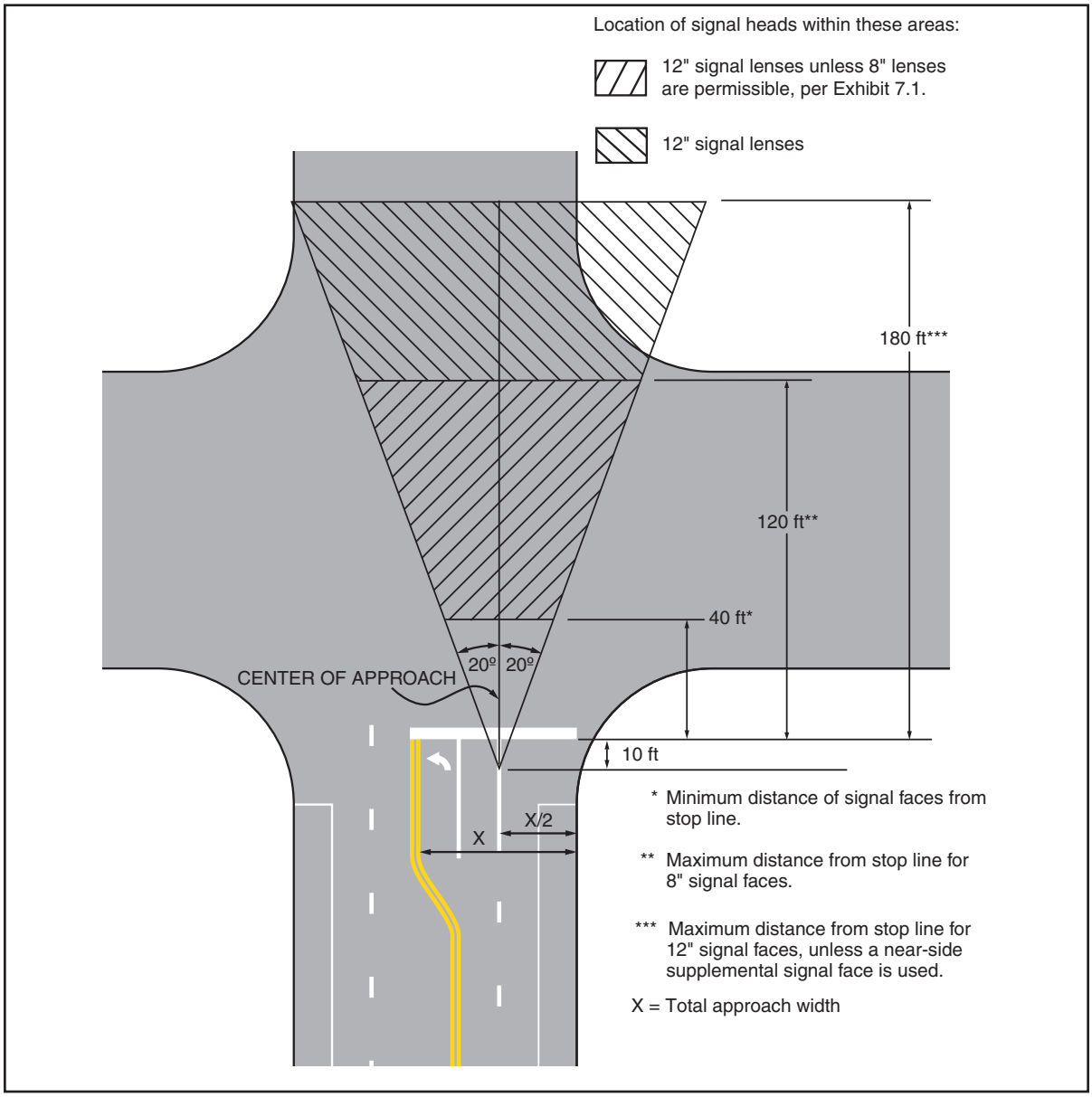
[2] A minimum of two through signal faces is always required. These recommended numbers of through signal faces may be exceeded. Also, see cone of vision requirements in Exhibit 7.3 on page 7-7.

[3] If practical, all of the recommended number of primary through signal faces should be located overhead.



Signal Head Components

Exhibit 7.3: Horizontal Location of Signal Faces



Source: FHWA, MUTCD

7.1.3. The Basics of Signal Timing and Operations

Proper timing and phasing of signalized intersections is critical in promoting safety and efficiency. There are four elements that make up the operation of a signalized intersection: interval, timing, phase, and cycle. These are defined in Exhibits 7.4 and 7.5.

The interval is the basic element of signal operations. All-red (clearance) and yellow (change) intervals must be calculated based on the speed, grade, and geometry of the intersection in order to ensure safe clearance of vehicles before a conflicting movement begins.

Green intervals proportionally distribute the total available green time based on the number of lanes and demand on each approach.

Exhibit 7.4: Signal Operation Elements

ELEMENTS	DESCRIPTION
INTERVAL	✓ The part of a signal cycle during which signal indications do not change. For example, red indication for one movement is considered an interval.
TIMING	✓ The period of time assigned to each signal interval. For example, the time given to the yellow indication is the timing for that interval.
PHASE	✓ The portion of a signal cycle when a single movement or a group of non-conflicting movements have the right-of-way. Typically, three intervals (green, yellow, red) make up a phase.
CYCLE	✓ A complete sequence of all signal indications. Typically, two or more phases make up a cycle.

Exhibit 7.5: Signal Phasing Intervals

INTERVAL	DESCRIPTION AND PURPOSE
GREEN INTERVAL	✓ Green times can be determined by several means. The basic principle for all methods is that green times should be proportional to the amount of traffic demand and the number of lanes on each approach. ✓ Green times should be recalculated periodically, especially when changes to traffic patterns occur.
YELLOW (CHANGE) INTERVAL	✓ The purpose of the yellow indication is to "warn" drivers that the green interval is ending and that a red interval will follow. In most jurisdictions, vehicles may legally enter the intersection while the yellow indication is displayed. ✓ Yellow intervals should have a duration of 3 to 6 seconds, which varies by speed.
ALL-RED (CLEARANCE) INTERVAL	✓ An all-red clearance interval will safely clear all vehicles from the intersection before an opposing flow of traffic begins. ✓ The all-red interval should not exceed 6 seconds, which varies by intersection width and speed.

KEY POINT

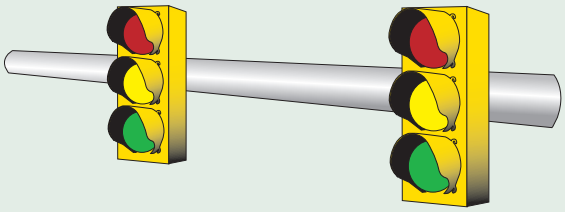
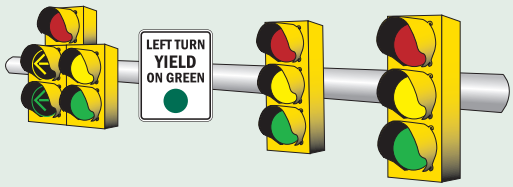
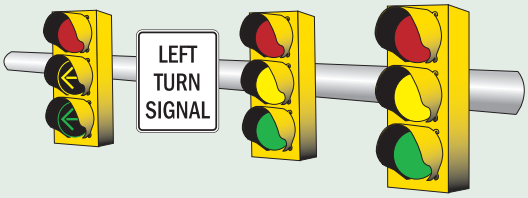
More signal phases are generally needed as traffic volumes and number of lanes increase.

Phasing can be simple or complex. To work effectively, a traffic signal system needs an appropriate signal phasing plan. A low-volume intersection normally operates with two phases, one for the main street, and one for the minor street. As traffic volumes and number of lanes increase, more phases may be required to give protected right-of-way to left-turn movements. Each phase added to the signal operation takes time away from existing phases.

Additional phases are sometimes added to accommodate left turns. In general, as left-turn volumes and opposing through traffic volumes increase, a point is reached where it is difficult for left-turn traffic to find adequate gaps in opposing traffic. Providing a separate left-turn lane alleviates the problem somewhat by providing storage space. However, a left-turn signal phase may still be warranted. Exhibit 7.6 describes the three types of left-turn phasing: Permissive, Protected/Permissive, and Protected Only.

When the number of phases required at an intersection is determined, the goals of safety and capacity may conflict. The added phases may result in longer cycle lengths and increased vehicle delays.

Exhibit 7.6: Left-Turn Phasing Options

TYPE OF LEFT-TURN PHASING	DESCRIPTION
PERMISSIVE 	✓ This is the simplest mode. ✓ No special phase or protection is included for left-turn movements. ✓ Left turns are permitted to turn against the opposing through-movement during acceptable gaps in traffic.
PROTECTED/PERMISSIVE 	✓ A special left-turn phase is provided, usually before the through movement of the opposing direction. ✓ During the through-movement phase, left turns are permitted to turn against the opposing through-movement during acceptable gaps in traffic. ✓ The 2009 *MUTCD* now allows the use of a flashing yellow arrow during permissive portion of this phase. Before using this, check with your state's DOT to see if they use this.
PROTECTED ONLY 	✓ A special protected left-turn phase is provided. ✓ Left turns can proceed only during the protected phase and are prohibited from turning during the through phase. ✓ An exclusive left-turn lane is required.

7.1.4. Maximizing Operations and Efficiency

KEY POINT

Traffic signals should be evaluated periodically to maximize efficiency.

Efficient operation of traffic signals requires the correct operation as well as periodic evaluations.

There are two primary types of traffic signal operation: fixed or pretimed operations, and actuated signal operations. Pretimed is the simplest type of operation. With pretimed signals, during each period of the day (a.m., midday, and p.m.) the amount of green time provided for each signal phase remains fixed within the specified time period. For example, if a left-turn lane is provided with a separate left-turn phase and that lane is free of vehicles, the green phase would still occur even with no vehicles present. Pretimed signals are effective where there is little fluctuation in volumes. Actuated signal operations use some form of detection, including loops beneath pavement, video cameras, or pedestrian push-buttons, to provide green time for a particular phase only if vehicular or pedestrian demand is present. Actuated signals are effective where traffic volumes vary throughout the day.

Exhibit 7.7 shows several features that should be considered in the design or upgrade of a traffic signal. These enhancements, along with periodic evaluations, can reduce intersection delay and fuel consumption by as much as 20 percent. Traffic signals should be evaluated periodically to maximize efficiency.

In California, 1,535 traffic signals were retimed at a total cost of $2 million ($1,300 per signal). Delay was reduced by 14 percent and fuel consumption decreased by 6 percent, saving California motorists nearly $8 million ($5,200 per signal) annually in delay and fuel costs resulting in a benefit-to-cost ratio of 4:1.

SDDCTEA performed a study at a large Army installation and found that by simply retiming the 50 traffic signals and adding detection where it was lacking yielded the following annual measures of effectiveness:

MEASURE OF EFFECTIVENESS	ANNUAL SAVINGS	FINANCIAL SAVINGS*
Total Delay	4,374,000 hr	$64,243,125.00
Fuel Consumed	3,396,600 gal	$10,189,800.00
CO Emissions	237,474 kg	
NOx Emissions	46,224 kg	
VOC Emissions	55,044 kg	

** Note: 1. Delay savings were equated to monetary value using $14.6875 per hour identified in Engineering News Record and NCHRP Report 133*
2. $3 per gallon was used for fuel savings.

Exhibit 7.7: Maximizing Traffic Signal Operations and Efficiency

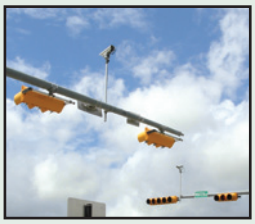
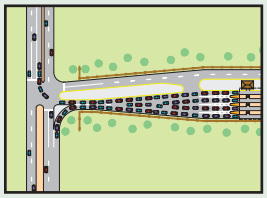
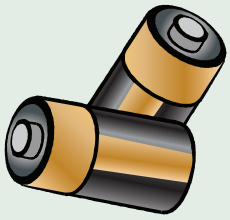
STRATEGY	CONSIDERATIONS	BENEFITS	COSTS
PERIODIC RETIMING	✓ Traffic flow patterns change over time due to land use or other changes. ✓ Typically, traffic signals should be retimed about every 3 years. ✓ Traffic signals adjacent to new facilities such as Commissaries and PXs should be retimed.	✓ An ITE article gave eight examples where retiming reduced delay by 8-40%.	✓ For analyses and implementation, signal retiming costs range from $1,300 to $2,500 per intersection.
ACTUATION 	✓ Actuated signals respond to variations of traffic to maximize operations. ✓ Actuation is accomplished through the use of detectors which can consist of inductive loops, radar, or video. ✓ Video detection costs are now almost equivalent to loop detector costs, while maintenance costs are greatly decreased. ✓ Actuation should be reviewed periodically (6 months or less) to ensure detectors are functioning properly and are not falsely calling phases, thus wasting green time from other movements.	✓ Actuation can reduce delay by 25 to 40% over pretimed signals.	✓ Analysis and implementation costs depend on the number of lanes, type of technology, and the amount of detection, but should range from $5,000 to $20,000 per intersection.
COORDINATION	✓ A coordinated traffic signal system consists of two or more traffic signals interconnected and timed such that platoons of traffic traveling at the design speed get green indications through successive intersections. ✓ Coordination can be achieved through hardwire methods (copper or fiber) or through wireless solutions (spread spectrum radio, cellular, or GPS communications). ✓ Spread spectrum radio communication may offer the most flexible communication method while minimizing connection fees and monthly utility charges.	✓ FHWA estimates that coordination can reduce delay by as much as 25%.	✓ Cost is estimated at $2,000 to $10,000 per intersection to provide physical interconnection between intersections and software upgrades.

Exhibit 7.7: Maximizing Traffic Signal Operations and Efficiency (continued)

STRATEGY	CONSIDERATIONS	BENEFITS	COSTS
PREEMPTION	✓ Emergency vehicle preemption allows traffic signal timing to be altered to provide priority for selected (emergency) vehicles thus improving response times. ✓ Emergency preemption gives immediate priority to emergency vehicles by providing a green indication for the emergency vehicle once vehicular and pedestrian clearances have been satisfied.	✓ FHWA found that emergency vehicle response times decreased between 16% and 23%.	✓ Cost is estimated at $8,000 to $10,000 per intersection.
GATE COORDINATION 	✓ Gate operations and the overall processing capacity should be considered when timing internal and external signalized intersections adjacent to gates.	✓ Traffic congestion is reduced, thus promoting safer operations.	✓ For analyses and implementation, signal retiming costs range from $1,300 to $2,500 per intersection.
LIGHT EMITTING DIODES (LEDS)	✓ LEDs represent a different technology than traditional incandescent signal bulbs. ✓ LEDs use less energy and burn out gradually. ✓ LEDs should be used on all new signal designs. LED inserts can replace incandescent bulbs on existing signals.	✓ California Energy Commission concluded that LEDs result in a 40% energy savings. ✓ With this energy savings, it is possible for traffic signals to be operated by solar power.	✓ Cost is estimated at approximately $5,000 per intersection, but have lower life cycle costs due to maintenance and energy savings.
BATTERY BACKUP SYSTEMS 	✓ Key intersections are vulnerable to higher crash rates during power outages. ✓ Battery backup systems can allow key intersections to function normally.	✓ Reduced crashes	✓ $5K per intersection

7.2. PEDESTRIAN ACCOMMODATIONS AT SIGNALS

Many traffic signals lack the appropriate pedestrian accommodations to allow pedestrians to safely cross. When designing or upgrading a signalized intersection, consider the basic needs of pedestrians including those with special needs (Exhibit 7.8).

Typically, pedestrians can cross concurrently with the green phase for traffic travelling in the same direction as the crosswalk. However, in downtown areas where pedestrian activity is much more frequent and comprises a considerably higher proportion of roadway users, signal phasing that offers more safety to pedestrians can be considered. Specifically, there are two types of phasing: All Pedestrian phase, and Lead Pedestrian Interval. Exhibit 7.9 summarizes these two options.

In addition to phasing, other approaches and technologies exist that can promote pedestrian safety at signalized intersections.

Countdown pedestrian indications are now required on all new signal designs where the DONT WALK interval exceeds 7 seconds. Countdown signals are preferred since, in addition to seeing traditional WALK and DONT WALK symbols, the pedestrian also sees how much time is left in the flashing DONT WALK interval.

Audible pedestrian tones can assist the visually impaired in locating pedestrian push buttons, and assist them in knowing when to cross.

Exhibit 7.8: Pedestrian Phasing Considerations

CONCEPT	ALL PEDESTRIAN PHASE	LEAD PEDESTRIAN INTERVAL (LPI)
DESCRIPTION	Pedestrians receive a dedicated phase which is typically timed to allow them to cross at least one leg and in some cases diagonally.	Traffic signals are programmed to allow the pedestrian to begin crossing before the vehicle traffic on the parallel street is given the green light. This is commonly referred to as a lead pedestrian interval (LPI) which lasts for 3-4 seconds. Pedestrians and motor vehicles are separated in time by providing a LPI, which permits pedestrians to gain a head start before turning vehicles are released.
PEDESTRIAN IMPACTS	✓ Pedestrian movements occur when vehicular traffic is halted. ✓ Pedestrian delays can actually increase versus LPIs if the pedestrian arrives just after the all pedestrian phase. ✓ Pedestrians may become impatient and cross with concurrent traffic.	Pedestrians enter traffic early before vehicular traffic to promote visibility; however, they move concurrently after the LPI expires.
TRAFFIC IMPACTS	✓ Traffic is delayed while pedestrian movements take place. ✓ At typical intersections this can be in the range of 25 seconds. ✓ If a pedestrian crosses before the phase comes up, the time will appear to be "wasted."	Traffic is delayed for 3-4 seconds per direction (E/W and N/S) for LPI.
OTHER CONSIDERATIONS	Pedestrians are able to cross diagonally across the intersection; however, they may not if there are no diagonal crosswalks and signal heads.	Research has shown that this treatment is associated with a decrease in pedestrian/motor vehicle conflicts and an increase in the percentage of motorists that yield right-of-way to pedestrians. This study examined the influence of a three-second LPI on pedestrian behavior and conflicts with turning vehicles (Van Houten, Retting, Farmer, Van Houten, & Malenfant, 2000).

Exhibit 7.9: Pedestrian Signal Features

FEATURE	CONSIDERATIONS
INFRASTRUCTURE 	✓ Intersections that are used by pedestrians should have sidewalks that are at least four feet wide. ✓ Ramps between sidewalks and crosswalks must be ADA compliant – a minimum width of 36 inches, a maximum slope of 8.3%, and a detectable warning surface immediately before entering the roadway. ✓ Crosswalks should be clearly marked in accordance with the *MUTCD*.
INDICATIONS 	✓ The use of pedestrian signals is encouraged to provide pedestrians a clear understanding when they should cross the roadway. New indications should be either a white WALKING PERSON or an orange UPRAISED HAND. ✓ Consider including countdown timer displays to show the pedestrian how many seconds until the termination of the pedestrian change interval (flashing UPRAISED HAND). ✓ Countdown pedestrian signals are now required per the 2009 *MUTCD* for all locations where the flashing DONT WALK interval exceeds 7 seconds.
TIMING NEEDS 	✓ It is essential to provide adequate time for pedestrians to enter the intersection, and to cross the street safely. • Generally, 3.5 feet per second is used under normal conditions and 3 feet per second is used where there is significant child or elderly pedestrian activity. • The minimum walk time is generally at least 7 seconds. • A flashing DONT WALK indication must be displayed long enough to allow any pedestrians that have left the curb to complete their crossing. This can be calculated by dividing the width of the crossing by the assumed walking speed.
PUSH BUTTONS 	✓ Where pedestrian activity is frequent or where pedestrian timing requirements do not impact traffic operations, pedestrian phases should be displayed without requiring activation. ✓ At locations where pedestrian activity is infrequent and pedestrian phasing is not warranted at all times, the use of pedestrian push buttons may be justified. ✓ In general, buttons should be within 10 feet of the ADA landing area. ✓ The large mushroom-plunger style (pictured at left) is preferred for ADA accessibility.

7.3. COMMON OPERATIONAL AND MAINTENANCE ISSUES

KEY POINT

Proper maintenance is critical to a traffic signal's efficiency and safety.

Maintenance of traffic signals is a very important topic. The Traffic Signal Installation and Maintenance Manual, published by ITE, discusses the maintenance of traffic signals in much detail.

A simple preventative maintenance program requires:

- ✓ Regularly replacing lamps before the end of their rated life.
- ✓ Overhauling the parts of controller units.
- ✓ Repainting equipment and hardware.
- ✓ Routine checking of voltage.
- ✓ Regular inspection of the equipment.

Traffic signal timings should be re-evaluated every 3 to 5 years or when significant changes to traffic flow patterns occur.

Traffic signal maintenance is either preventive or in response to an identified need. Poor traffic signal maintenance leads to frequent breakdowns resulting in motorist complaints and discredit to the responsible authority.

Based on ITE data, an average intersection requires 52 hours of signal maintenance annually. Too often, traffic signal maintenance becomes a secondary, noncritical responsibility.

Military installations not able to fully staff and operate a signal maintenance shop should consider hiring a contractor for signal maintenance work.

Exhibit 7.10 explains the problems, symptoms, and remedies of traffic signal maintenance. The lay person can see a traffic signal cycle between green, yellow, and red and believe that everything is operating acceptably. However, there are other symptoms to watch for, including malfunctioning loops, improper signal timing, and malfunctioning equipment.

Proper maintenance is critical to a traffic signal's efficiency and safety.

SDDCTEA Can Help!

One of SDDCTEA's services is an Operational Audit for Traffic Signal Sustainability (OATSS) study. With this type of study, we will perform the following:

- ✓ Collect traffic data at four to six signalized locations
- ✓ Identify existing signal equipment and operational deficiencies
- ✓ Conduct traffic analyses to determine delay and levels of service
- ✓ Develop optimized traffic signal timings

Special Features

- ✓ Conduct traffic data collection, traffic analyses, and field implementation of new signal timings
- ✓ Record deficient signal equipment
- ✓ Enter new signal timing parameters into controllers.

This type of study can be completed in one week.

Exhibit 7.10: Traffic Signal Maintenance Issues

PROBLEM	SYMPTOMS	WHY IS IT A PROBLEM	REMEDIES
MALFUNCTIONING LOOPS	At an actuated signal, a side street or mainline left-turn phase will always be called for its maximum time, regardless of demand.	Actuated signals are intended to be more efficient than pretimed signals, but when phases are called unnecessarily, they lose that efficiency.	Contact a signal technician to repair or replace the loop. If the pavement condition is so poor that it cannot support loops, consider using video detection.
IMPROPER SIGNAL TIMING	Traffic on side streets must wait for unnecessarily long periods of time for the green light, and/or does not get sufficient green time to accommodate demand. One approach may have frequent queuing while other approaches are free flowing.	Whether actuated or pretimed, traffic signals generally use preprogrammed timing plans. If the timing plans are not appropriate for the traffic demand, the traffic signal operates inefficiently. Additionally, whenever any improvement occurs that changes traffic demand through an intersection, the signal must be retimed.	Contact a signal technician to retime the traffic signal. To properly design the timings that should be used, a turning movement count should be conducted at the intersection, along with using software such as *HCS* or *Synchro* to calculate timings.
MALFUNCTIONING EQUIPMENT	Deteriorating equipment often includes missing or broken tunnel visors or signal heads; burnt or broken lenses, or even bulbs that are burned out.	Problems with equipment can detract from the signal's visibility. Missing visors prevent shading from the sun; broken or burned lenses lack visibility; and burned out bulbs do not give any information to the motorist. Malfunctioning equipment can cause crashes.	All of these can often be fixed fairly easily once the signal head can be accessed. A bucket truck is necessary to access overhead signal heads. Screws attach visors and lenses onto the signal head. Although bulbs can be replaced easily, consider using LED indications which use less power, are brighter, and require less maintenance.

7.4. WARNING BEACONS

Use warning beacons to call a driver's attention to an appropriate warning or regulatory sign or marker. Typical applications of this driver-aid treatment include:

- ✓ At obstructions in or immediately adjacent to the roadway.
- ✓ As supplemental emphasis to regulatory or warning signs.
- ✓ As emphasis for mid-block crosswalks.
- ✓ On approaches to intersections where additional warning is required, or where special conditions exist.
- ✓ As supplements to regulatory signs, except STOP, YIELD, DO NOT ENTER, and Speed Limit signs.

Warning beacon example

7.5. ITS STRATEGIES

KEY POINT

Consider opportunities for ITS, particularly at entry control facilities.

Intelligent Transportation Systems (ITS) involve the application of technologies and innovative practices to improve all aspects of transportation service. Common examples of ITS include dynamic message signs (DMS), detection devices, closed circuit televisions (CCTV), highway advisory radio (HAR), and over-height detection.

Dynamic Message Signs

DMS offers the ability to change the information being provided to motorists. A DMS can advise motorists of the security level, roadway status, or other information. DMS messages should be clear and concise, with no more than three alternating screens. Ideally, a DMS should be placed such that a driver can select an alternate route to their destination if necessary. A good example of DMS use is off base, where signs could inform motorists of relative congestion of several ECFs.

DMS example

Closed Circuit Televisions

CCTV offers security benefits and also provides a mechanism to monitor traffic conditions. They can monitor congested roadways and intersections. In ECF applications they can be used to monitor ID check areas, inspection areas, visitor's centers, ECF approach and departure zones, and neighboring intersections and roadways that may be impacted by ECF operations.

CCTV example

Highway Advisory Radio

HAR informs motorists of traffic conditions. They can be used to inform of roadway incidents, closures, which ECFs are open or closed, or to direct visitors and trucks to the appropriate ECF.

HAR example

Variable Speed Limits

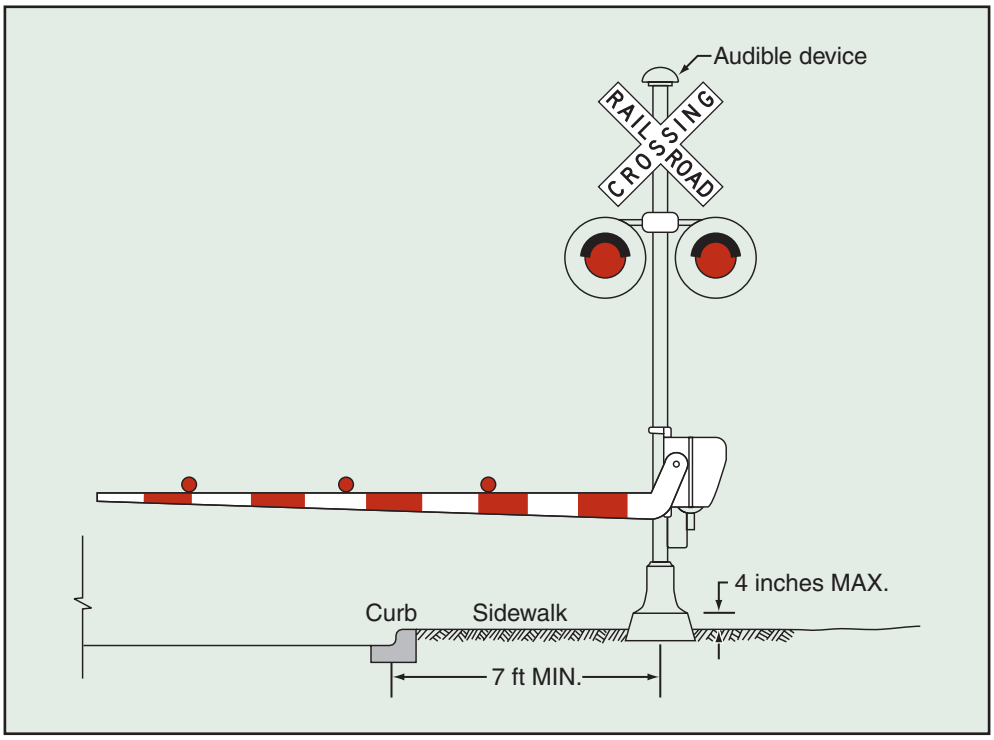
It is sometimes desired to post variable speed limits. A roadway that is prone to effects of fog, snow, or ice may be a candidate for a variable speed limit. Variable speeds could also be used for advisory conditions. In this type of use, use it with an advisory speed sign.

Variable speed limit sign example

Drop Arms

Drop arms are typically used at railroad crossings. When these are used, they must consist of a drive mechanism and a fully retroreflectorized red- and white-striped gate arm with lights. When in the down position, the gate arm shall extend across the approaching lanes of highway traffic. They are to be used in conjunction with flashing light signals.

There may be other cases where a drop arm may be desired. These may include: closure of the roadway at a runway if there are low-flying planes, or at active vehicle barriers at ECFs. When considering alternate uses for gates, contact SDDCTEA for additional traffic control to be used in conjunction with them.



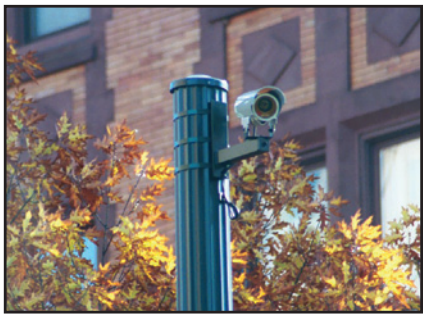
Example of a Railroad Crossbuck with Gate

Detection Devices

Detection devices can monitor speed, volume, direction, and classification of traffic. Types of detection devices include video, loop detectors, radar detectors, and infrared systems. Loops, video, and radar detectors are commonly used for traffic signal and congestion detection. Other example benefits include several ECF-related uses, such as monitoring approach speeds, monitoring traffic conditions and queuing, monitoring illegal entry on outbound lanes, and detection of over-height vehicles.

Loop Detector

Radar Detector



Video Detector

Detection device examples

CHAPTER 8 – YOU SHOULD CONSIDER A ROUNDABOUT!

8.1. YOU SHOULD CONSIDER A ROUNDABOUT 8-1

8.2. ROUNDABOUTS VS. TRAFFIC CIRCLES 8-2

8.3. ADVANTAGES OF ROUNDABOUTS 8-4

8.4. DESIGN CONSIDERATIONS 8-7

8.1. YOU SHOULD CONSIDER A ROUNDABOUT

Traffic circles have been used in the United States for over 100 years, but there have been very few new installations in the last 50 years because traffic circles are not especially safe or efficient. However, the modern circular intersection, hereafter referred to as a "roundabout," was developed in the United Kingdom in the 1960s to address the problems with traffic circles.

Multiple roundabouts in a small area

Two key characteristics of any roundabout include:

- ✓ Entering traffic must yield to circulating traffic.
- ✓ Each approach has a splitter island designed to slow traffic and to ensure that all vehicles travel in the proper direction around the central island.

Many studies have shown that roundabouts are safe and effective, and they are now widely used internationally. Perhaps because traffic circles did not work well in the United States, there has been some reluctance from the public to use roundabouts.

However, roundabouts are addictive because after an initial installation, local communities typically ask for more. As a result, there are clusters of roundabouts scattered around the United States. It is estimated that there are now over 1,000 roundabouts in the United States, but many smaller countries have a lot more. For example, it is estimated that there are about 20,000 roundabouts in France and 10,000 in the United Kingdom.[1]

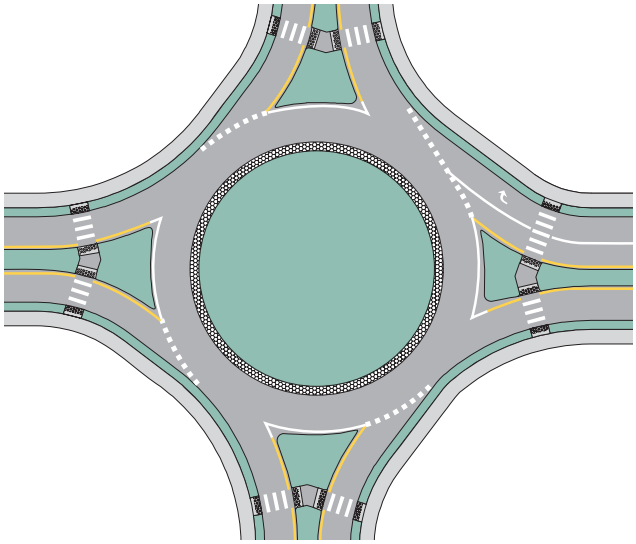
When asked about roundabouts, most unfamiliar drivers in United States say that they do not like them; but, after one is constructed locally, the majority of drivers in that area like the roundabout and want more of them.

A roundabout is defined as a circular intersection with yield control at entry, which permits a vehicle on the circulatory roadway to proceed, and with deflection of the approaching vehicle counter-clockwise around a central island. Further, it is a modified traffic circle that conforms to specific geometric design criteria that promotes driver awareness, reduced traffic speeds, and improved traffic flow. Roundabouts reduce traffic congestion by eliminating left turns. Since each approach to the roundabout is essentially an intersection with a one-way street, the driver is not delayed by traffic flow from two directions. Only right turns are allowed.

[1] *Q&As: Roundabouts. Insurance Institute for Highway Safety, Highway Loss Data Institute. Arlington, VA, January 2009.*

Roundabouts eliminate angle and head-on crashes. Roundabouts promote slower speeds due to the diversion in travel path. Crashes that occur at roundabouts are at a much lower speed than at traditional intersections, and are, therefore, less severe.

Roundabouts can range from a very simplistic single-lane design to complex multilane configurations. Single-lane designs are rather straightforward, but today's multilane configurations are designed so that, if drivers enter a roundabout in the correct approach lane they should be able to follow the lane, lines to their intended exit roadway without crossing any solid lane lines.



8.2. ROUNDABOUTS VS. TRAFFIC CIRCLES

KEY POINT

Roundabouts are generally the safest intersection design available.

Roundabouts are generally smaller than traffic circles and they always have a splitter island to help channelize vehicles and force drivers to travel at a slower speed.

In addition, roundabouts always require entering vehicles to yield to traffic within the circle, which is similar to merging with traffic at a freeway on-ramp.

Traffic within a traffic circle frequently has to weave across high-speed travel lanes, whereas a properly designed roundabout is more structured to avoid lane changing. The bottom line from a driver's point-of-view is that the design and operation of roundabouts are much more consistent than the design and operation of traffic circles. Other differences are included in Exhibit 8.1.

Exhibit 8.1: Differences Between Roundabouts and Traffic Circles

ELEMENT	ROUNDABOUT	TRAFFIC CIRCLE
TRAFFIC CONTROL	YIELD signs are used on all approach roadways; circulating vehicles always have the right of way. Merging is similar to a freeway on-ramp, but at a much slower speed.	Some circles use STOP signs on some approaches and no control on other approaches, and some use STOP or YIELD signs within the circle.
DEFLECTION	A splitter island is used on all approaches to slow traffic and to ensure that traffic goes to the right.	Traffic typically enters the circle at a right angle.
PEDESTRIANS	Pedestrians can only cross the approach legs, at a distance of at least one car length from the circulatory roadway.	Some circles have sidewalks across or on the outer edge of the central island.
PARKING	Parking is not allowed within the circulatory roadway or near the splitter islands.	Parking is sometimes allowed within a circle.

8.3. ADVANTAGES OF ROUNDABOUTS

KEY POINT

A traffic circle is NOT a roundabout.

Roundabouts are designed to meet the needs of all road users—drivers, pedestrians, pedestrians with disabilities, and bicyclists. In contrast to traditional intersections, roundabouts eliminate many of the traffic conflicts, such as left turns and crossing conflicts, both of which are significant contributors to the number and severity of crashes. Because traffic enters and exits only through right turns, the number of severe crashes at roundabouts is substantially reduced. Small-angle collisions that may occur as a result of a right-hand turn are typically less severe than other types of collisions.

A list of advantages and disadvantages of roundabouts is included as Exhibit 8.2.

In United States, 45 percent of all crashes occur at intersections. However, research shows that converting an existing intersection to a roundabout typically results in a 35 percent reduction in the number of crashes and a 76 percent reduction in the number of injury crashes.[2] In addition, many researchers believe that United States is still on the learning curve because crash rates in United States are higher than in other countries where roundabouts are more common.

As illustrated in Exhibit 8.3, the number of vehicle-to-vehicle conflict points for a single-lane roundabout is only 25 percent of the number at a conventional intersection. Perhaps even more important, the roundabout does not have any crossing conflicts—the type of conflict that causes the dangerous, side-impact type crashes. Therefore, the safety record for roundabouts is not a fluke.

[2] *NCHRP Report 572, Transportation Research Board, 2007, Table 28.*

Exhibit 8.2: Roundabouts vs. Other Types of Intersections

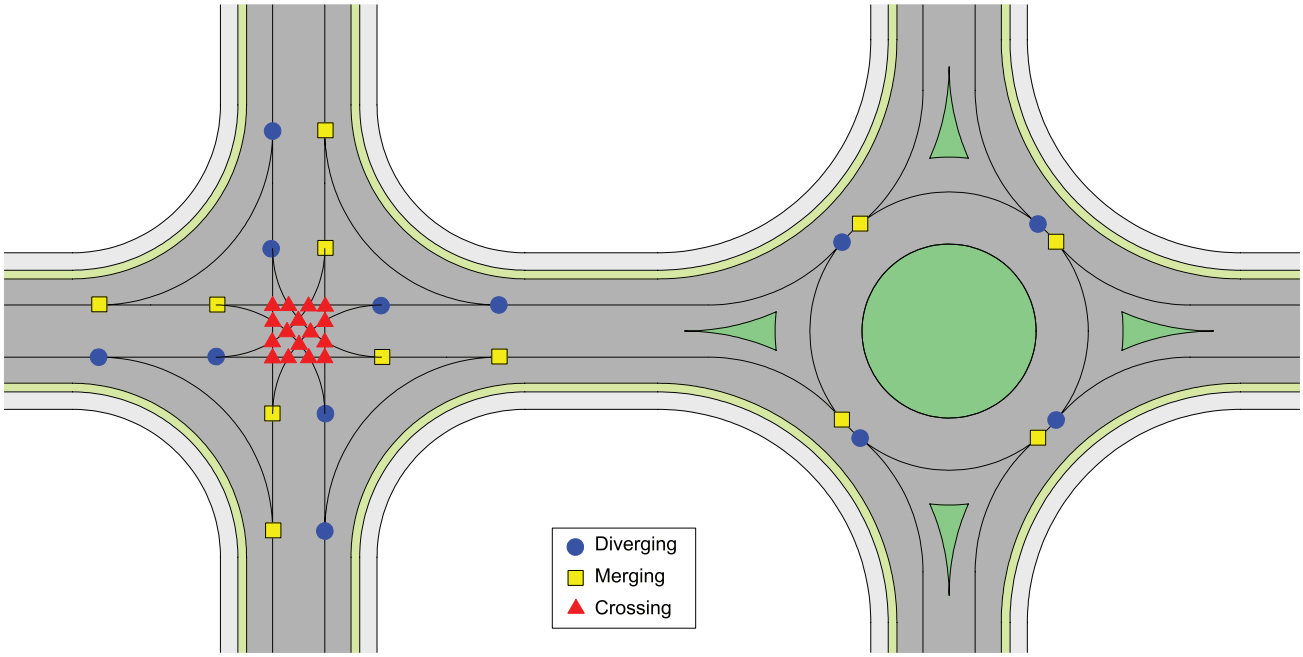
Advantages:

- ✓ Fewer and less serious crashes.
- ✓ Improves safety for pedestrians—the splitter island provides a refuge for pedestrians to allow a two-stage crossing, with each stage crossing a one-way roadway.
- ✓ Can be used for speed control, especially speed mitigation at Entry Control Facilities.
- ✓ Improves traffic flow with fewer stops.
- ✓ Resolves issues with not obeying traffic signals.
- ✓ When traffic is light, no wasted time for drivers as you would have with a signal.
- ✓ Accommodates U-turns, even for larger trucks.
- ✓ Safely operates during power outages.
- ✓ No overhead traffic signals to hinder over-height loads.
- ✓ Facilitates the junction of more than four roadway approaches.
- ✓ Issues with left turns are eliminated.
- ✓ Can easily be designed to prohibit exiting at an intersection leg with turn prohibitions.
- ✓ Unlike signalized intersections, storage lanes are not required.
- ✓ Simplifies the driver decisions when entering an intersection because all traffic is coming from the left (this is especially helpful for older drivers).
- ✓ From an environmental standpoint—improves air quality, reduces energy consumption, requires fewer travel lanes, and provides more landscaping opportunities.
- ✓ Has considerably less maintenance costs versus traffic signals.

Disadvantages:

- ✓ May require a larger intersection footprint.
- ✓ May require pedestrians to walk a greater distance.
- ✓ Cannot assign a priority to a specific roadway – roundabouts treat all approaches equally.
- ✓ Unfamiliar drivers may find roundabouts confusing.
- ✓ It may cost more to convert a stop-controlled intersection to a roundabout than to a signalized intersection, unless a signalized intersection requires a lot of widening for turning and storage lanes.
- ✓ With too many roundabouts in close proximity to each other, drivers may get disoriented or dizzy.

Exhibit 8.3: Comparison of Conflict Points



The number of conflict points for pedestrians is also reduced by at least 50 percent, and pedestrians only need to cross one direction of traffic at a time. Therefore, safety benefits are not just for vehicles, but also for pedestrians.

The only intersection traffic control that is approximately as safe as a roundabout is a multiway stop intersection. However, multiway stop intersections have less capacity, more delay, many negative environmental consequences due to stopped traffic, and create disrespect for STOP signs.

In addition to safety, efficiency is another major benefit of roundabouts. Many studies have documented reductions in delay, unnecessary stops, fuel consumption, emissions, and energy usage.

8.4. DESIGN CONSIDERATIONS

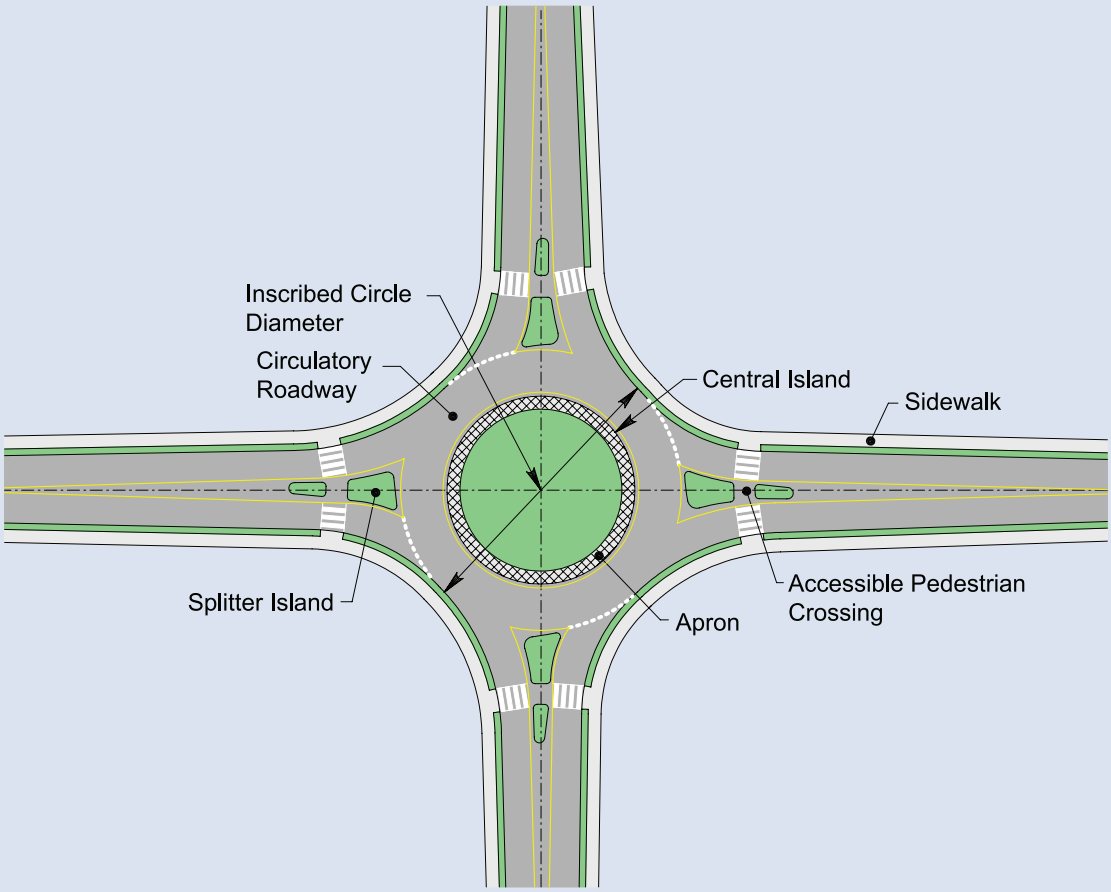
The design of a roundabout is essentially an iterative process that should only be done by a professional with a thorough knowledge of roundabouts. Among other references, the designer should consult FHWA's book entitled *Roundabouts: An Information Guide* (*Publication FHWA-RD-00-067*), June 2007.

With reference to Exhibit 8.4 and the definitions, the splitter island must be of sufficient length to accommodate pedestrians, curved to slow and deflect approaching traffic, and aligned with the central island. The width of the splitter island should not be so wide that it encourages high speeds. Moreover, traffic signs and pavement markings must act in concert to ensure safety.

Size – The basic term used to reflect the size of a roundabout is the inscribed circle diameter, which is the measurement between opposite outer edges of the circulatory roadway. This diameter is based on the design speed and the number of lanes in the circulatory roadway—as the design speed or the number of circulatory lanes increase, the inscribed circle diameter should also increase.

The recommended design speed within the circulatory roadway is a function of the speed of approaching vehicles when they are 300 or 350 feet from the center of the roundabout. For vehicles approaching at about 45 mph, the design speed should be about 50 percent of the approach speed (or 22.5 mph), and for vehicles approaching at 25 mph the design speed should be about 62 percent of the approach speed (or about 15.5 mph). If the approach roadways have different approach speeds, the roundabout should be designed for the higher speed. Design speeds for the merge point and at the exit point may be slightly higher than the design speed on the circulatory roadway.

Exhibit 8.4: Key Roundabout Features



Definitions

Apron – When used, it is the outer portion of the central island that is designed for off-tracking of the rear wheels of trucks, buses and tractor trailers. This portion of the central island must be able to physically accommodate these large vehicles, but it should be raised above the roadway and have a rough texture to discourage other vehicles from using it.

Central Island – The raised area in the center of the roundabout, around which traffic circulates.

Circulatory Roadway – The curved path available for use by vehicles to travel in a counter-clockwise direction around the central island.

Inscribed Circle Diameter – The basic term used to describe the size of a roundabout. It is the minimum measurement between opposite outer edges of the circulatory roadway.

Splitter Island – The raised island on an approach to the circulatory roadway that separates entering traffic from exiting traffic, deflects and slows entering traffic, and provides a refuge for pedestrians.

The capacity of a one-lane roundabout is approximately 20,000 vehicles per day; therefore, if the volumes are greater than that, additional lanes generally will be required. However, the capacity is highly dependent upon the traffic volumes during the peak hours, specifically the distribution of the volumes across the approaches and whether vehicles are making left-turns, right-turns, U-turns, or straight-through movements.

In an urban environment, the inscribed circle diameter typically would be about 100 to 130 feet for a single-lane roundabout, and 150 to 180 feet for a double-lane roundabout. Additional area is also needed outside of the inscribed circle for sidewalks.

Alignment – Ideally, the centerline of each roadway leg should pass through the center of the inscribed circle so that entry and exiting speeds are balanced and the central island is conspicuous to approaching drivers.

Central Island Shape – Although most central islands are round, other shapes include:

- ✓ Elliptical.
- ✓ Tear-shaped, especially if one-way roads are involved.
- ✓ Turbo-shaped with push-outs to emphasize the beginning of left-turn lanes.

For example, the central island in Exhibit 8.5 could be expanded outward to include the yellow crosshatched areas on the bottom and right sides of the central island to force drivers to spiral outward so that they are not accidentally trapped in an added left-turn lane.

Things that may affect the shape of the central island include: the number and alignment of the approach roadways; the number of lanes on each approach; the presence of exclusive left-turn or right-turn lanes; and the presence of one-way roads.

Exhibit 8.5: What's Wrong With This Roundabout?

- ✓ The splitter islands are too wide, which encourages higher speeds.
- ✓ Sidewalks should be continuous and crosswalks should cross each splitter island.
- ✓ Ideally, pavement markings should define the islands and the merge point.
- ✓ Missing signs include an advance Circular Intersection (W2-6) symbol sign, and the new black-and-white Roundabout Directional Arrow within the central island as included in the 2009 MUTCD (see Exhibit 8.6).
- ✓ A Keep Right (R4-7) sign is also desirable at the beginning of the splitter island because there are no center line pavement markings.

Pedestrians – Pedestrians should be accommodated on the outside of the circulatory roadway and across the splitter island. The most common crossing is a bent crosswalk to make the crossing as short as possible (see Exhibit 8.4). The *MUTCD* states that crosswalks should be located a minimum of 20 feet from the edge of the circulatory roadway, but we recommend a minimum of 25 feet in advance of any yield line.

The capacity of a roundabout is directly related to the turning movements. The highest capacity would occur if all approaches had the same volume and everyone wanted to make a right turn. On the other hand, the worst scenario would be if everyone wanted to make a U-turn.

Bicyclists – Cycling through a roundabout should be safer than through a conventional intersection because:

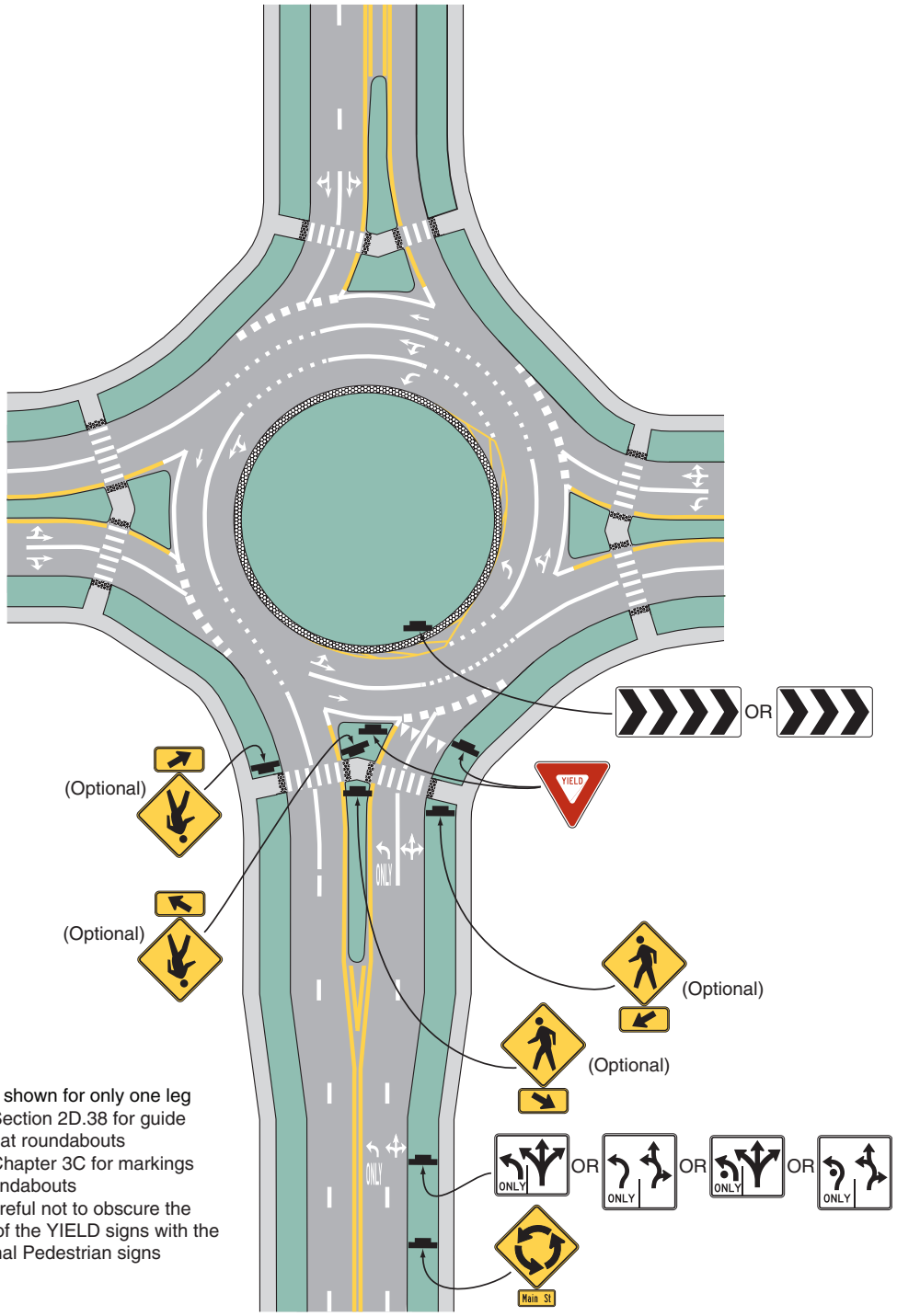
- ✓ Travel speeds are generally lower, and
- ✓ Cyclists can normally merge with other traffic without stopping.

Trucks and Other Large Vehicles – It is important to design roundabouts to accommodate the largest trucks, buses, and tractor-trailers that will be using the intersection. These vehicles can be accommodated by using an apron on the outer portion of the central island. To help prevent smaller vehicles from driving on this part of the central island, the surface of the apron can be raised.

Multilane Roundabouts – The design of multilane roundabouts is more critical than the design of single-lane roundabouts. Specifically, it is essential that the roundabout be designed so that, if drivers enter the roundabout in the correct approach lane, they will be able to follow the lane lines to their exit roadway without crossing any solid lane lines.

Exhibit 8.6 illustrates a multilane roundabout with several different lane assignments. Lane assignments should be custom designed for each intersection, based on the design-hour traffic volumes. The lanes on each approach should always line up with the lanes in the circulatory roadway.

Exhibit 8.6: Sample Design for a Multilane Roundabout



Notes:
1. Signs shown for only one leg
2. See Section 2D.38 for guide signs at roundabouts
3. See Chapter 3C for markings at roundabouts
4. Be careful not to obscure the view of the YIELD signs with the optional Pedestrian signs

Source: Figure 2B-23 of the MUTCD, *with modifications*

Signs and Markings – Signs and pavement markings on the approaches and on the circulatory roadway should be compatible with each other to provide a consistent message. See Sections 2B.43, 2B.44, 2B.45 and 2D.38, and Chapter 3C of the *MUTCD* for additional design details. In addition, review the various examples of roundabouts in Chapter 2C.

Studies show that roundabouts:

- ✓ Are safe and efficient.
- ✓ Are environmentally friendly.
- ✓ Reduce travel speeds.
- ✓ Provide for landscaping and beautification.
- ✓ Are contagious.

Therefore, everyone will be seeing more of them in the future; so why not consider them at your military installation?

CHAPTER 9 – ROADWAY SAFETY

9.1. ROADWAY SAFETY FACTS 9-1

9.2. FORGIVING ROADSIDE CONCEPT, CLEAR ZONE AND LATERAL CLEARANCE 9-2

9.3. COMMON ROADWAY HAZARDS AND MITIGATION STRATEGIES 9-5

9.4. DRIVER-AID TREATMENTS 9-18

9.1. ROADWAY SAFETY FACTS

KEY POINT

A "forgiving roadside" reduces the seriousness of run-off-the-road crashes.

In a typical year, one-third of motor vehicle deaths involve vehicles leaving the roadway and hitting fixed objects such as trees or utility poles along the road.

- ✓ 16 percent of roadside fatalities involve trees and utility poles.
- ✓ 49 percent of roadside fatalities occur between 9:00 p.m. and 6:00 a.m.
- ✓ 45 percent of drivers killed in roadside crashes have a blood alcohol content at or above 0.10 percent.
- ✓ 43 percent of drivers killed in roadside crashes are men younger than 35 years old.

Regardless of the reason for a vehicle leaving the road, a roadside that is free of fixed objects such as trees and poles, with stable, flattened slopes, helps to reduce the frequency and/or severity of crashes. The concept of the "forgiving roadside" accounts for errant vehicles that leave the roadway, and supports a roadside design where serious consequences of such incidents are reduced. Reasons why vehicles leave the travel way and encroach on the roadside include:

- ✓ Driver fatigue and inattention
- ✓ Driving under the influence of drugs or alcohol
- ✓ Excessive speed
- ✓ Roadway conditions
- ✓ Bad visibility, possibly due to deficient roadway delineation
- ✓ Collision avoidance
- ✓ Vehicle failure

Crashes caused by driver error, such as driving under the influence of alcohol, speeding, or falling asleep, can be addressed by educational and enforcement programs. Contact your safety office for more information about these educational programs.

Severe crash example

9.2. FORGIVING ROADSIDE CONCEPT, CLEAR ZONE AND LATERAL CLEARANCE

KEY POINT

Clear zone is a measured distance from the edge of the travel way that should be free from obstructions.

A clear zone is the total roadside border area from the edge of the travel way that is available for safe use by errant drivers. Providing adequate clear zones can enhance roadway safety by providing motorists with certain levels of expectation.

The required clear zone is a function of the design speed of the adjacent roadway, the ADT volumes, and roadside geometry. The minimum lateral clearance for an object adjacent to the travel way behind vertical curbing is 2 feet, but should not be construed as an acceptable clear zone. The values presented in Exhibit 9.1 should be used as the minimum, and every other option should be exhausted before using values less than those presented.

The clear zones described in Exhibit 9.1 are appropriate for tangent sections and the inside of horizontal curves. On the outside of horizontal curves, a correction factor from Exhibit 9.2 should be applied to the value shown in Exhibit 9.1. For curves with a radius greater than 2,900 feet, a correction factor for the outside of the curve is not necessary.

CLEAR ZONE LOCATION

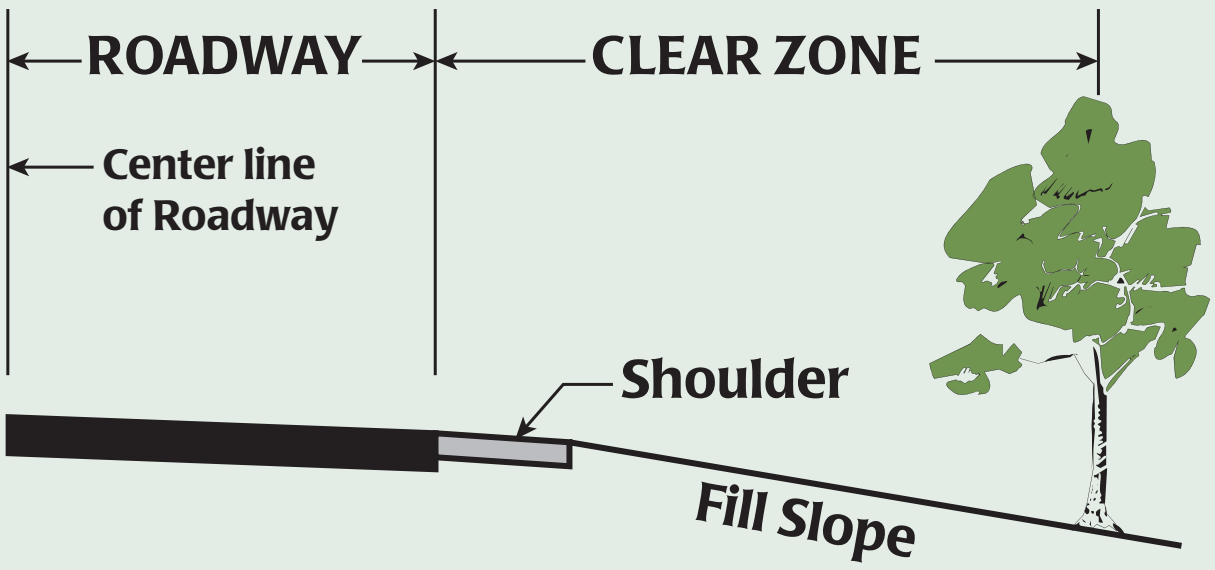


Exhibit 9.1: Clear Zone Distances
(In feet from edge of travel way)

DESIGN SPEED	DESIGN ADT	FILL SLOPES			CUT SLOPES		
		6:1 OR FLATTER	5:1 TO 4:1	3:1	3:1	4:1 TO 5:1	6:1 OR FLATTER
40 MPH OR LESS	Under 750	7-10	7-10	*	7-10	7-10	7-10
	750-1500	10-12	12-14	*	10-12	10-12	10-12
	1500-6000	12-14	14-16	*	12-14	12-14	12-14
	Over 6000	14-16	16-18	*	14-16	14-16	14-16
45 - 50 MPH	Under 750	10-12	12-14	*	8-10	8-10	10-12
	750-1500	12-14	16-20	*	10-12	12-14	14-16
	1500-6000	16-18	20-26	*	12-14	14-16	16-18
	Over 6000	18-20	24-28	*	14-16	18-20	20-22

** Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concerns, economic factors, safety needs, and crash histories. Also, the distance between the edge of the through travel lane and the beginning of the 3:1 slope should influence the recovery area provided at the toe of the slope.*

CUT SLOPE AND FILL SLOPE

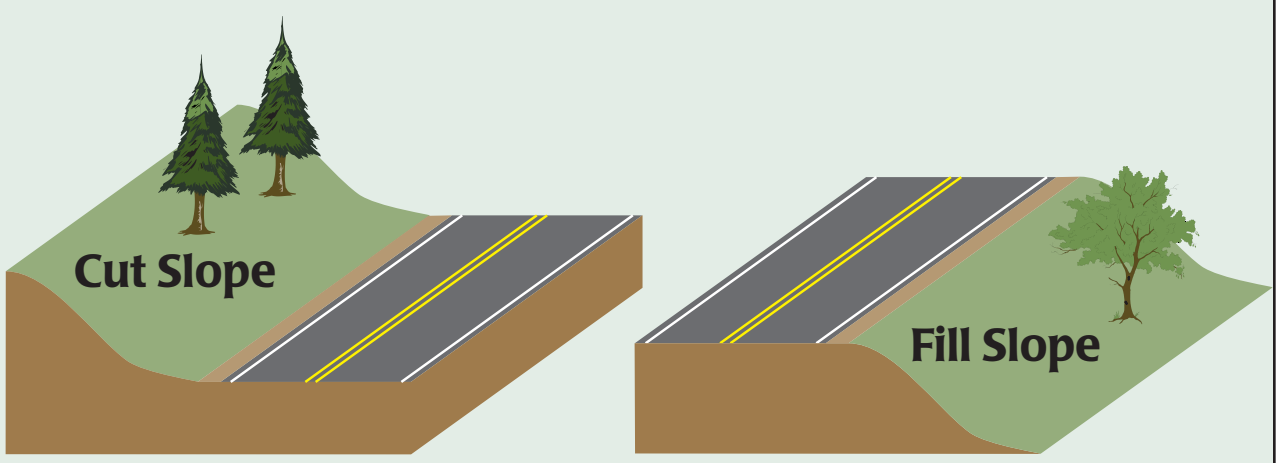
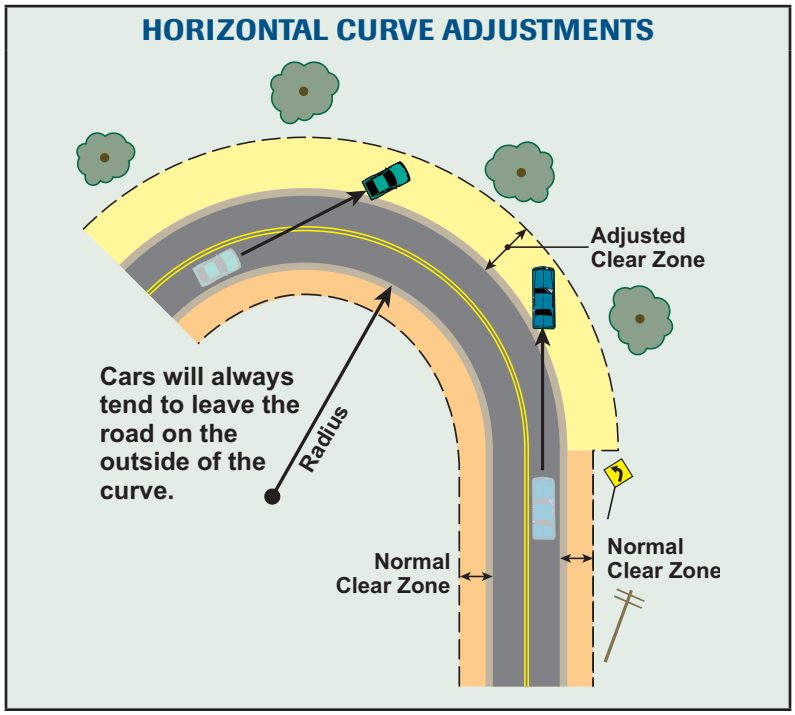


Exhibit 9.2: Horizontal Curve Adjustments*
(Clear zone curve corrections)

RADIUS (FEET)	DESIGN SPEED (MPH)		
	40	45	50
2900	1.08	1.10	1.12
2300	1.10	1.12	1.15
1950	1.11	1.15	1.18
1650	1.13	1.17	1.22
1450	1.15	1.19	1.25
1300	1.17	1.22	1.28
1150	1.19	1.24	1.31
1000	1.23	1.29	1.36
850	1.26	1.34	1.42
750	1.30	1.38	1.48
650	1.34	1.43	1.53
600	1.37	1.47	
400	1.54		

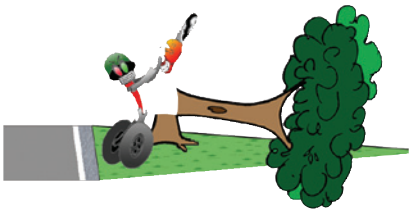
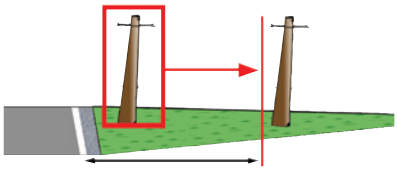
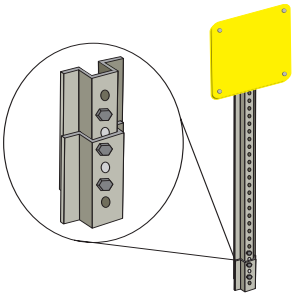
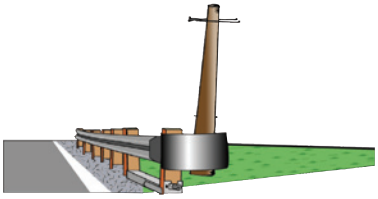
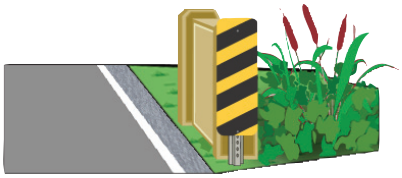
**Multiply the clear zone distance derived from Exhibit 9.1 by the curve correction factor derived from Exhibit 9.2 to obtain the proper clear zone on the outside of the curve in feet. This factor applies only to the outside of curves. Curves flatter than 2900 feet do not require an adjusted clear zone.*



9.3. COMMON ROADWAY HAZARDS AND MITIGATION STRATEGIES

When a roadside hazard, such as a tree or utility pole, is in the clear zone, there are five options to mitigate the hazard. These options, shown in Exhibit 9.3, should be considered in the order in which they are presented.

Exhibit 9.3: Options to Mitigate Hazards

OPTION 1		Remove the hazard.
OPTION 2		Relocate the hazard (outside the clear zone).
OPTION 3		Reduce the impact severity (breakaway support).
OPTION 4		Shield the hazard with a traffic barrier (guardrail).
OPTION 5		Delineate the hazard with an object marker.

9.3.1. Trees

Trees are typically involved in 28 percent of roadside fatalities. Essentially there are two methods to address the problem of roadside trees.

Driver-aid treatments – Help to keep the motorist on the road.

- ✓ **Rumble strips** – A series of intermittent, narrow, transverse areas of rough-textured, slightly raised, or depressed road surface that are installed to alert road users to unusual traffic conditions.
- ✓ **Pavement markings** – Center line and edge line pavement markings, in good condition, provide a particularly effective method of defining roadway edges.
- ✓ **Delineators and signs** – Installing advance warning signs and roadway delineators can help to alert motorists where extra caution is advised.
- ✓ **Roadway improvements** – Improvements to the roadway itself can help reduce run-off-the-road crashes.

Forgiving roadside – Protect motorists if they do leave the road.

- ✓ **Remove** – Removal of trees should be considered when those trees are determined both to be obstructions and to be in a location likely to be hit.
- ✓ **Shield** – Roadside barriers should only be used when the severity of striking the tree is greater than the severity of striking the barrier; and when removal is not a viable option.

In general ALL plantings within a clear zone should consist of shrubs and other plantings that will not grow into fixed objects. Consider any planting with an expected mature trunk size of greater than 4 inches in diameter as a fixed object.

9.3.2. Utility Poles

Utility poles pose the same problems as trees and are typically involved in 9 percent of roadway fatalities. Measures to alleviate utility pole hazards include:

- ✓ Bury utility lines.
- ✓ Increase the lateral offset of utility poles from the roadway edge. Ideally, utility poles should be located outside the clear zone.
- ✓ Reduce the number of utility poles. Often the number of utility poles can be reduced by combining uses such as telephone and electricity on one pole. Also, in many cases the number of poles can be reduced by increasing spacing between the poles.
- ✓ Install breakaway utility poles. This method is designed to decrease the severity, not the frequency of roadside crashes.
- ✓ Install guardrails in front of utility poles. This method is designed to decrease the severity, not the frequency of roadside crashes.

Since utility poles are generally privately owned and installed devices, improvements can often be complicated. Installations should encourage cooperation with utility companies in making improvements. Implementing these suggestions will greatly help to reduce injuries and fatalities on installation roadways.

Example of wide clear zone

9.3.3. Breakaway Supports

Removing or relocating a roadside hazard from the clear zone is not always feasible. Some objects must be mounted near the roadway, and some objects may have been mounted close to the roadway long before the clear zone concept was considered. Man-made objects such as signs, mailboxes, light poles, utility poles, bollards, etc., are often mounted within the clear zone.

One-third of motor vehicle deaths involve vehicles leaving the roadway and hitting fixed objects. In cases where these objects cannot be removed or relocated, using an appropriate breakaway support will reduce the impact severity.

A breakaway support refers to all types of devices that yield when hit by a vehicle. They yield because the design of the support purposely incorporates a weak spot. Two criteria dictate that these supports fail in a predictable manner:

- ✓ AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*
- ✓ *National Cooperative Highway Research Program (NCHRP) Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features*

While it is not important to memorize these publications, it is critical to understand that strict specifications exist for the performance of breakaway supports. Since most states have a standard design for breakaway supports that have been crash tested and approved, consult your state's standards for an appropriate design.

Breakaway supports are available for objects such as:

- ✓ Post mounted signs
- ✓ Luminaires
- ✓ Traffic signals
- ✓ Fire hydrants
- ✓ Mailboxes
- ✓ Utility poles

Give special care and consideration to breakaway supports for luminaries, traffic signals, and utility poles. If not designed or constructed properly, a falling support can be hazardous to other vehicles on the roadway. See Section 6.1.6 for additional information on breakaway sign posts.

9.3.4. Drainage Features

As shown in Exhibit 9.4, many of the drainage structures on military installations were installed before roadside safety was considered an important topic.

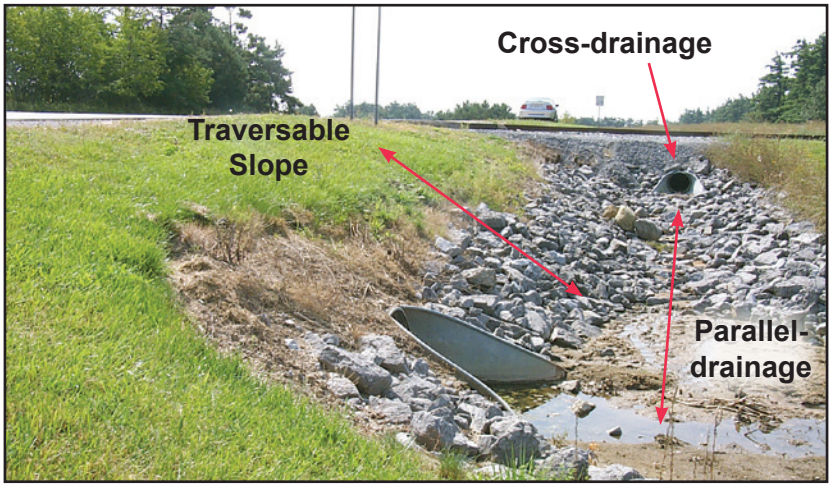
Exhibit 9.4: Common Deficiency Examples

Protruding endwalls for cross-drainage structure

Endwalls too close to roadway edge for cross-drainage structures

Parallel-drainage ditches within the clear zone

Two types of drainage structures exist along roadways: cross-drainage structures and parallel-drainage structures. Cross-drainage structures are designed to carry water underneath the roadway, while parallel-drainage structures are designed to carry water parallel to the roadway.



Culvert with end section

9.3.4.1. Cross-drainage Structures

For cross-drainage structures, consider the following options to minimize their impact on safety:

- ✓ **Use a traversable slope** – For smaller diameter culverts (40” or less), the end of the culvert should match the slope of the surrounding embankment. This design can be accomplished with the use of end sections or wingwalls. For larger culverts (greater than 40” in diameter), consider treatments such as extending, shielding, or delineating the structure.
- ✓ **Extend the structure so it is less likely to be hit** – If the end of a culvert cannot be made traversable, it should be moved to a location outside of the clear zone.
- ✓ **Shield the structure** – Sometimes a structure cannot be made traversable or moved beyond the clear zone. This is especially true for larger structures. In those cases, consider installing a barrier such as guardrail.
- ✓ **Delineate the structure** – If the above alternatives are not appropriate, the structure should be delineated as shown below.

Delineate the structure

9.3.4.2. Parallel-Drainage Structures

For parallel-drainage structures, the following options should be considered to minimize their impact on safety:

✓ **Eliminate the structure** – In some cases parallel-drainage structures can be eliminated. For example, at a crossroad, the water can be carried over the cross street rather than underneath it.

Eliminate parallel-drainage structures

- ✓ **Use a traversable design** – Use of a rounded flat-bottom ditch (Exhibit 9.5) provides the best combination for safety and drainage.
- ✓ **Move the structure** – Structures should be moved laterally, preferably to a location outside the clear zone.
- ✓ **Shield the structure** – Sometimes a structure cannot be removed or relocated outside the clear zone. This is especially true for large structures. In those cases, consider installing a barrier such as guardrail.
- ✓ **Delineate the structure** – If the above alternatives are not appropriate, the structure should be delineated.

Refer to Exhibit 9.6 for a summary of drainage feature mitigation measures.

Exhibit 9.5: Ditch Designs

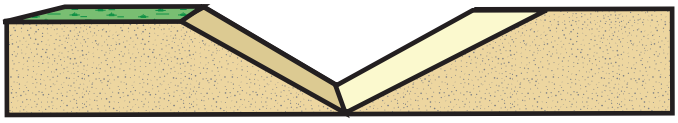
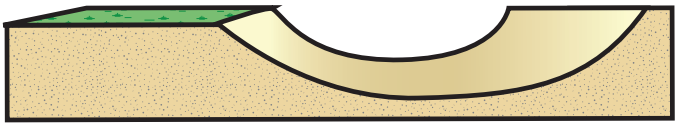
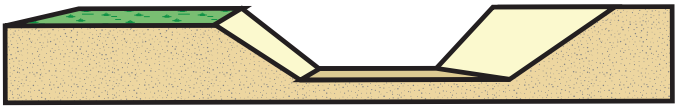
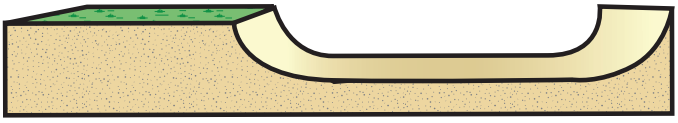
BEST FOR SAFETY		BEST FOR DRAINAGE
	V-DITCH 	
✓	ROUNDED DITCH 	
	FLAT BOTTOM DITCH 	✓
✓	ROUNDED/FLAT BOTTOM DITCH 	✓

Exhibit 9.6: Drainage Feature Mitigation Measures

TYPE OF DRAINAGE STRUCTURE	DEFICIENCY	POTENTIAL MITIGATION MEASURES
CROSS-DRAINAGE STRUCTURE	Non-traversable slope at the end of a culvert	✓ Install metal end section. ✓ Install concrete wingwalls. ✓ For larger culverts (>40 inches in diameter), consider extending the culvert or installing barrier.
	Protruding headwall (>4 inches)	✓ Remove headwall and install end section or wingwalls. ✓ Remove the top of the headwall. ✓ Regrade the area around the headwall.
	Culvert end close to edge of roadway	✓ Extend the culvert laterally outside the clear zone. ✓ If culvert extension is not possible, shield or delineate the end of the culvert.
PARALLEL-DRAINAGE STRUCTURE	Non-traversable parallel ditch	✓ Convert the drainage system to a "closed" system (i.e., installing pipes and inlets). ✓ If a "closed" system is not feasible, regrade the ditch to a rounded flat-bottom ditch.
	Culvert underneath a cross street within the clear zone	✓ Relocate the culvert outside the clear zone. ✓ If relocation is not feasible, flatten the slope around the end of the culvert as much as possible. The use of an end section or wingwalls may be necessary.

9.3.5. Guardrail Basics

A roadside barrier is a longitudinal device used to shield motorists from natural or manmade obstructions located along a roadway. Remember, barriers are themselves hazards. They are intended to reduce the severity, not the frequency of crashes. Use barriers only where the result of striking the object or leaving the roadway would be more severe than the consequences of striking the barrier. Guardrails are the most common type of barrier. Another common type is a concrete jersey barrier.

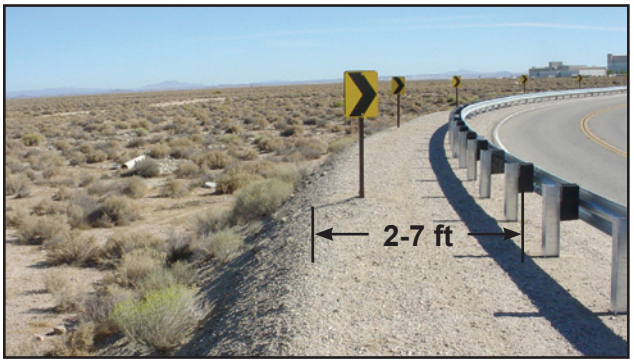
9.3.5.1. Guardrail Design

When designing or choosing a guardrail system, consider the following:

- ✓ Lateral placement and deflection
- ✓ Length of need
- ✓ End treatment

Lateral Placement and Deflection

The type and design of a guardrail used depends on the maximum deflection and the location of the roadside obstacle. The minimum lateral distance between a guardrail and an obstruction varies between 2 and 7 feet, depending on the type of guardrail used.



Lateral placement and deflection

For barrier application on steep slopes, provide a minimum of 2 feet of barrier-to-embankment distance to prevent the posts from coming out of the side slope upon impact.

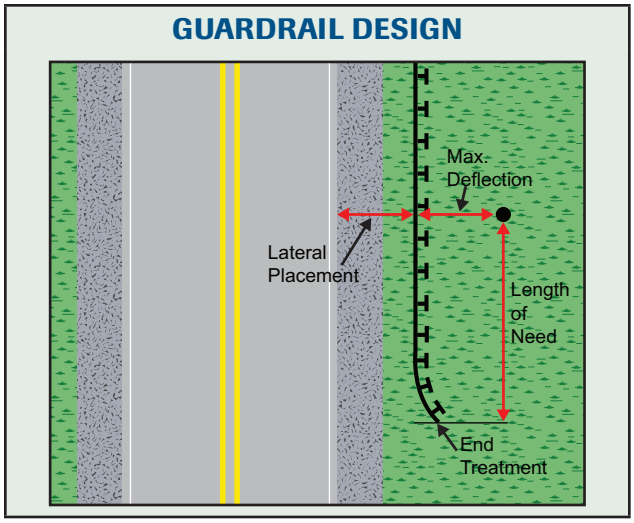
Place roadside barriers as far from the road edge as possible. At a minimum, place beyond the "shy line," or the distance from the edge of the travel way that an obstacle will not be perceived as an immediate hazard by a typical driver. The distance between the barrier and obstruction must always allow for maximum barrier deflection.

On high speed roads, avoid using guardrail-curb combinations due to the potential for vehicle vaulting. Where curbing is absolutely necessary to control drainage, the curb should be no higher than 4 inches and the guardrail should be semi-rigid. The face of the guardrail and the face of the curb should align. The use of guardrail with curbs should be evaluated by a qualified engineer.

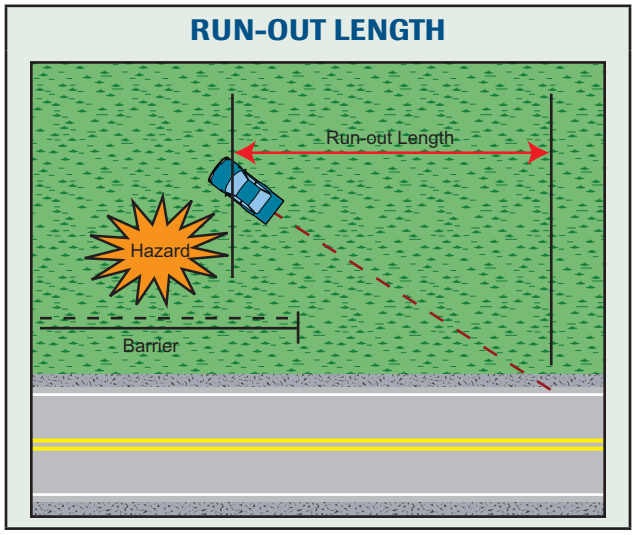
In some instances where barrier is warranted, installing guardrail may appear to be a less expensive option than removing or relocating the hazard. Consider the life cycle costs of maintaining the guardrail.

Length of Need

To prevent a vehicle from striking an obstacle, install a guardrail in front of, and for a distance in advance of, the obstruction. The distance that guardrail should be installed in advance of the obstruction is called the length of need. Length of need should be determined by a qualified engineer and depends on flare, run-out length, and the offset between the obstacle and the guardrail.



The "run-out length" is the distance that a vehicle travels after leaving the roadway before it can come to a stop. It is measured from the obstacle to the point at which a vehicle would leave the roadway. AASHTO has developed suggested run-out lengths based on design speed and traffic volume.



End Treatments

Guardrail runs that end within the clear zone require an end treatment. An end treatment should provide a "forgiving" apparatus for the exposed ends of a guardrail system. On two-lane, two-way highways, both ends require an appropriate end treatment.

NCHRP Report 350 outlines minimum crash performance criteria that roadside hardware should meet. *NCHRP Report 350* approved devices are required on:

- ✓ National Highway System (NHS) roads.
- ✓ Roads where daily traffic volumes exceed 6,000 vehicles.
- ✓ Roads where the design speed is greater than 50 mph.

NCHRP Report 350 approved devices are considered crashworthy.

Crashworthy end treatments can be categorized by their application and characteristics. Some end treatments are gating, meaning they allow a vehicle to pass through on impact. Others are nongating, meaning they will gradually stop or redirect a vehicle. End treatments can also be categorized as flared or parallel, depending on whether they are installed parallel with the roadway or flared away from the roadway. An anchored backslope terminal is the most desirable end treatment.

Turned-down end treatments are not crashworthy and should be avoided. Although less expensive than other types of end treatments, turned-down end treatments may cause vehicles to vault or flip. Exhibit 9.7 shows examples of guardrail end treatments.

Exhibit 9.7: Guardrail End Treatment Examples

	Turned-down end treatment
	Guardrail with no end treatment
	Proper end treatment
	Proper end treatment

9.3.5.2. Common Mistakes

Some common mistakes of guardrail installation include those in Exhibit 9.8.

Exhibit 9.8: Common Guardrail Mistakes

	Obstacles in front of a barrier
	Inadequate guardrail lengths
	Gaps in guardrail (gaps that are less than 200 feet should be avoided)

9.3.6. Roadway Shoulders

KEY POINT

A contributing factor in crashes is often poorly maintained shoulders.

Too often, improper shoulder maintenance leads to crashes. The story is common: a car's wheels drop off the edge of the pavement of a highway; the driver attempts to bring the vehicle back into the travel lane, but the rear wheel catches the shoulder drop-off; the driver oversteers and the vehicle swings into the opposing lane of traffic. Usually this situation can be avoided by controlling shoulder erosion.

Roadway shoulder maintenance should include:

- ✓ **Erosion control** – Proper construction and grading of shoulders and road edges is critical for controlling erosion. Proper construction provides lateral support for the shoulder and prevents the edges from cracking and eroding. Proper grading allows water to flow from the roadway and into the drainage system, rather than standing and eroding the shoulder or pavement edge.
- ✓ **Removal of build-up** – Remove vegetation and dirt build-up along roadway shoulders and edges to expedite the drainage of water from the roadway surface.
- ✓ **Control of shoulder cracking** – Apply a seal coat to the roadway shoulders to control cracking and assist in maintaining its structural integrity.

Poorly maintained shoulder

9.4. DRIVER-AID TREATMENTS

Driver-aid treatments minimize highway crashes by helping to keep the road user on the travel way. Many severe crashes occur in curves and turns due to driver fatigue or impairment. The most common driver-aid treatments are:

- ✓ Rumble strips
- ✓ Signs and pavement markings
- ✓ Roadway improvements/ITS
- ✓ Delineators and object markers
- ✓ Warning beacons

9.4.1. Rumble Strips

Rumble strips are a series of various type surface textures used on paved roads and shoulders that produce noise and vibration to alert road users of a traffic condition or hazard (Exhibit 9.9).

A rumble strip becomes a "rumble stripe" when an edge line or center line pavement marking is placed on it. The contour of the rumble strip drains water, and provides a reflective back wall that allows the pavement marking to maintain its retroreflectivity at night during rain and post-rain events (when normal pavement markings lose their function).

Application of Rumble Strips

- ✓ **Shoulder** – rumble strips effectively alert drivers if they leave the travel way, thus reducing run-off-the-road crashes.
- ✓ **Center line** – rumble strips are useful in areas with undivided, two-way traffic roads where there is a history of head-on crashes.
- ✓ **Transverse** – or travel-lane rumble strips, are a useful tool for alerting motorists of an upcoming unsafe condition, such as an unexpected intersection or a tight curve.

Different DOTs locate shoulder edge line rumble strips at different points with respect to the actual travel lane edge. To accommodate bicyclists, common modifications to shoulder rumble strips include:

- ✓ Avoiding rumbles unless a minimum of 4 feet of paved shoulder is available
- ✓ Leaving a periodic gap in the rumble line to allow bicycles to travel between the shoulder and travel lane
- ✓ Modifying the depth and width of the rumble cut to make traversing the rumble strips safer for cyclists.

Exhibit 9.9: Pavement Marking Detail for Rumble Strips and Stripes

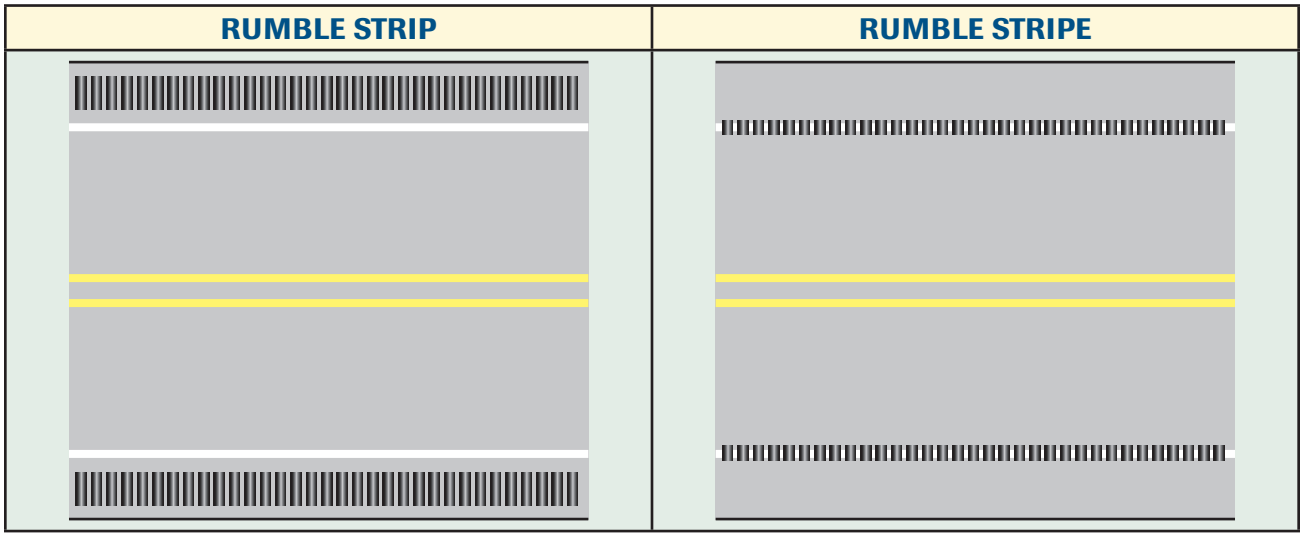
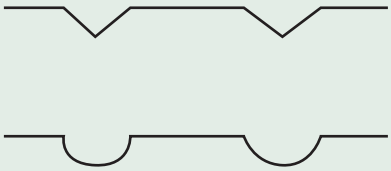


Exhibit 9.10: Common Types of Rumble Strips*

TYPE	DESCRIPTION	COMMENTS
MILLED	✓ Machine-milled ✓ Longitudinal width of 7 inches ✓ Transverse width of 16-17 inches ✓ Offset 12-16 inches from travel lane ✓ Tires drop ½ inch into groove	✓ Favorite type of most states because they are easy to install ✓ Do not affect pavement integrity ✓ Produce greater noise and vibration than other types of rumble strips
ROLLED/FORMED 	✓ Made by a roller with steel pipes welded to drums ✓ 1¼ inches deep ✓ 1½ inches wide ✓ 8 inches between grooves	✓ Do not create the same feel of noise and vibration as milled rumble strips

**The type of rumble strip and the exact dimensions vary from state to state. Contact your State DOT for further guidance.*

Shoulder and center line rumble stripes

Related Concerns

- ✓ **Noise** – Noise is both a benefit and a concern with rumble strips. Noise serves as a benefit when it alerts motorists. However, when installed near residential areas, the noise is often perceived as a nuisance. A solution to this concern may be to move the rumble strips farther away from the travel way, reducing the likelihood of them being traveled on. However, this may also reduce their effectiveness.
- ✓ **Bicycles** – Rumble strips pose problems for bicycles. On facilities that have bicycle traffic, redesign roadway and shoulders when possible to accommodate both rumble strips and bicycles. Many states have, or are in the process of developing, bicycle-friendly rumble strips. Check out www.fhwa.dot.gov for more information on states' rumble strip details and specifications.
- ✓ **Maintenance** – Rumble strips cause little, if any, deterioration in roadway surfaces. By their design, rumble strips are self-cleaning since passing vehicles create a wind force that blows debris from the rumble strips.

Costs vs. Benefits

- ✓ The 350+ mile Pennsylvania Turnpike system experienced a 70 percent reduction in run-off-the-road crashes after rumble strips were installed.
- ✓ California experienced an average reduction of 33 percent in run-off-the-road crashes statewide with rumble strip installation.
- ✓ The cost of milled shoulder rumble strips is about $0.35 per linear foot of shoulder.
- ✓ New York State Thruway data indicate a benefit/cost ratio ranging from 66:1 to 182:1.
- ✓ Nevada DOT calculated a benefit/cost ratio ranging from 30:1 to 60:1 for interstate rumble strips.

9.4.2. Signs and Pavement Markings

Signs

Signs are another effective driver-aid treatment. Examples of warning sign treatments for horizontal alignment changes include Turn, Curve, Reverse Turn, and Reverse Curve signs. These signs are very helpful but are commonly misused. Use the criteria in the *MUTCD* as the basis for deciding what type of sign to install.

Pavement Markings

Pavement markings make up the primary delineation and control for road users to navigate the highway system. Markings have an enormous impact on highway safety since they regulate and guide the movement of traffic. Markings provide the best system of roadway delineation for the least cost. Cost is about $0.50 per linear foot for a four-inch wide solid line.

9.4.3. Roadway Improvements and Intelligent Transportation Systems

Roadway improvements can also be effective driver-aid treatments. Many times common improvements can yield the highest reduction in crashes.

- ✓ Realign unconventional roadway conditions.
- ✓ Improve roadway drainage by improving roadway crown and superelevation.
- ✓ Reconstruct deteriorated roadway surface.

ITS has become mainstream and has greatly decreased in cost. Because of its use of technology, these systems can yield reductions in crashes that other improvements cannot.

- ✓ Horizontal alignment warning systems are used to warn motorists if they are traveling too fast for the impending change in horizontal alignment.
- ✓ "RED WHEN FLASHING" signs are used to warn of a red indication at nearby traffic signals where sight distance is limited.
- ✓ Weather sensors and signs are used to provide advance warning of conditions such as black ice on a bridge.
- ✓ Collision countermeasure systems are used to warn of approaching, conflicting traffic at intersections with insufficient sight distance.

9.4.4. Delineators and Object Markers

Delineators

Delineators provide all-weather delineation of roadway edges and are beneficial at locations where alignment may be confusing, such as lane reductions or curves. The color of the delineator must conform to the color of line it is supplementing.

- ✓ 30% reduction in crashes
- ✓ Benefits outweigh costs on roadways with greater than 1,000 vehicles daily

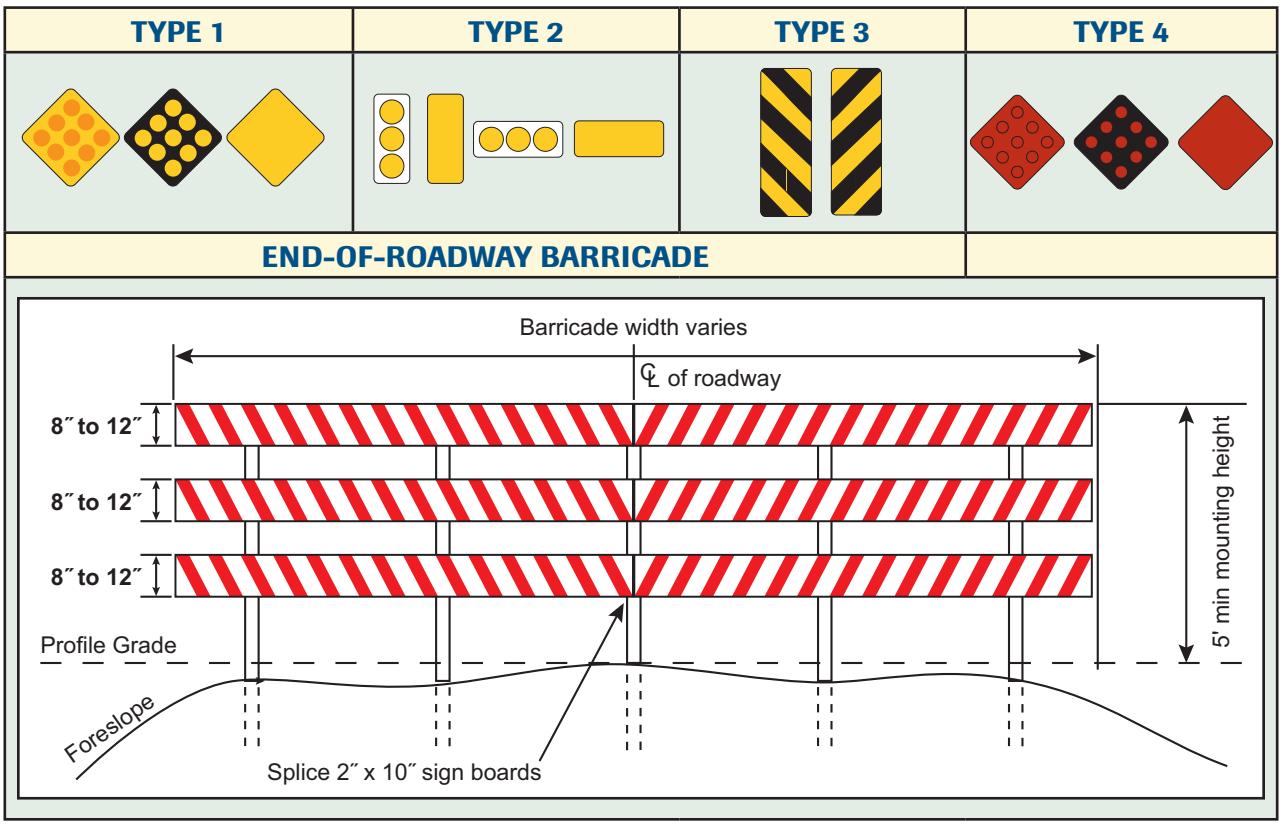
Proper use of delineators

Object Markers

Use object markers to mark obstructions within or adjacent to the roadway. Mark obstructions with a Type 1 or Type 3 marker. Type 3 Markers have stripes sloping downward on the side traffic should pass.

Mark roadside hazards adjacent to the roadway with Type 2 or Type 3 markers. These include underpass piers, bridge abutments, handrails, and culvert headwalls. In some cases they may be used to mark roadside conditions such as narrow shoulder drop-offs, gores, small islands, and abrupt changes in roadway alignment. End-of-roadway markers are typically used at the end of a dead-end roadway. They can be supplemented with an end-of-roadway barricade when conditions warrant. The advantage of this type of marker is that they delineate the entire roadway width. These markers are shown in Exhibit 9.11.

Exhibit 9.11: Object Markers



10.1. VEHICULAR CRASHES 10-1
10.2. CRASH RECORDS 10-5
10.3. IMPROVING ROADWAY SAFETY 10-7
10.4. IMPLEMENTATION OF A ROADWAY SAFETY IMPROVEMENT PLAN 10-12

It is well known that safety on our public roadways is regulated and documented and methods of improving safety are constantly being investigated. It is just as important that roadway safety on military bases is addressed, and all military roadways should provide safe traveling for motorized and nonmotorized traffic. Providing for a safe travelway includes educating the roadway users on safe driving habits, providing a roadway that is designed for the posted speed limit, intersections consisting of the proper traffic control devices and sight distance requirements, and maintaining safe travel through work zone areas.

10.1. VEHICULAR CRASHES

KEY POINT

Vehicular accidents can occur due to a variety of reasons including: inclement weather, driver distraction or error, road debris or animal obstruction, or substandard roadway geometrics or traffic control devices.

Since vehicular crashes fall into multiple categories, maintaining records of crashes that have occurred can be very helpful for determining safety upgrades. Exhibit 10.1 shows mitigation techniques for several different crash types.

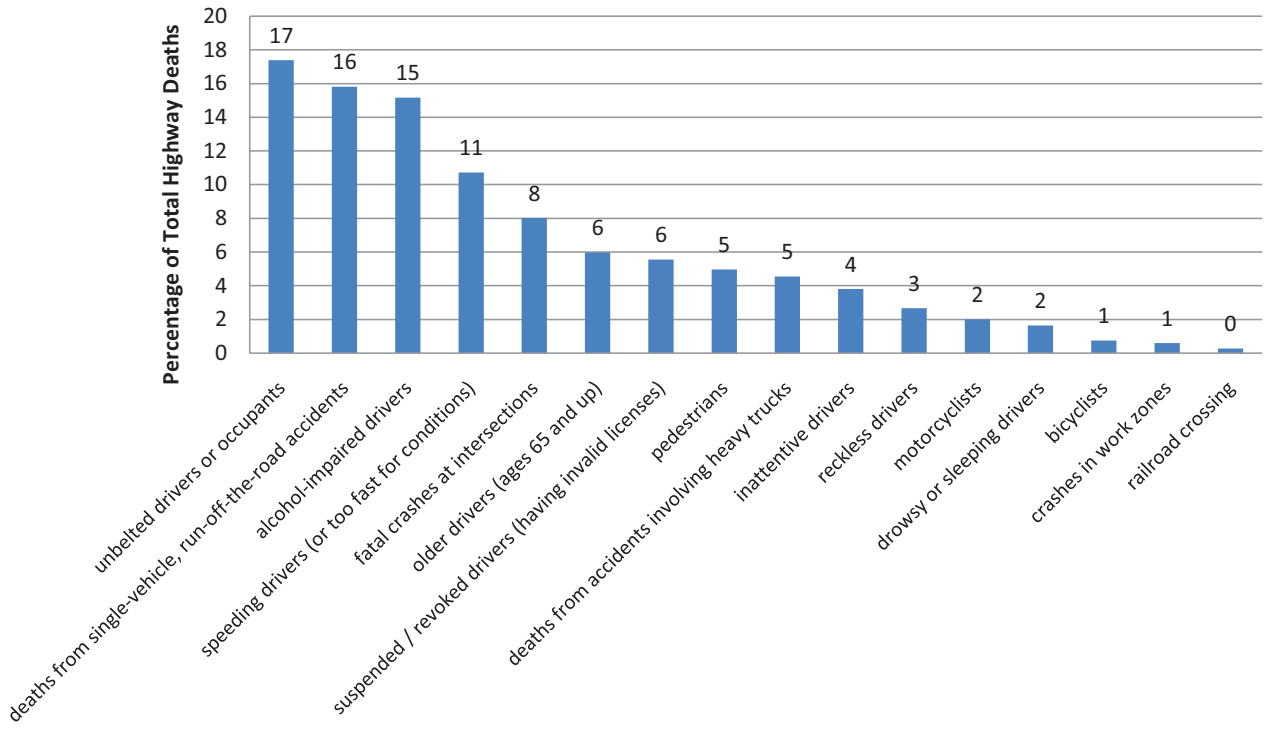
Importance of safety – motorized and nonmotorized traffic sharing the same roadway

Exhibit 10.1: Common Crash Types

TYPE OF CRASH	COMMON CAUSES	SAFETY UPGRADES/ RECOMMENDATIONS
REAR IMPACT	✓ Not maintaining proper distance between vehicles ✓ Traveling at too high of a speed for conditions and nonfunctional ✓ Unexpected congested conditions ✓ Obstructed vehicle break lights.	✓ Educate public on properly maintaining vehicle ✓ Staying a safe distance and speed when traveling behind a vehicle.
SIDE IMPACT/ SIDESWIPE/ANGLE	✓ Failure to stop for a traffic control device ✓ Lose control of vehicle due to unsafe speed or weather conditions ✓ Driver drifting out of lane due to distraction or impairment.	✓ Check intersections for proper traffic control devices with no obstructions ✓ Educate public on maintaining safe speeds, and not being distracted or impaired while driving.
HEAD-ON COLLISION	✓ Driver encroaching into opposing traffic due to weather conditions, distraction, or impairment ✓ Driver enters a highway or one-way street from the wrong direction.	✓ Educate public on not driving while impaired and avoid distractions ✓ Increase DUI checkpoints, and ✓ Check that proper traffic control devices are utilized at highways and one-way streets.
ROLLOVER	✓ Turning too sharply at too high of a speed ✓ A result from a rear, side, or head-on collision.	✓ Refer to the rear, side, and head-on collision recommendations.
SINGLE CAR INCIDENT/RUNOFF	✓ Substandard roadway geometrics ✓ Driver distraction or impairment ✓ Driver avoiding obstacle (i.e. other vehicle, pedestrian, animal, or debris).	✓ Check roadway for geometric deficiencies ✓ Educate public on not driving while distracted or impaired.

Exhibit 10.2 displays the major categories that cause or are associated with deaths on highways. Additionally, from the ITE Journal of July 2001, an analysis of crashes in Great Britain between 2005 and 2009 reveals that human factors play a large role in crashes at all levels of severity. In fact, the top 10 contributory factors were "human factors," such as: failing to look properly; being careless, being reckless, or in a hurry; failing to correctly judge the other vehicle's path or speed; travelling too fast for conditions; braking too suddenly; following too close; and being impaired by alcohol.

Exhibit 10.2: Major Categories of Highway Deaths in 2009



ITE Traffic Safety Toolbox, Chapter 1 on Safety Management, Table 1-1

Highway Safety Improvement Program (HSIP)

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which was signed into law on August 10, 2005, established the Highway Safety Improvement Program (HSIP) as a core Federal-aid program. The overall purpose of this program is to achieve a significant reduction in traffic fatalities and serious injuries on all public roads through the implementation of infrastructure-related highway safety improvements.

The specific provisions pertaining to the HSIP, are defined in Section 1401 of SAFETEA-LU, which amended Section 148 of Title 23, United States Code (23 USC 148) to incorporate these provisions. These requirements include the development of Strategic Highway Safety Plans (SHSPs), in consultation with other key State and local highway safety stakeholders, and a number of reporting requirements.

As part of the HSIP, $220 million is set aside each fiscal year for the Railway-Highway Crossings Program to eliminate hazards and install protective devices at public railway-highway crossings. Also as part of the HSIP, a new High Risk Rural Roads Program was established that provides funding for construction and operational improvements on rural major or minor collectors or rural local roads.

To ensure that the HSIP is carried out in an organized, systematic manner where the greatest benefits are achieved, a formalized HSIP process follows three major components: planning, implementation and evaluation. For more information, see: http://edocket.access.gpo.gov/2008/pdf/E8-30168.pdf.

10.2. CRASH RECORDS

As discussed in Section 10.1, it is important to maintain vehicular crash records in order to develop methods to increase safety on military base roadways.

10.2.1. Military Crash Records

- ✓ **Current System** – many bases currently do not maintain adequate crash records. Crash forms are currently tied into general personal, property, and vehicular information and are mainly used to quantify and track monetary damage. These forms do not give specific information on the crash itself. Generally, military security forces are in charge of crash data, and the data is not readily given to engineering personnel or agencies performing transportation studies. Thus it is very difficult to use existing military base crash data for engineering purposes.
- ✓ **Improvements to Current System** – Potential improvements that could be implemented on military bases include:
  - Make the crash reports accessible for engineering safety improvement analysis.
  - Make the current form more detailed to include information about the crash itself. It is less important to obtain all of the personal information that is being done now. An example of a crash and its associated form is shown in Exhibit 10.3.

10.2.2. Crash Record Resources

There are multiple national and local safety organizations that compile transportation accident data, are continuously developing new technology for improving safety, and offer resources to assist in improving safety at all levels.

- ✓ The NHTSA compiles a vast array of accident data, including state specific crash information. Individual state crash data and forms can be obtained through the NHTSA.
- ✓ The Safety section of the Federal Highway Administration (FHWA) references multiple resources listed in this chapter, and also contains information on crash tested hardware.
- ✓ The *Model Minimum Uniform Crash Criteria (MMUCC) Guideline* is a document that provides a dataset for describing motor vehicle accidents that can be used to improve highway safety within each State and nationally.
- ✓ The Transportation Safety Planning Working Group developed the *Transportation Planner's Safety Desk Reference* which contains general crash data, and gives an overview on what safety improvements can be implemented and the resources that can be used to develop a Safety Improvement Plan.

Exhibit 10.3: Crash Form

CRASH FORM	
Date and Time:	5/18/08, 1032
Roadway Number or Name:	Base parking lot
Collision Type:	Rear end
Intersection Type:	N/A
Urban or Rural:	Urban
Number of Vehicles Involved:	1
Number of People Involved:	2
Severity of Accident:	Minor
Number of Fatalities:	0
Number of Injuries:	0
Illumination within the Accident Area:	Some daylight, parking lot lights
Weather Conditions:	Raining
Road Surface Conditions:	Wet
Short Description of the Accident:	While pulling out of parking spot, car struck pole.

Car pulled out of parking spot and hit pole

10.3. IMPROVING ROADWAY SAFETY

The two key elements to increasing safety on military roadways are to educate roadway users on elements of safety and implementing roadway safety improvements.

10.3.1. Roadway User Safety Considerations

The various elements involved with roadway user safety include: the driver, the vehicle, pedestrians and bicyclists, and temporary work zones.

Exhibit 10.4: Roadway User Safety Considerations

ELEMENT	COMMON ISSUES	SAFETY IMPROVEMENT RECOMMENDATIONS
DRIVER	✓ Impairments – drug or alcohol use ✓ Distractions – eating, cell phones, radio, GPS ✓ Speeding ✓ Not obeying traffic control devices ✓ Not wearing seatbelts ✓ Not using turning signals ✓ Motorcyclists not wearing helmets	✓ Enforce DUI regulations ✓ Educate on the importance of not being distracted while driving ✓ Enforce Executive Order 13513, no texting while driving a government vehicle, or driving for government business ✓ Enforce traffic violations
VEHICLE	✓ Vehicle not in good operating condition or with clear vision ✓ Vehicle lights not operational ✓ Vehicle's windshield wipers or tires are in need of replacement	✓ Educate on the importance of keeping vehicle in good condition ✓ Consider requiring proof of annual vehicle inspections
PEDESTRIANS/ BICYCLISTS	✓ Bicyclists not wearing helmet ✓ Not wearing high visibility safety apparel ✓ Not using retroreflective vests at nighttime ✓ Bicyclists not following traffic control devices ✓ Not using sidewalks or crosswalks	✓ Educate on the importance of practicing safe bicycling ✓ Designate and enforce the use of cross walks within high volume areas ✓ Reduce motor vehicle speed in high pedestrian accident areas ✓ Create or designate pedestrian/ bicyclist pathways to keep them off of roadways
TEMPORARY WORK ZONE	✓ Does not have the proper temporary traffic control devices ✓ Workers not wearing the proper safety apparel	✓ Enforce the use of a Temporary Traffic Control plan that is designed to current standards (see *MUTCD* Part 6) ✓ Enforce driver compliance to work zone traffic controls ✓ Enforce workers to practice standard safety precautions

10.3.2. Roadway Safety Improvement

KEY POINT

The Knowledge Official Safety Magazine of the U.S. Army frequently has advice, tips, and statistics on safe driving. See: https://safety.army.mil.

In addition to addressing safety issues involving the drivers, vehicles, pedestrians/bicyclists, and work zones, the transportation network that these elements utilize can also be improved from a safety standpoint.

10.3.2.1. FHWA-Recommended Improvements

According to the FHWA's Safety department, there are nine proven crash countermeasures that can be incorporated into a transportation facility to help increase safety. Of the nine countermeasures, seven could be directly applied to roadways on military bases.

Exhibit 10.5: FHWA-Recommended Crash Countermeasures

CRASH COUNTERMEASURE	FHWA'S DESCRIPTION	GUIDANCE
ROAD SAFETY AUDITS	A formal safety performance examination of an existing or future road/intersection by an independent and multi-disciplinary team. The audit helps identify potential road safety issues and opportunities for safety improvements for all road users.	*FHWA's Road Safety Audit Guidelines*
RUMBLE STRIPS AND RUMBLE STRIPES	Raised or grooved patterns on the roadway that produce an audible and physical vibration to alert drivers that they have veered off of the travelway.	*NCHRP Project 17-32, Guidance for the Design and Application of Shoulder and Centerline Rumble Strips*
MEDIAN BARRIERS	Median barriers are longitudinal barriers used to separate opposing traffic on a divided highway. They are designed to redirect vehicles striking either side of the barrier. Median barriers can significantly reduce the occurrence of cross-median crashes and the overall severity of median-related crashes.	*AASHTO Roadside Design Guide, 3rd Edition, 2006* *NCHRP Report 350 Recommended Procedures for the Safety Performance Evaluation of Highway Features.* *FAQ on Median Barriers on Divided Highways with Less than Full Access Control*

Exhibit 10.5: FHWA-Recommended Crash Countermeasures (continued)

CRASH COUNTERMEASURE	FHWA'S DESCRIPTION	GUIDANCE
ROUNDABOUTS	This is a type of circular intersection defined by the basic operational principle of entering traffic yielding to vehicles on the circulatory roadway and certain key design principles to achieve deflection of entering traffic by channelization at the entrance and deflection around a center island.	*Roundabouts: An Informational Guide (Report No. FHWA-RD-00-067)* *Public Rights-of-Way Access Advisory* *Pedestrian Access to Modern Roundabouts: Design and Operational Issues for Pedestrians who are Blind* *NCHRP Project 03-78A, Crossing Solutions at Round-abouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities* *Desktop Reference for Crash Reduction Factors, FHWA-SA-07-015, 2007* *NCHRP Report 572: Round-abouts in the United States* *Guide for the Planning, Design, and Operation of Pedestrian Facilities, AASHTO, 2004*
SAFETY EDGE	A specific asphalt paving technique where the interface between the roadway and graded shoulder is paved at an optimal angle to minimize vertical drop-off and provide a safer roadway edge.	*FHWA-SA-07-023, The Safety Edge: Pavement Edge Treatment*
LEFT AND RIGHT TURN LANES AT STOP-CONTROLLED INTERSECTIONS	Left-turn lanes are auxiliary lanes for storage or speed change of left-turning vehicles. Installation of left-turn lanes reduces crash potential and motorist inconvenience, and improves operational efficiency. Right-turn lanes provide a separation between right-turning traffic and adjacent through traffic at intersection approaches, reducing conflicts and improving intersection safety.	*FHWA, SA-07-015, Desktop Reference for Crash Reduction Factors* *AASHTO's Left-Turn Accommodations at Unsignalized Intersections (underway) Guide for the Planning, Design, and Operation of Pedestrian Facilities*

Exhibit 10.5: FHWA-Recommended Crash Countermeasures (continued)

CRASH COUNTERMEASURE	FHWA'S DESCRIPTION	GUIDANCE
YELLOW CHANGE INTERVALS	The interval following a green signal indication during which the yellow signal indication is displayed to warn drivers of the impending change in right-of-way assignment. Yellow change intervals that are not consistent with normal operating speeds create a dilemma zone in which drivers can neither stop safely nor reach the intersection before the signal turns red.	*FHWA's Desktop Reference for Crash Reduction Factors*
MEDIANS AND PEDESTRIAN REFUGE AREAS	The median is the area between opposing lanes of traffic, excluding turn lanes. Medians can either be open or they can be channelized to separate various road users. Pedestrian Refuge Areas are raised islands placed in the street at intersection or midblock locations to separate crossing pedestrians from motor vehicles.	*Pedestrian Facility User's Guide: Providing Safety and Mobility* *A Review of Pedestrian Safety Research in the United States and Abroad*
WALKWAYS	Several types of pedestrian walkways have been defined: ✓ **Pedestrian Walkway:** A continuous way designated for pedestrians and separated from motor vehicle traffic by a space or barrier. ✓ **Shared Use Path:** A bikeway or pedestrian walkway physically separated from motorized vehicular traffic by an open space or barrier ✓ **Sidewalks:** Walkways that are paved and separated from the street, generally by curb and gutter. ✓ **Roadway Shoulder:** In rural areas where sidewalks and pathways are not feasible, gravel or paved highway shoulders provide an area for pedestrians to walk next to the roadway.	*AASHTO's Guide for the Planning, Design, and Operation of Pedestrian Facilities* *A Review of Pedestrian Safety Research in the United States and Abroad* *An Analysis of Factors Contributing to 'Walking Along Roadway' Crashes: Research Study and Guidelines for Sidewalks and Walkways*

Example of a pedestrian refuge

10.3.2.2. AASHTO-Recommended Improvements

AASHTO has developed the *Highway Safety Manual (HSM)* which introduces the science behind safety analysis and provides roadway improvements for multiple types of crash conditions. The manual has the following goals:

- ✓ Identifying sites with the most potential for crash frequency or severity reduction;
- ✓ Identifying factors contributing to crashes and associated potential countermeasures to address these issues;
- ✓ Conducting economic appraisals of potential improvements and prioritizing projects;
- ✓ Evaluating the crash reduction benefits of implemented treatments; and
- ✓ Estimating potential effects on crash frequency and severity of planning, design operations, and policy decisions.

10.4. IMPLEMENTATION OF A ROADWAY SAFETY IMPROVEMENT PLAN

KEY POINT

Form a Roadway Safety Committee to implement a safety improvement plan.

In order to improve roadway safety on military bases, it may be necessary to form a Safety Committee. The committee could then pinpoint specific safety needs, and develop a Roadway Safety Improvement Plan in order to address those needs. Exhibit 10.6 outlines the steps to formulating the plan.

Exhibit 10.6: Steps to Formulating a Safety Improvement Plan

STEP 1	✓ Each installation should have a Safety Committee consisting of a multi-disciplinary team. • Members should include planners, traffic engineers, installation police, safety personnel, offbase police, and pedestrian/bicycle coordinators. ✓ The purpose of the committee is to develop a base-wide Traffic Safety Plan and a Roadway Safety Plan. • The safety committee will also be responsible for implementing Roadway Safety Improvement Plans, as well as Temporary Traffic Control plans as needed.
STEP 2	✓ The Safety Committee should organize a safety audit on existing or proposed roadways, which will include an analysis of existing crash data (see Section 10.2).
STEP 3	✓ For the Roadway Safety Improvement Plan, the committee should then identify through the safety audit, areas with safety concerns (high crash areas) and determine the potential causes for the accidents in that area.
STEP 4	✓ The committee could then identify potential safety improvements, the cost of the improvements, and potential reduction in accidents due to those improvements (see AASHTO *Highway Safety Manual*).
STEP 5	✓ The committee should use this data to develop the Roadway Safety Improvement Plan which can either address general base-wide roadway safety issues, or can be more specific to address a particular issue.
STEP 6	✓ Implement the plan. • Many safety-related improvements are low cost. • Higher cost improvements can be phased for implementation.

11.1. SIDEWALKS 11-1
11.2. PEDESTRIAN CRASH MITIGATION 11-9
11.3. PEDESTRIAN-VEHICLE RIGHT-OF-WAY 11-9
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11.5. USE OF TRAFFIC SIGNALS FOR PEDESTRIAN ACCOMMODATIONS 11-14
11.6. SIGNING CROSSWALKS 11-16

KEY POINT

Pedestrian crashes are of particular concern and can best be reduced through engineering, education, and enforcement.

According to FHWA crash data in 2005:

- ✓ 4,881 pedestrians were killed and 64,000 pedestrians were injured in traffic crashes in the United States.
- ✓ On average, a pedestrian is killed in a traffic crash every 108 minutes, and injured in a traffic crash every 8 minutes.
- ✓ Most pedestrian fatalities occur at non-intersection locations (80 percent) and at night (67 percent).
- ✓ Forty-three percent of all young (under age 16) pedestrian fatalities occurred between 3:00 p.m. and 7:00 p.m.

Crosswalk example

11.1. SIDEWALKS

KEY POINT

Provide sidewalks along any roadway that does not have shoulder.

Sidewalks are one of the most basic forms of pedestrian accommodations. Sidewalks are generally used significantly more in urban areas than in rural areas. Built-up portions of military bases generally have an urban feel. More open areas of bases have a rural feel. Therefore, there are areas on bases where sidewalks are more appropriate versus where they may not be necessary. As a general rule, provide sidewalks anywhere along a roadway that does not have shoulder, regardless of pedestrian demand. If there are two separate areas on a base located close to each other which generate significant pedestrian traffic, they should be connected by sidewalk or other pedestrian walking facility. Worn paths adjacent to a roadway are an indication of pedestrian demand. Such locations generally indicate the need for sidewalk.

Worn path indicates need for sidewalk

Sidewalk width can vary from four feet to eight feet, depending on pedestrian demand. For ADA reasons, if a four-foot wide sidewalk is used, a 5-foot by 5-foot wheelchair passing area must be provided every 200 feet. Provide some form of a buffer between the roadway and the sidewalk. This can be a planted strip or curb. If the sidewalk is adjacent to the roadway curb, provide an additional two-feet of sidewalk width.

When locating sidewalk, locate it with respect to the adjacent roadway, not with respect to a building. For example, if sidewalk is being added in conjunction with a building project, the sidewalk should be located such that it clearly appears to be a sidewalk intended for all pedestrians, versus a pedestrian access to the building.

When placing sidewalk, it should be continuous. Sidewalks should not have gaps. For example, a case where sidewalk is provided in front of one building and not in front of an adjacent building is not desirable. When sidewalk ends, end it at a logical location that is ADA compliant.

Example of undesirable sidewalk termination

11.1.1. PT Accommodations

Physical Training (PT) is a key part of military training. PT is frequently performed during morning hours, which frequently coincides with peak vehicular traffic. This results in an increased potential for vehicle-pedestrian conflicts if conditions are not favorable. The ideal location for PT is on sidewalks, as opposed to roadways. When planning for PT routes, it is ideal to have routes that travel adjacent to barracks buildings. This reduces the need for personnel to drive to PT locations.

Exhibit 11.1: Preferred PT Locations, by order of preference

LOCATION	CONSIDERATIONS
1. Sidewalk	Sidewalks are generally located in built-up parts of a base. Barracks are also generally located in built-up parts of a base. If PT routes are located on sidewalks, it may eliminate the need to drive to PT.
2. Jogging/walking trails	Trails should be used to keep PT routes away from roadways. This is advantageous because it minimizes vehicle-pedestrian conflicts.
3. Low-volume roadways	If roadways are used for PT, they should be low-volume roads which can be closed to vehicular traffic. Station crossing guards at cross roads in order to maximize awareness of pedestrian traffic by vehicular traffic.
4. Moderate Volume Roadways	If roadways with higher traffic volumes are used, it is preferred for the safety of troops to close the roadway. If this is not possible, post a low speed limit which applies when troops are present. Also, use flaggers or even a vehicular escort to clearly indicate the presence of troops on the roadway.
5. High Volume Roadway	PT routes located on high volume roadways is not recommended. If key roadways through an installation are closed to traffic, particularly in the morning peak period, adjacent roadways, often lower classification, must accommodate the diverted traffic. This results in degraded traffic operations.

11.1.2. Pedestrian-Related ADA Considerations

KEY POINT

All pedestrian features should be upgraded to current ADA standards when adjacent construction occurs.

A very commonly occurring problem on military installations is lack of ADA compliance for pedestrian facilities. ADA compliance is extremely important. Even though the military population is generally fit, there are many additional users of pedestrian facilities. Civilian employees and retirees are examples of non-military pedestrian facility users who may be benefit from ADA facilities. Additionally, full compliance with ADA requirements is the law.

> It is the goal of the Department of Defense (DoD) to make its facilities accessible to persons with disabilities. To achieve that goal, the Department intends to go beyond the minimum requirements of law. Even if a facility is exempt from coverage under the Architectural Barriers Act of 1968 (ABA), compliance with the standards identified in this memorandum is recommended to the maximum extent that is reasonable and practicable without degrading the facility's military utility.
>
> *Source: DEPUTY SECRETARY OF DEFENSE; 10-31-2008: http://www.access-board.gov/ada-aba/dod-memorandum.htm.*

According to the Americans with Disabilities Act "All new construction and modifications must be accessible to individuals with disabilities. For existing facilities, barriers to services must be removed if readily achievable."

According to "Designing Sidewalks and Trails for Access" published by the Federal Highway Administration (FHWA), the type of provisions needed vary by location. Different types of curb ramps are needed at sidewalks and crosswalk locations. Page 11-5 illustrates various ramp configurations that can be used.

Detectable warning surfaces must also be provided at the road edge in order to give blind pedestrians the message that they are about to enter a roadway. The detectable warning surface must differ in color from the sidewalk, must be at least two feet deep measured parallel to the direction of the sidewalk, and should not be diagonal to the crosswalk.

In addition to the detectable warning surface, provide a landing area at least 4-foot by 4-foot intended for wheelchair mobility. The maximum cross-slope of this landing area should be no greater than two percent, the minimum for drainage.

At signalized intersections where pedestrian push buttons are used, it must be located no greater than 10 inches from the landing area. Sometimes, in order to achieve this, pedestrian push button stub poles are needed. The pedestrian push button should be mounted at 42 inches from the elevation of the sidewalk. These features are illustrated in the photo on the following page.

Examples of the detectable warning surface are shown in Exhibit 11.2. In general, when designing for ADA, Exhibit 11.3 shows several design considerations.

Pedestrian Features at Signalized Intersections

Exhibit 11.2: Detectable Warning Surface Examples

	Crosswalk lacks curb cuts.
	Detectable warning surface is diagonal to the crosswalks. This alignment directs the pedestrian into the center of the intersection.
	Detectable warning surface not adjacent to roadway.
	Correctly designed curb cut.

Exhibit 11.3: ADA Design Considerations

DESIGN ELEMENT	ADA CONSIDERATIONS
Sidewalks	✓ Firm, stable, and slip resistant ✓ Separated from travel lanes ○ Curbs ○ Planting strips ○ Other barriers ✓ 2% maximum cross slope ✓ Maximum grade is the higher of 5% or the grade of the adjacent street
Curb Ramps	✓ 8.3% maximum gradient ✓ 11% maximum change in gradient ✓ Toe of curb must be flush with pavement ✓ Detectable warning surface at ramp / roadway interface ✓ $15 to $35 per square foot
Ramp Landings	✓ Needed at changes in direction ✓ Minimum 4' x 4' (5' x 5' desirable) ✓ 2% max cross-slope in all directions
Traffic Signals	✓ Where pedestrian activity is frequent or where pedestrian timing requirements do not impact traffic operations, pedestrian phases should be displayed without requiring activation. ✓ At locations where pedestrian activity is infrequent and pedestrian phasing is not warranted at all times, the use of pedestrian push buttons may be justified. ✓ Pedestrian signals are required for all new signals ✓ Accompanied by signage explaining their purpose and use ✓ Push buttons must be accessible ○ Firm, stable, slip resistant landing - 4' x 4' - 2% max cross slope ○ 10" maximum reach ○ 42" mounting height ○ 10' maximum distance from waiting area ✓ Accommodation for the visually impaired as warranted

11.1.3. Bicycle Accommodations

Often there is an opportunity to integrate bicycle facilities into the site design. For example, roadway shoulder should be paved and designed to be wide enough to accommodate a potentially striped bike lane. The normally accepted roadway shoulder width to accommodate bicycle travel is four feet. As a short term method in locations where bicycle accommodation is desired, shoulders can be evaluated to ensure that their condition is such that bike travel is safe and that cyclists can expect some measure of protection from traffic resulting from distance from the travel lanes. Pavement markings to designate bike lanes add a measure of safety by serving as a visual deterrent for motorists and defining roadway space identified for cyclists. The minimum width required to provide a bike lane in both directions on a 2-lane roadway is 32 feet. This would allow for two 12-foot lanes and two 4-foot shoulders. If at least 28 feet is available, a bike lane could be provided in one direction; however, there is the potential that some bicyclists would use this lane traveling against the direction of traffic, which would be hazardous.

Design Guidance

AASHTO's *Guide for the Development of Bicycle Facilities* provides these guidelines for accommodating bicyclists on shared roadways:

- ✓ Shoulders may be used where provided. Shoulders should be paved with a minimum desirable width of four feet, or five feet where there is a guardrail, curb, or other longitudinal barrier. If significant bicycle traffic is expected, shoulders should be wider.
- ✓ In urban areas, a wide curb lane, 14 feet, can be provided in the absence of a shoulder.
- ✓ Where on-street parking exists, 12 feet for combined bicycle travel and parking width should be provided.

Bike Share Programs

Bike share programs are not really new but have not received much publicity. Cities such as Hoboken, NJ; Washington, D.C.; and Montreal have used these programs with success. The way the program works differs in each city, but the basic concept is that people can use bicycles for free or for a small charge at various pick-up points. The concept could work on military bases as well.

Stop for Pedestrians

11.2. PEDESTRIAN CRASH MITIGATION

ITE recognizes that reduction of pedestrian crashes can only be accomplished through engineering, education, and enforcement; otherwise known as the 3 E's. The 3 E's are interrelated and only successful if all three are addressed.

Engineering and Maintenance

It is the engineering and maintenance staff's responsibility to provide the appropriate pedestrian accommodations and to ensure that these accommodations are properly maintained.

Education

Education of motorists and pedestrians alike can help ensure that everyone understands their responsibilities. A common method to educate motorists and pedestrians is through periodic articles or ads in installation newspapers. Additionally, school-based education campaigns can promote pedestrian safety to children. The FHWA Web site is an excellent source of free educational sources, located at http://safety.fhwa.dot.gov/ped_bike/ped_cmnity/ped_walkguide/ch3_edu.cfm.

Enforcement

Proper enforcement can ensure compliance with laws and traffic control devices. Because Security Forces' responsibilities are numerous, their ability to routinely patrol crosswalk compliance is limited. However, even occasional (once a month) enforcement will result in improved compliance.

Pedestrian crashes are of particular concern and can best be reduced through engineering, education, and enforcement.

11.3. PEDESTRIAN-VEHICLE RIGHT-OF-WAY

KEY POINT

At crosswalks, vehicles shall yield to pedestrians in a crosswalk, but pedestrians shall not enter the path of a vehicle to constitute an immediate hazard.

The Uniform Vehicle Code and Model Traffic Ordinances is the model traffic ordinance for most states; however, each state may have its own traffic ordinances, which may vary. The traffic model ordinance states that pedestrians have certain rights and duties.

So what does that mean? Regarding unsignalized crosswalks, both drivers and pedestrians have responsibilities. The driver must yield to pedestrians; however, pedestrians should use caution when entering crosswalks. At unmarked, non-intersection locations, the pedestrian should always yield to motorists. State codes may vary; therefore, consult your state's vehicle code for exact language.

EXCERPT FROM ARTICLE V - PEDESTRIAN'S RIGHTS AND DUTIES

11-502-Pedestrians' right-of-way in crosswalks

(a) When traffic-control signals are not in place or not in operation, the driver of a vehicle shall yield the right-of-way, slowing down or stopping if need be to yield to a pedestrian crossing the roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger.

(b) No pedestrian shall suddenly leave a curb or other place of safety and walk or run into the path of a vehicle which is so close as to constitute an immediate hazard.

11-503-Crossing at other than crosswalks

(a) Every pedestrian crossing a roadway at any point other than within a marked crosswalk or within an unmarked crosswalk at an intersection shall yield the right-of-way to all vehicles upon the roadway.

(b) Any pedestrian crossing a roadway at a point where a pedestrian tunnel or overhead pedestrian crossing has been provided shall yield the right-of-way to all vehicles upon the roadway.

(c) Between adjacent intersections at which traffic-control signals are in operation pedestrians shall not cross at any place except in a marked crosswalk.

(d) No pedestrian shall cross a roadway intersection diagonally unless authorized by official traffic-control devices; and when authorized to cross diagonally, pedestrians shall cross only in accordance with the official traffic-control devices pertaining to such crossing movements.

Source: Uniform Vehicle Code and Model Traffic Ordinances

11.4. CROSSWALKS

What is a crosswalk?

The formal definition of a crosswalk appears below. Summarized, a crosswalk basically is the connection of two sidewalks or designated pedestrian crossing across a roadway.

> The *MUTCD* defines the term Crosswalk: (a) that part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or in the absence of curbs, from the edges of the traversable roadway, and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the sidewalk at right angles to the center line; (b) any portion of a roadway at an intersection or elsewhere distinctly indicated as a pedestrian crossing by pavement marking lines on the surface, which might be supplemented by contrasting pavement texture, style, or color.

Where should crosswalks be used?

Crosswalks should not be used where speeds exceed 45 mph at unsignalized intersections, and where sight distance is not adequate. Generally, crosswalks should be marked based on the following guidelines:

- ✓ All signalized intersections with pedestrian signal heads;
- ✓ All locations where a school crossing guard is normally stationed to assist children in crossing the street; and
- ✓ All intersections and mid-block crossings satisfying minimum vehicle and pedestrian volume guidelines.

What about mid-block crosswalks?

The use of marked mid-block crosswalks is highly debated on military installations. Some proponents argue that marked mid-block crosswalks enhance safety while others argue that they give pedestrians a false sense of security. When developing plans for new facilities, avoid situations such as locating the primary parking area on the opposite side of a busy street. Also, marking mid-block crosswalks at every location where pedestrians cross results in disrespect of crosswalks, including those that truly are warranted.

Should marked or unmarked crosswalks be used?

Recently, FHWA completed a study entitled Safety Effects of Marked vs Unmarked Crosswalks at Uncontrolled Locations (www.tfhrc.gov/safety/pubs/04100/04100.pdf). The study results reveal that under no condition was the presence of a marked crosswalk alone (absent of other improvements including signing, special pavement, flashing lights, or geometric improvement) at an uncontrolled location associated with a significantly lower pedestrian crash rate, as compared to an unmarked crosswalk.

However, the study notes that this is not justification to do nothing. Pedestrian needs in crossing streets should routinely be identified and appropriate solutions should be selected to improve pedestrian safety and access. In some cases crosswalks should be marked in association with other improvements.

Use Exhibit 11.4 to determine if a pedestrian crossing location is:

1. A candidate for a marked crosswalk;
2. A candidate for a marked crosswalk combined with other pedestrian improvements; or
3. Not a candidate for a marked crosswalk.

If, based on the chart, additional treatments in association with a marked crosswalk warrant consideration, evaluate the appropriateness of treatments that should be considered such as:

- ✓ Enhancing crosswalk treatments with items such as textured pavements, enhanced crosswalk patterns, and/or in-street pedestrian crossing signs.
- ✓ Providing raised medians or intersection crossing islands.
- ✓ Reducing the effective street crossing distance for pedestrians by narrowing the roads or by providing curb extensions (an extension of the sidewalk and curbing across a parking lane to reduce the crossing distance).
- ✓ Installing other traffic calming measures where appropriate.
- ✓ Installing traffic signals (with pedestrian signals) where warranted.
- ✓ Providing adequate nighttime lighting for pedestrians.
- ✓ Installing pedestrian warning signs, flashers, and other traffic control devices that are sometimes used to supplement marked crosswalks.
- ✓ Constructing grade-separated crossings or pedestrian-only streets.

A traffic engineering study should be performed to identify which treatments, if any, should be used.

Exhibit 11.4: Recommendations for Installing Marked Crosswalks and Other Needed Pedestrian Improvements at Uncontrolled Locations*

ROADWAY TYPE	VEHICLE ADT ≤ 9,000			VEHICLE ADT 9,001-12,000			VEHICLE ADT 12,001-15,000			VEHICLE ADT > 15,000		
	Speed Limit** (in mph)											
	≤ 30	35	40	≤ 30	35	40	≤ 30	35	40	≤ 30	35	40
Two Lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three Lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane with raised median	C	C	P	C	P	N	P	P	N	N	N	N
Multilane without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and mid-block locations with no traffic signals or stop sign on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations which could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, substantial volumes of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossing safer, nor necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements, as needed, to improve the safety of the crossing (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic calming measures, curb extensions). These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where speed limit exceeds 40 mph, marked crosswalks alone should not be used at unsignalized locations.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to show whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volumes, vehicle speeds, sight distance, vehicle mix, and so on may be needed at other sites. It is recommended that a minimum of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) exist at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are not recommended, since pedestrian crash risk may be increased with marked crosswalks. Consider using other treatments, such as traffic signals with pedestrian signals to improve crossing safety for pedestrians.

Source: www.tfhrc.gov/safety/pubs/04100/04100.pdf

11.5. USE OF TRAFFIC SIGNALS FOR PEDESTRIAN ACCOMMODATIONS

KEY POINT

A traffic signal, even when used for pedestrians, must meet at least one traffic signal warrant.

Another perceived cure-all is the installation of traffic signals to accommodate pedestrians. Although properly designed and equipped traffic signals can better accommodate pedestrians, a traffic signal must satisfy one of the warrants contained in the *MUTCD* for installation. The *MUTCD* contains several warrants for traffic signal installation, including criteria based on traffic volumes and crash history. Warrants 4 and 5 described below directly correspond to pedestrian activity.

WARRANT 4, PEDESTRIAN VOLUME

The Pedestrian Volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street.

The need for a traffic control signal at an intersection or mid-block crossing shall be considered if an engineering study finds that the pedestrian and traffic volume data falls above the curves shown in the *MUTCD*.

WARRANT 5, SCHOOL CROSSING

The School Crossing signal warrant is intended for application where the fact that school children cross the major street is the principal reason to consider installing a traffic control signal. The *MUTCD* limits school children to elementary through high school levels.

The need for a traffic control signal shall be considered when an engineering study of the frequency and adequacy of gaps in the vehicular traffic stream, as related to the number and size of groups of school children at an established school crossing across the major street, shows that:

- ✓ The number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period; and
- ✓ There is a minimum of 20 schoolchildren during the highest crossing hour.

Before a decision is made to install a traffic control signal, consideration shall be given to the implementation of other remedial measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing.

In both cases the signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 300 feet, unless the proposed traffic control signal will not restrict the progressive movement of traffic.

Exhibit 11.5 shows proper signal timing. Proper timing of pedestrian signal phases is critical in ensuring safe pedestrian crossings. Install pedestrian signal heads at any signalized location meeting one or more of the following conditions:

1. If a traffic control signal is justified by an engineering study and meets Warrant 4 or Warrant 5 (page 11-14);
2. If an exclusive signal phase is provided or made available for pedestrian movements with all conflicting vehicular movements being stopped;
3. At an established school crossing at any signalized location; or
4. Where engineering judgment determines that elaborate signal phasing would tend to confuse or cause conflicts with pedestrians.

Exhibit 11.5: Pedestrian Signal Timing

	The WALK interval should be at least 7 seconds in length so that pedestrians have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. However, if pedestrian volumes and characteristics do not require a 7-second WALK interval, WALK intervals as short as 4 seconds may be used.
	The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk to travel at a walking speed of 4 feet per second, to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait. Where children, elderly, or disabled populations are present, walking speeds of 3 feet per second should be considered.
The pedestrian clearance time may be entirely contained within the vehicular green interval, or may be entirely contained within the vehicular green and yellow change intervals. However, there must be a minimum 3-second buffer between the end of the DONT WALK interval and the beginning of an opposite direction's green phase.	

11.5.1. Additional Crosswalk Enhancements

Flashing crosswalks are a form of active warning devices. These have high-intensity, bi-directional in-pavement lights that are activated by a push button or microwave sensor at either curb. Once activated, the lights emit a rapidly flashing yellow light in both directions of traffic. The advantage to using these is that they only are activated when a pedestrian is in the crossing. Studies show that when flashing crosswalks are used, drivers tend to yield to pedestrians more frequently, and the advanced warning leads to slower approach speeds.

Currently, there are no "warrants" in the *MUTCD* regarding the use of flashing crosswalks; therefore, it is left to engineering judgment as to where these devices should be considered. Additionally, be sure to check with your state Department of Transportation to verify that these are acceptable for use in your state.

11.6. SIGNING CROSSWALKS

KEY POINT

Signing requirements for crosswalks have changed with the 2003 version of the *MUTCD*.

Because mid-block pedestrian crossings are generally unexpected by the road user, warning signs (W11-2) should be installed and adequate visibility should be provided by parking prohibitions.

When used in advance of a crossing, warning signs shall be supplemented with one of the following plaques:

- ✓ AHEAD (W16-9P)
- ✓ XX FEET (W16-2)
- ✓ NEXT XX FEET (W16-4)

These plaques provide advance notice to road users of crossing activity. When used at mid-block crossings, warning signs shall be supplemented with a diagonal downward pointing arrow (W16-7) plaque showing the location of the crossing. Designated school crossings are signed in a similar fashion, but require a specific type of sign.

Corridors with several crossings can be signed at the start of the corridor to make motorists aware of pedestrian activity. It is important to be consistent in sign placement. If signing a group of crosswalks, take care to ensure that either all of them are signed or none of the intermediate crosswalks are signed.

KEY POINT

Signing requirements for school crosswalks have changed with the 2009 version of the *MUTCD*.

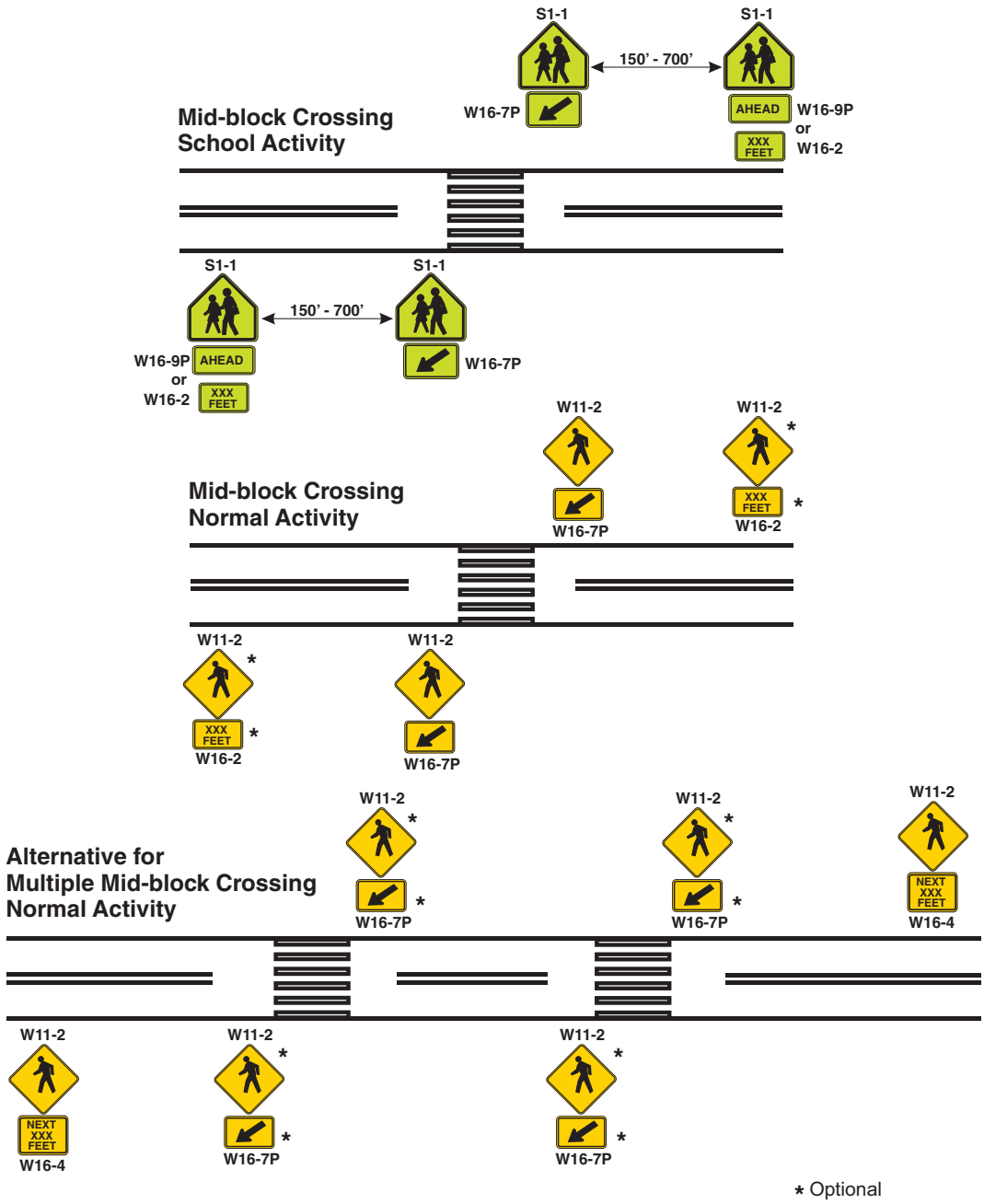
Crosswalk signing requirements for normal and school activity are illustrated on the following page.

Pedestrian, bicycle, school signs, and their related supplemental plaques may utilize a fluorescent yellow-green background with a black legend and border instead of the traditional yellow background. Avoid mixing standard yellow backgrounds within a selected site area.

In addition to providing correct crosswalk signing, it is equally important to provide correct crosswalk markings. These are shown on page 6-35.

Typical pedestrian crossing signs with downward pointing arrow plaque

CROSSWALK SIGNING FOR NORMAL AND SCHOOL ACTIVITY



Note: Mid-block crosswalks are discouraged. Motorists will least expect pedestrians to cross at these locations. It is reasonable to expect pedestrians to walk a block (300-600 feet) to a better crossing location (intersection, etc). Where it is considered desirable to install mid-block crosswalks, pedestrian warning signs should be used.

12.1. WORK ZONE SAFETY 12-1
12.2. FUNDAMENTAL TEMPORARY TRAFFIC CONTROL PRINCIPLES 12-3
12.3. TEMPORARY TRAFFIC CONTROL PLANS 12-5
12.4. TEMPORARY TRAFFIC CONTROL ZONES 12-6
12.5. CHANNELIZING DEVICES 12-8
12.6. TAPER DESIGN. 12-10
12.7. TYPICAL TTC APPLICATIONS 12-12
12.8. TTC DEVICES. 12-25
12.9. FLAGGER CONSIDERATIONS 12-28
12.10. WORKER SAFETY CONSIDERATIONS. 12-30
12.11. PEDESTRIAN CONSIDERATIONS 12-32

12.1. WORK ZONE SAFETY

Work zones are areas on installations that are under construction or receiving maintenance. These areas require special attention in order to provide safety to the travelling public (vehicular, pedestrian, bicyclists and persons with disabilities), and to the workers involved with the activities. It is essential that work zones have the proper traffic control regardless of the volume of traffic, lack of funding, or properly written specifications.

Work zone with lack of proper tapers, signing, and temporary pavement markings

Work zone involving a closed roadway with no signing to indicate the closure of the roadway

Part 6 of the *MUTCD* puts work zone traffic control under the umbrella of Temporary Traffic Control (TTC). Part 6 of the *MUTCD* covers many TTC scenarios and devices in depth. These topics are summarized in this chapter and cover important points more commonly encountered on military installations.

When designing temporary traffic control plans, be sure to investigate for any local and state temporary traffic control standards. There may be state-specific laws related to speed limits, cell phone use in work zones, and special signing needed in work zones.

12.2. FUNDAMENTAL TEMPORARY TRAFFIC CONTROL PRINCIPLES

The *MUTCD* identifies seven basic principles of TTC, as summarized in Exhibit 12.1. These apply not only to the civilian world, but to military projects as well.

Exhibit 12.1: Basic Principles of Temporary Traffic Control

1. General plans or guidelines should be developed to provide safety for motorists, bicyclists, pedestrians, workers, enforcement/emergency officials, and equipment. The basic safety principles governing the design of permanent roadways and roadsides should also govern the design of TTC zones.	✓ A TTC plan should be developed that is appropriate to the complexity of the work project. ✓ This applies to all types of projects regardless of contracting mechanism. Design-Bid-Build projects should include TTC plans which the contractor is required to follow. Design-build projects should require the development of TTC plans.
2. Road user movement should be inhibited as little as practical. When designing TTC, assume that drivers will only reduce their speeds if they clearly perceive a need to do so.	✓ Avoid abrupt changes in geometrics such as lane narrowing, dropped lanes, or main roadway transitions that require rapid maneuvers. Schedule the work such that the need for lane closures or alternate routes is minimized, while still getting the work completed quickly.
3. Motorists, bicyclists, and pedestrians should be guided in a clear and positive manner while approaching and traveling through TTC zones. Provide adequate warning, delineation, and channelization to assist in guiding road users in advance of and through the TTC zone.	✓ TTC devices inconsistent with intended travel paths through TTC zones should be removed or covered. ✓ If flagging procedures are used, they should provide positive guidance to road users traversing the TTC zone.
4. To provide acceptable levels of operations, routine day and night inspections of TTC elements should be performed. Individuals who are knowledgeable in the principles of proper TTC should be responsible for safety in TTC zones. The most important duty should be to check that all TTC devices are consistent with the TTC plan.	✓ As the work progresses, TTCs can be modified, if appropriate, in order to provide better mobility and positive guidance to the road user and to provide worker safety. ✓ Monitor TTC zones under varying conditions of road user volumes, light, and weather to check that applicable TTC devices are effective, clearly visible, clean, and in compliance with the TTC plan. ✓ Crash records in TTC zones should be monitored and studied to identify the need for changes in the TTC zone. ✓ Maintenance of the TTC devices is equally as important as initial installation of the correct devices.

Exhibit 12.1: Basic Principles of Temporary Traffic Control (continued)

5. Attention should be given to the maintenance of roadside safety during the life of the TTC zone. To accommodate run-off-the-road incidents, disabled vehicles, or emergency situations, unencumbered roadside recovery areas or clear zones should be provided whenever possible.	✓ Channelization should be accomplished by the use of pavement markings, signing, and crashworthy, detectable channelizing devices. ✓ Work equipment, workers' private vehicles, materials, and debris should be stored in such a manner to reduce the probability of being impacted by run-off-the-road vehicles.
6. Each person whose actions affect TTC zone safety, from the upper-level management to the field workers, should receive training appropriate to the job decisions each individual is required to make.	✓ Only those individuals who are trained in proper TTC practices and have a basic understanding of the principles should supervise the selection, placement, and maintenance of TTC devices used for TTC zones.
7. Maintain good public relations. Consider the needs of all road users such that appropriate advance notice is given and alternative paths are provided.	✓ Use basewide PR to identify the existence of and reasons for TTC zones to assist in keeping the road users well informed. ✓ The needs of emergency service providers (law enforcement, fire, and medical) should be assessed and appropriate coordination and accommodations made. ✓ The needs of operators of commercial vehicles such as buses and large trucks should be assessed and appropriate accommodations made.

12.3. TEMPORARY TRAFFIC CONTROL PLANS

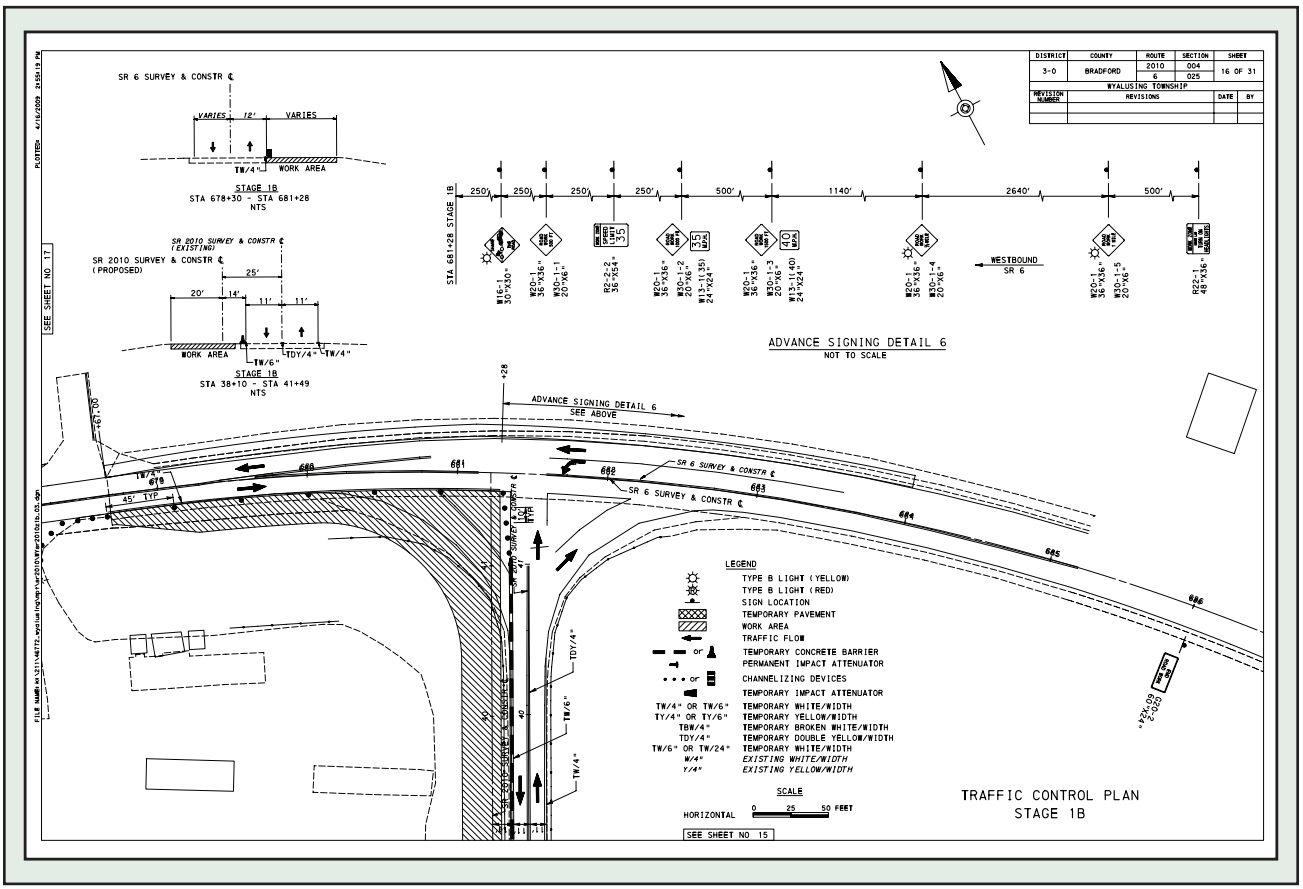
Temporary Traffic Control Plans (TTCPs) should describe the TTC measures that are to be used for safely facilitating roadway users through a work zone or incident area.

TTCPs should be developed by an experienced individual, and should follow design criteria set forth by the *MUTCD* or other documented design criteria. TTCPs can be developed in multiple types of formats, including:

- Written in a TTCP project specification
- Referencing by citation to other policies or documents
- Displayed graphically on the construction project plans
- Developing a standalone TTCP including graphics and written narrative.

An example of a TTCP is shown as Exhibit 12.2.

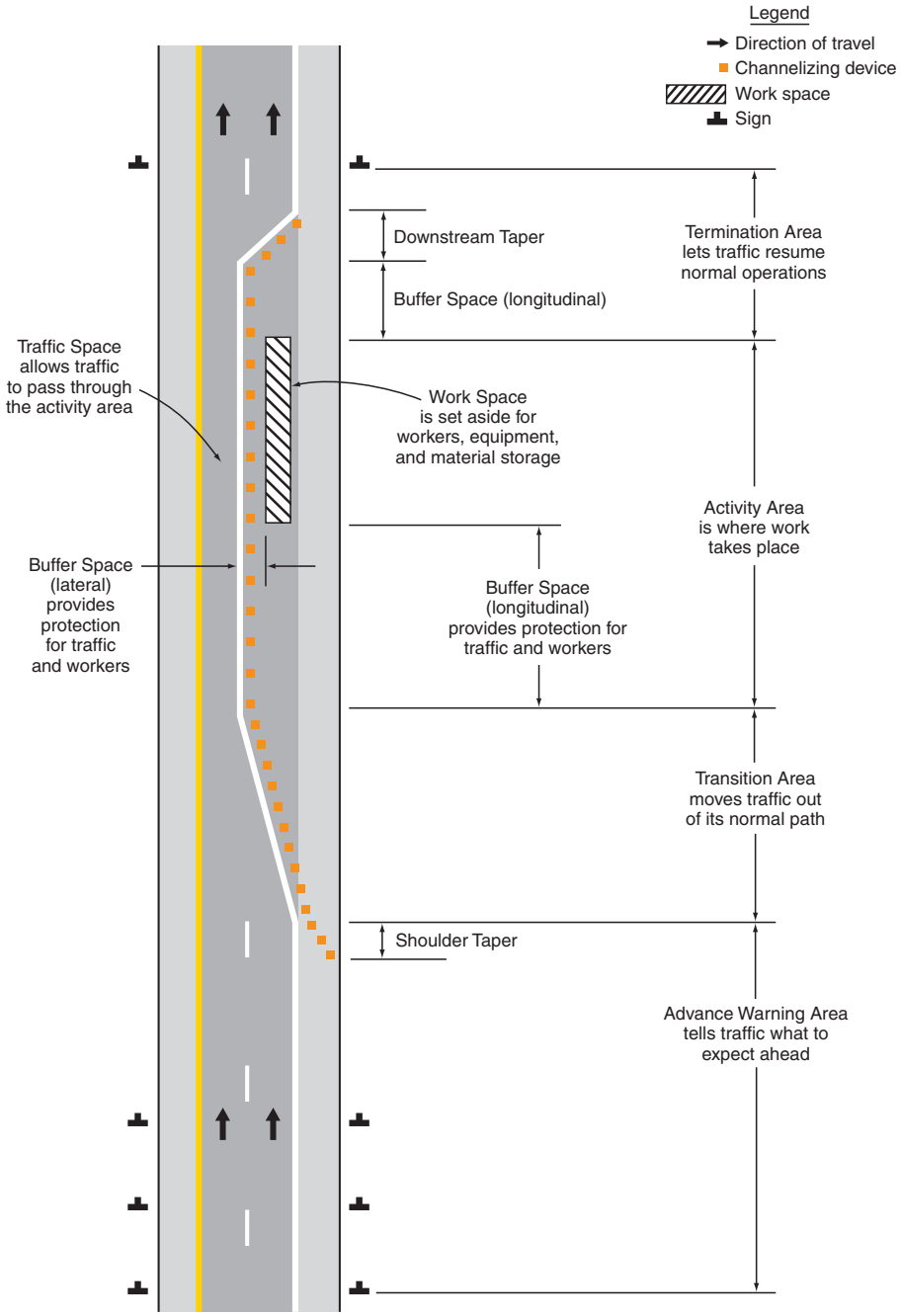
Exhibit 12.2: Example Temporary Traffic Control Plan



12.4. TEMPORARY TRAFFIC CONTROL ZONES

A TTC zone is an area where construction activities or an unplanned incident requires modifications to the expected traffic pattern. Most TTC zones are divided into four areas as shown in Exhibit 12.3.

Exhibit 12.3: TTC Zones



Source: MUTCD

12.4.1. Advance Warning Area

Advance Warning Area is the zone located in advance of the construction or unplanned incident area, where road users are informed about the upcoming work zone.

Advance warning of the work zone is critical. Mainly this is accomplished through the use of advance signing, but can also consist of a vehicle with warning beacons for short-term work zones. As a motorist approaches a typical work zone, there are several steps in providing important information. The first step is to inform the roadway user of the changing condition through a "ROAD WORK AHEAD" sign. The second step should inform the roadway user of what traffic flow changes are occurring, such as "LANE CLOSED AHEAD," or "DETOUR AHEAD" signs. The last step should inform the roadway user of the immediate situation, which could include "Merge Left" or "STOP HERE ON RED" signs. Exhibit 12.8 on page 12-14 shows recommended sign spacing.

12.4.2. Transition Area

The transition area is where roadway users are redirected from the typical traffic pattern. Possible Transition area signs include: "BE PREPARED TO STOP" and "Merge Right." Commonly, the Transition area consists of tapering the roadway, which is shown in Exhibit 12.3.

12.4.3. Activity Area

The Activity area is where the work activity or incident is located and consists of the work, traffic, and buffer space (see Exhibit 12.3). This area can involve direct interaction of motorized and nonmotorized traffic with the work area, workers, and equipment which can pose as a safety risk. It is important that sufficient lateral or longitudinal buffer space is allowed in order to separate road user flow from the potentially unsafe work zone. The buffer space depends on stopping sight distance. Therefore, use the values in Exhibit 12.4 to determine the minimum length of the buffer space.

Exhibit 12.4: Stopping Sight Distance as a Function of Speed

SPEED*	DISTANCE
20 MPH	115 feet
25 MPH	155 feet
30 MPH	200 feet
35 MPH	250 feet
40 MPH	305 feet
45 MPH	360 feet
50 MPH	425 feet
55 MPH	495 feet
60 MPH	570 feet
65 MPH	645 feet
70 MPH	730 feet
75 MPH	820 feet
*Posted speed, off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed.	

Source: MUTCD

12.4.4. Termination Area

The Termination area is the portion of the TTC zone where roadway users are returned to their normal driving pattern. A typical sign used in this area is an "END ROAD WORK" sign.

12.5. CHANNELIZING DEVICES

KEY POINTS

Channelizing devices are typically used to close areas off from travel which are normally open to travel.

Traffic cones or vertical panels can be used effectively for temporary channelization of traffic during lane reversal and lane closures. And, if struck, they generally will not damage vehicles.

These devices are convenient since, unlike steel drums, they can be quickly placed and removed.

When traffic cones are used, they should be:

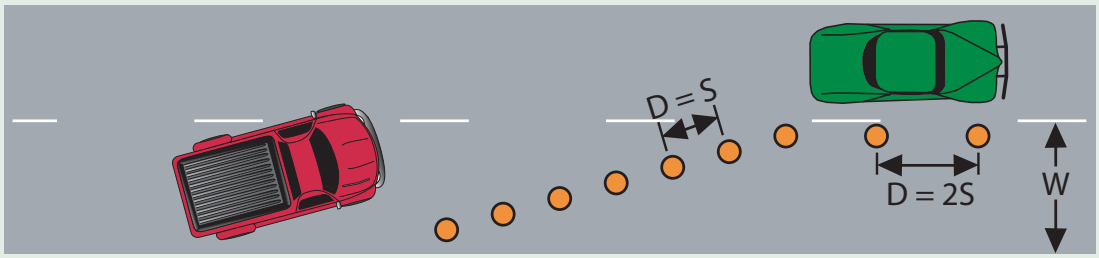
- ✓ 28-inch minimum height.
- ✓ Reflectorized.
- ✓ Orange in color (although other colors are permitted in certain situations).

Within transitions, the distance between cones in feet should equal the posted speed limit in miles per hour. For example, if the posted speed limit is 25 mph, the cone spacing should be 25 feet. At other locations, such as adjacent to closed lanes, the distance between cones in feet may be double the speed limit in miles per hour.

The use of traffic cones should follow standard transition requirements and should not result in an abrupt change in traffic patterns. As a general rule, the taper length in feet should equal $WS^2/60$ for a speed limit of 40 mph or less, or WS for speed limits greater than 40 mph (where W is the width of the shift in feet and S is the posted speed in miles per hour) or 100 feet, whichever is greater.

Object markers are used to mark obstructions within or adjacent to the roadway. These are discussed in Section 9.4.

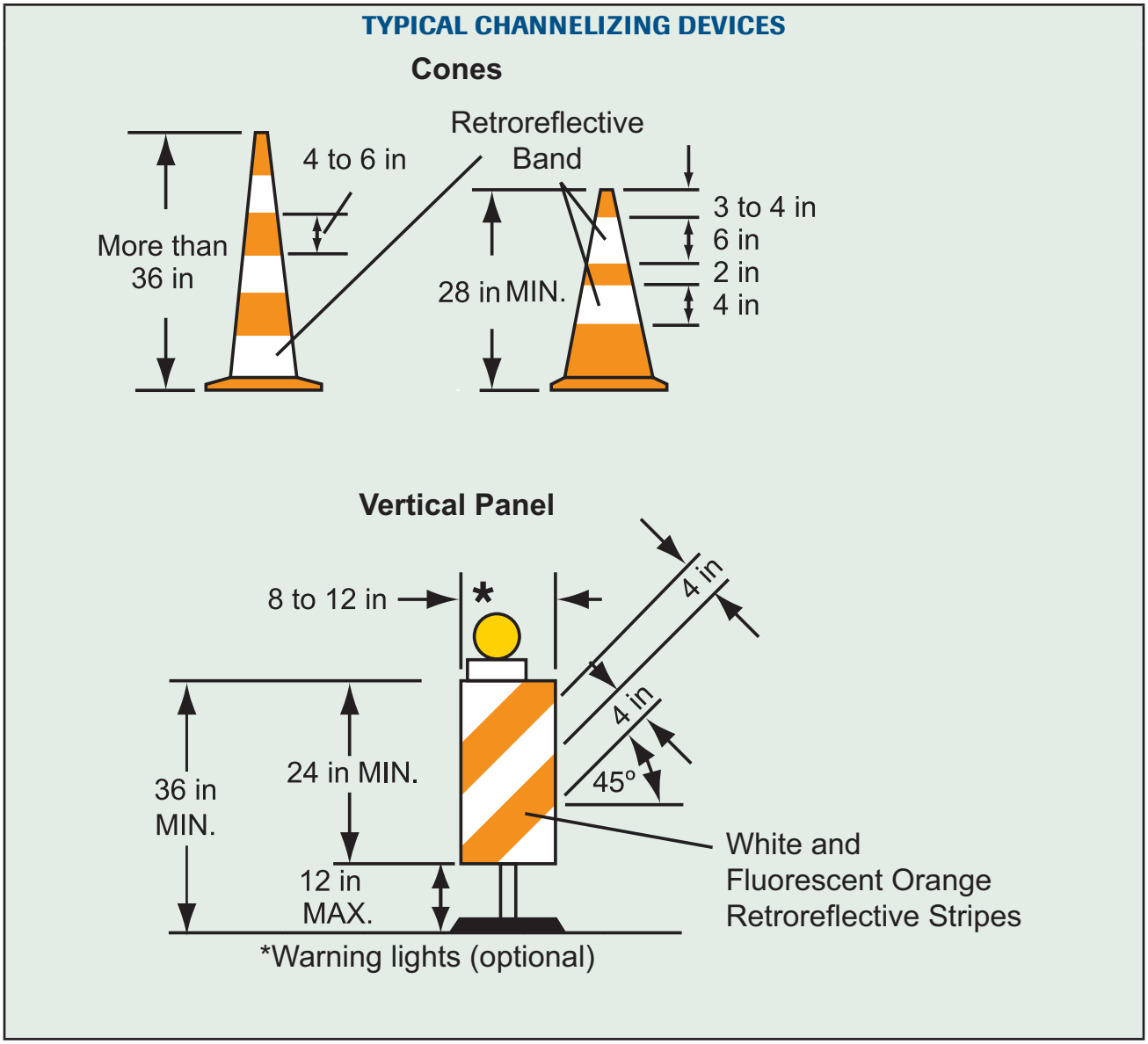
LANE REDUCTION TAPER LENGTHS



W = Width of Transition (feet)
S = Speed Limit (mph)
L = Length of Transition (feet)
D = Distance Between Channelizing Devices (feet)

$$L = \frac{WS^2}{60}$$
(For $S \leq 40$ mph)

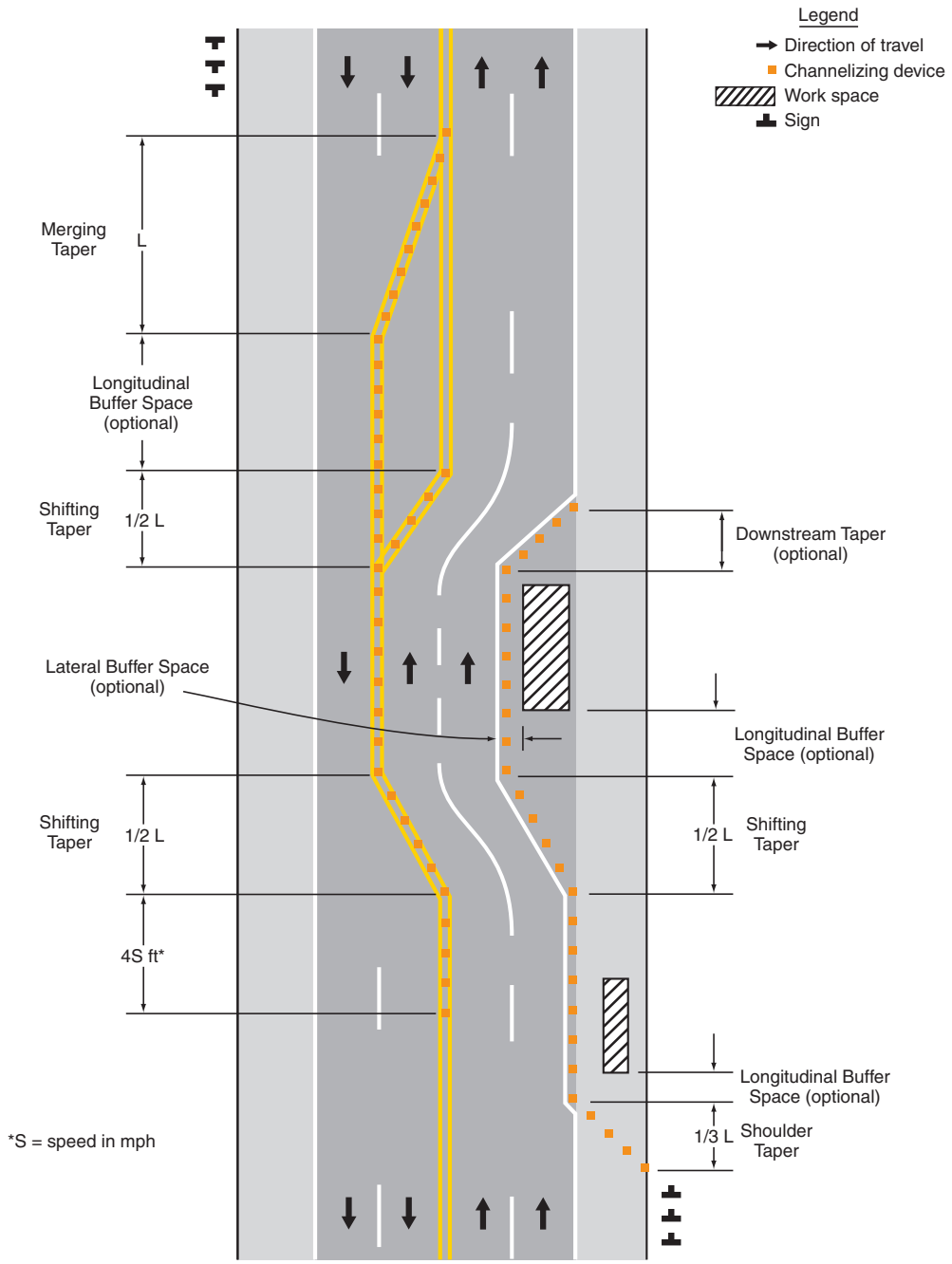
$$L = WS$$
(For $S > 40$ mph)



Source: FHWA, MUTCD

12.6. TAPER DESIGN

Tapers are required to safely shift roadway users to a new traffic pattern. They can be used in both the Transition and Termination areas, and are typically delineated by channelizing devices or temporary pavement markings. Use Exhibits 12.5 and 12.6 to determine the length of the taper.



Source: MUTCD

Exhibit 12.5: Taper Length Criteria for Temporary Traffic Control Zones

TYPE OF TAPER	TAPER LENGTH
MERGING TAPER	at least L
SHIFTING TAPER	at least 0.5 L
SHOULDER TAPER	at least 0.33 L
ONE-LANE, TWO-WAY TRAFFIC TAPER	50 feet minimum, 100 feet maximum
DOWNSTREAM TAPER	50 feet minimum, 100 feet maximum
Note: Use Exhibit 12.6 to calculate L	

Exhibit 12.6: Formulas for Determining Taper Length

SPEED (S)	TAPER LENGTH (L) IN FEET
40 MPH OR LESS	$L = \frac{WS}{60}$
45 MPH OR MORE	$L = WS$
Where: L = Taper length in feet W = Width of offset in feet S = Posted speed limit, or off-peak 85th-percentile speed prior to work starting, or the anticipated operating speed in mph	

Source: MUTCD

12.7. TYPICAL TTC APPLICATIONS

Every TTC zone is unique. The needs can be variable due to the work location and duration, traffic volumes, and roadway usage. The types of work durations and work locations common to military installations are summarized within this section. More detailed information is located in Part 6 of the *MUTCD*.

12.7.1. Work Duration

Long-term stationary – Construction occupies a location for longer than three days. This duration will extend into the nighttime; therefore, retroreflective and/or illuminated devices must be used. Traffic control devices required could include temporary pavement markings, temporary signals, signed detour route, or diversion.

Intermediate-term stations – Construction that occupies a location from one to three days, or nighttime work longer than 1 hour. Commonly this includes maintenance or utility operations.

Short-term stationary – Construction or incident that occupies the location from one hour to one day (daylight hours only).

Short duration – Construction or incident that occupies the location up to one hour. Vehicles with appropriate signing and lighting, and channeling devices easy to install and remove should be used in lieu of numerous signs or temporary pavement markings that take longer to install.

Mobile – Work that is continuously moving such as pothole patching, roadway cleaning, or some utility operations. TTC devices that could be used for mobile operations include: flaggers, shadow vehicle with appropriate signing and devices (high-intensity rotating, flashing, oscillating, or strobe lights).

Long-term, stationary work zone

12.7.2. Work Location

The figures shown on the subsequent pages show typical work zone applications for various scenarios. These scenarios are those deemed to be most applicable to military installations. The *MUTCD* contains additional scenarios beyond those that are shown in this section.

Exhibit 12.7 shows the legend for symbols used within this section. Exhibit 12.8 shows the distances referred to with letters shown as dimensions within the figures. Note that the distances shown are minimum distances. In order to provide additional warning time, the distances can be increased.

Exhibit 12.7: Symbol Legend for Work Location Drawings

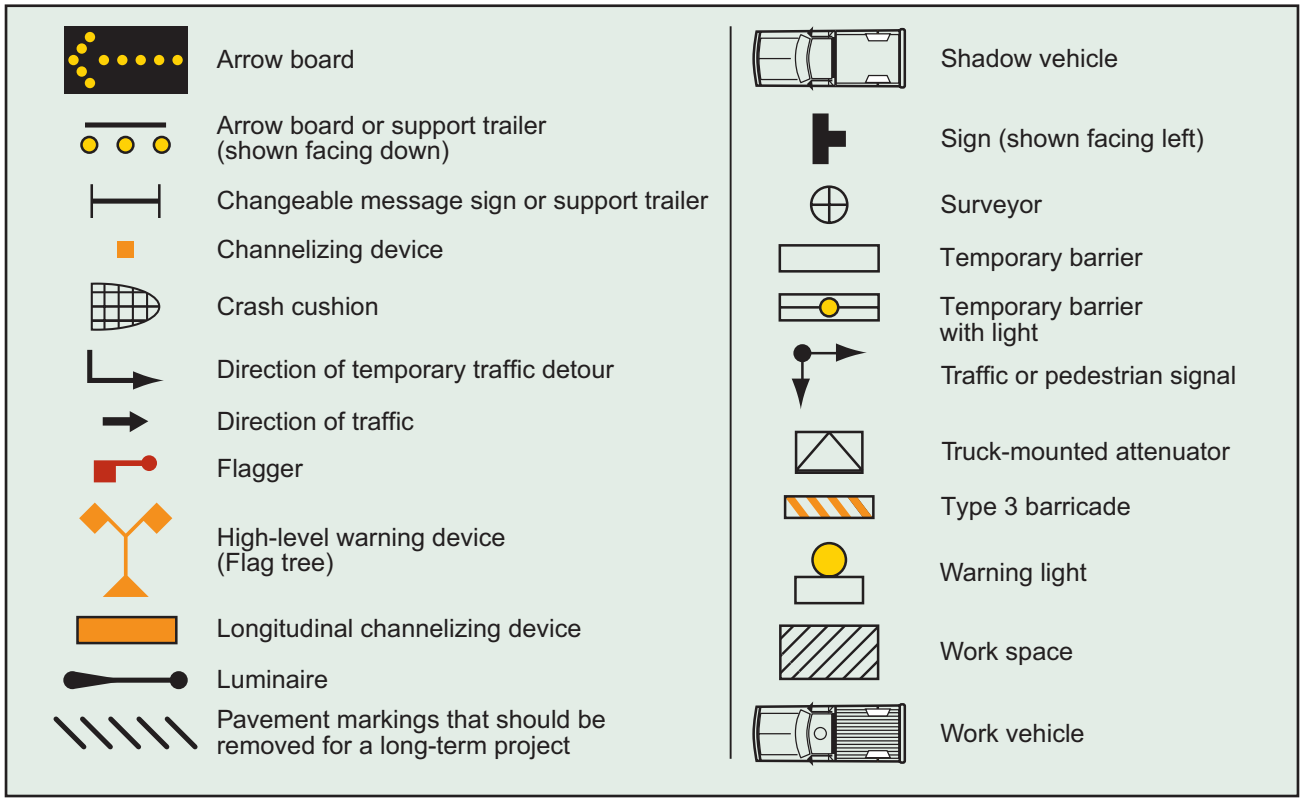


Exhibit 12.8: Recommended Advance Warning Sign Minimum Spacing (Reference for Letter Code Designations on Work Location Drawings)

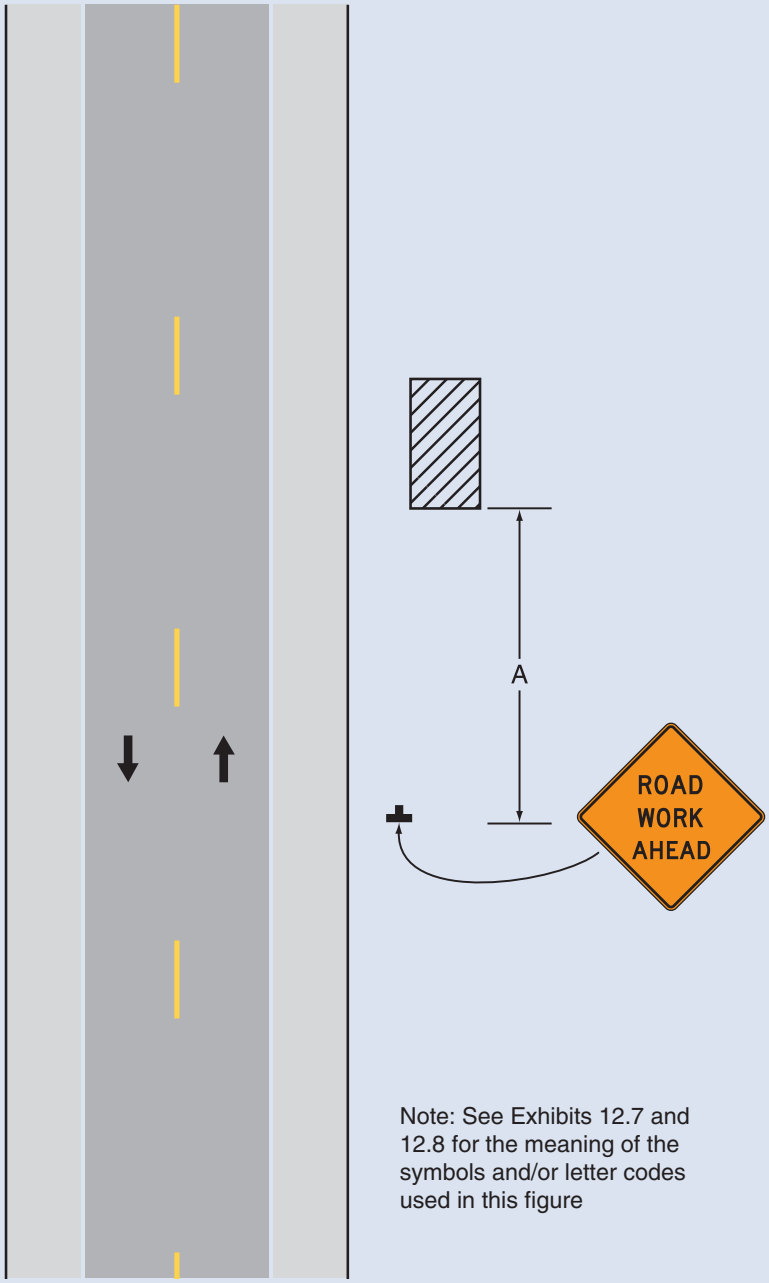
ROAD TYPE	DISTANCE BETWEEN SIGNS**		
	A	B	C
URBAN (LOW SPEED)*	100 feet	100 feet	100 feet
URBAN (HIGH SPEED)*	350 feet	350 feet	350 feet
RURAL	500 feet	500 feet	500 feet
EXPRESSWAY/FREEWAY	1,000 feet	1,500 feet	2,640 feet

* Speed category to be determined by the highway agency

** The column headings A, B, and C are the dimensions shown in *MUTCD* Figures 6H-1 through 6H-46, some of which are shown in Section 12.7.2. The A dimension is the distance from the transition or point of restriction to the first sign. The B dimension is the distance between the first and second signs. The C dimension is the distance between the second and third signs. (The "first sign" is the sign in a three-sign series that is closest to the TTC zone. The "third sign" is the sign that is furthest upstream from the TTC zone.)

Source: MUTCD

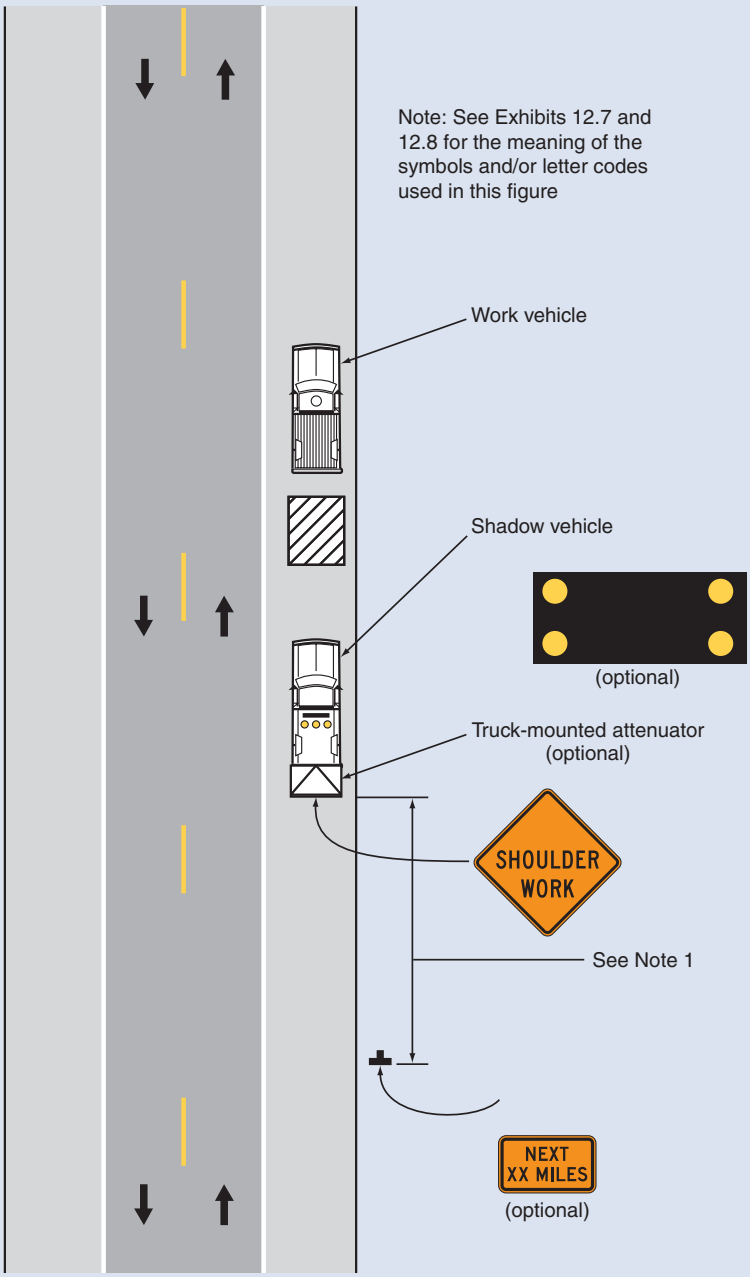
Work Beyond Shoulder – TTC needed if vehicles will be parked on the shoulder or travelling the roadway. TTC is generally not needed if all work and vehicles is located more than fifteen feet from the edge of the travel way. Vehicle hazard lights shall not be used in lieu of high intensity rotating, flashing, oscillating, or strobe lights.



Note: See Exhibits 12.7 and 12.8 for the meaning of the symbols and/or letter codes used in this figure

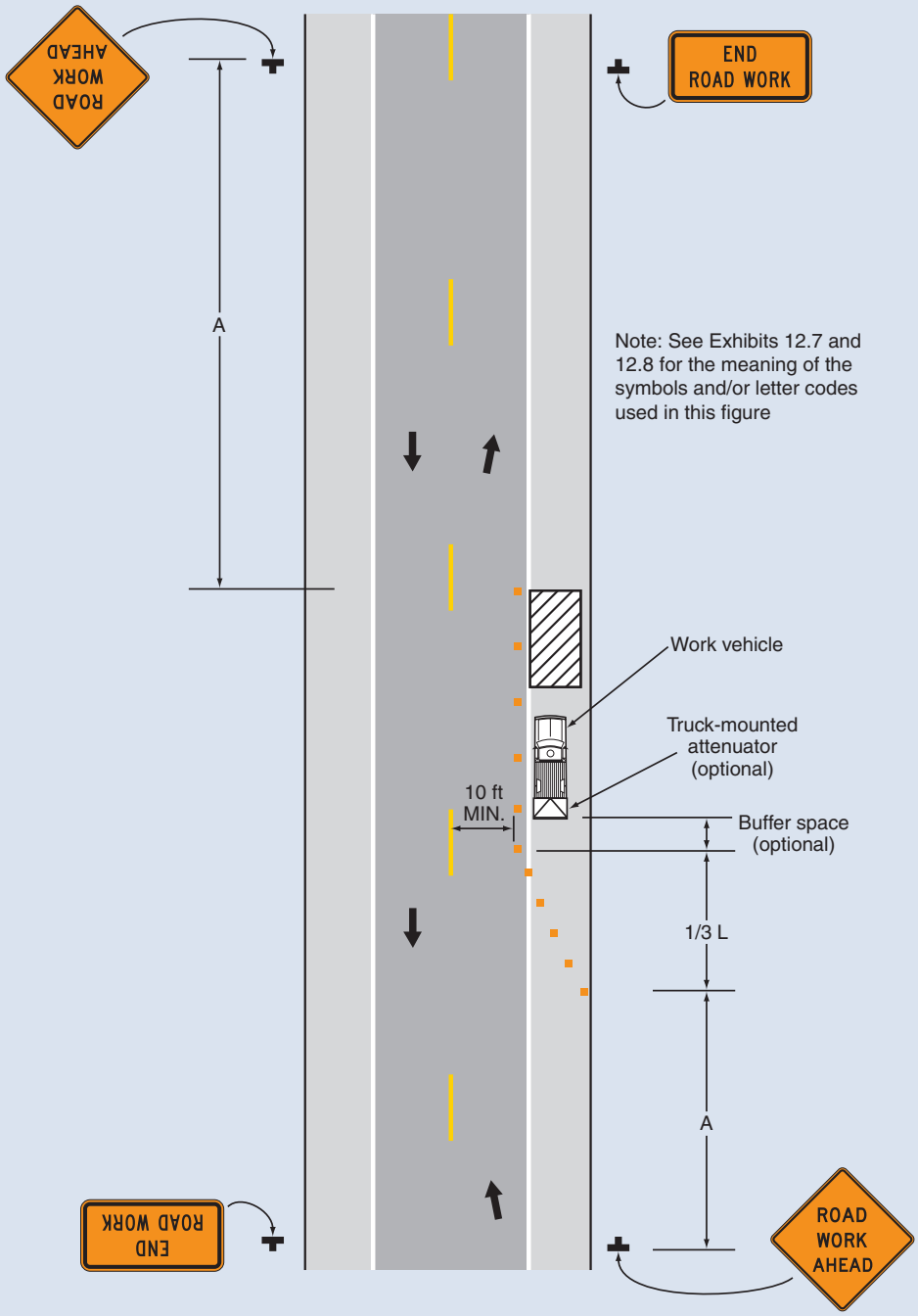
Source: MUTCD *Figure 6H-1*

Work on Shoulder with no encroachment – At least one advance warning sign shall be used if a paved shoulder eight feet or wider is closed. Channelizing devices shall also be used to provide the road user with advance warning to stay in the travel way. Vehicle hazard lights shall not be used in lieu of high intensity rotating, flashing, oscillating, or strobe lights. Vehicle mounted signs should not be obstructed by equipment, and arrow boards shall use the caution mode.



Source: MUTCD *Figure 6H-4*

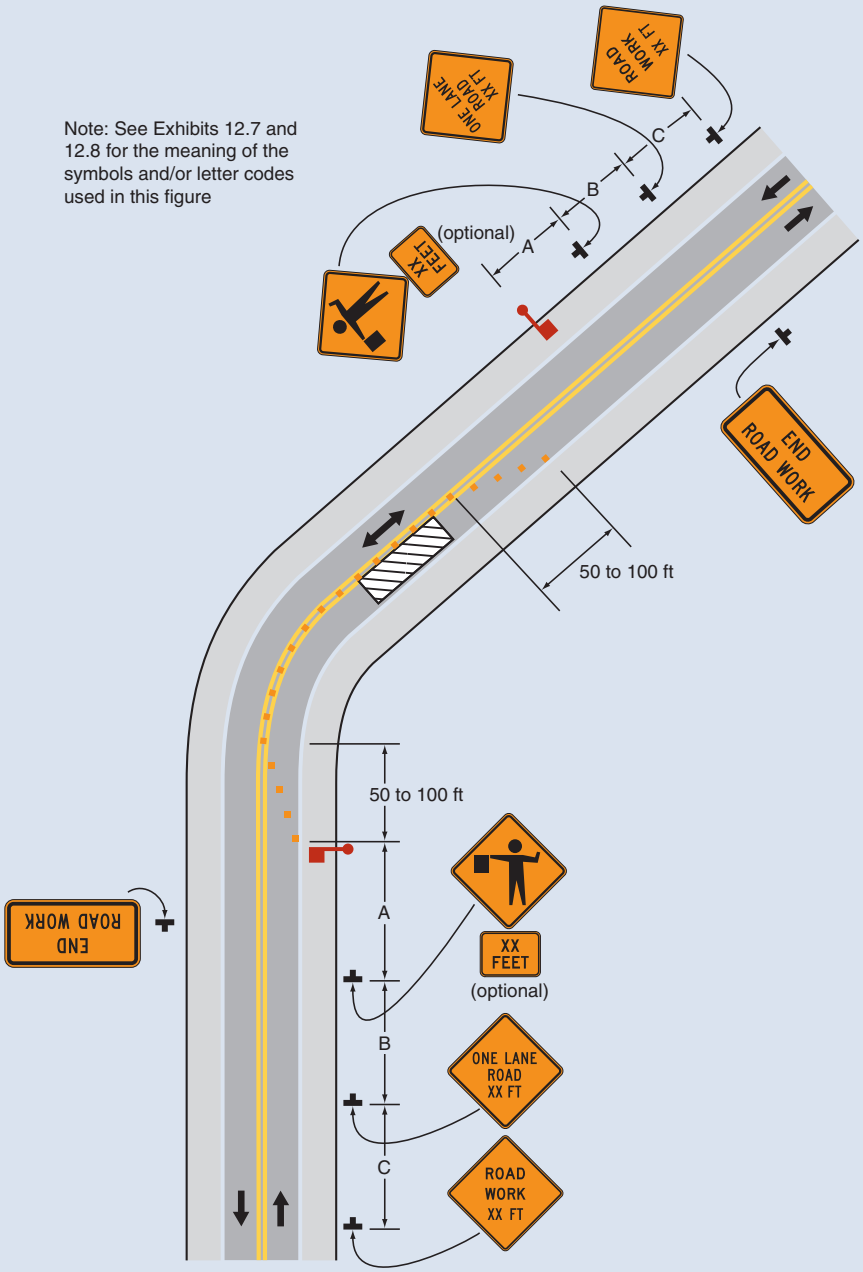
Work on Shoulder with minor encroachment – If the encroachment doesn't allow for at least a ten-foot travel way, then the lane should be closed. A nine-foot lane could be used in certain situations.



Source: MUTCD *Figure 6H-6*

Work within Traveled Way - One-Lane Closure on Two-Way Roadway –This involves lane closure for a limited distance, and the movements at each end of the closure need to be coordinated. This coordination can occur through the following methods:

Flagger Method – Flaggers located at both ends of closure, and are coordinated.

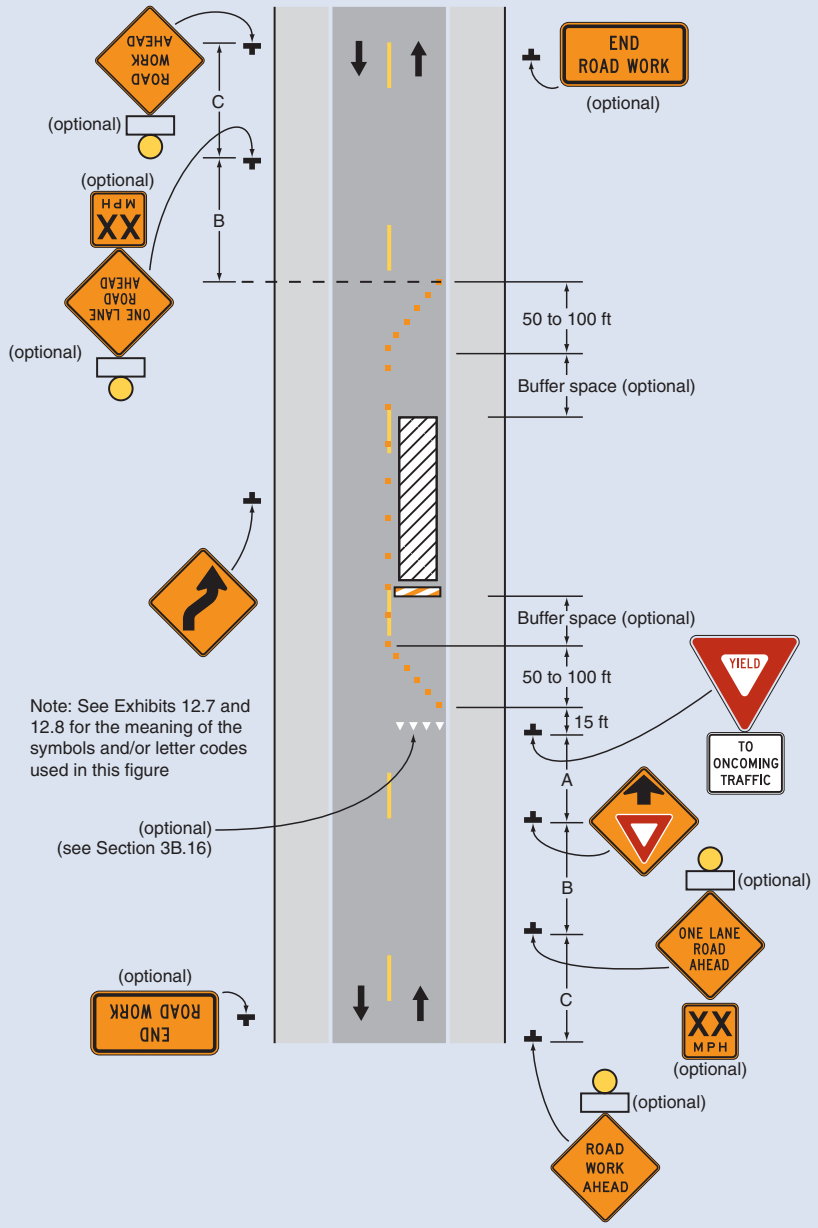


Source: MUTCD *Figure 6H-10*

Lane closure on a two-lane road with low traffic volumes

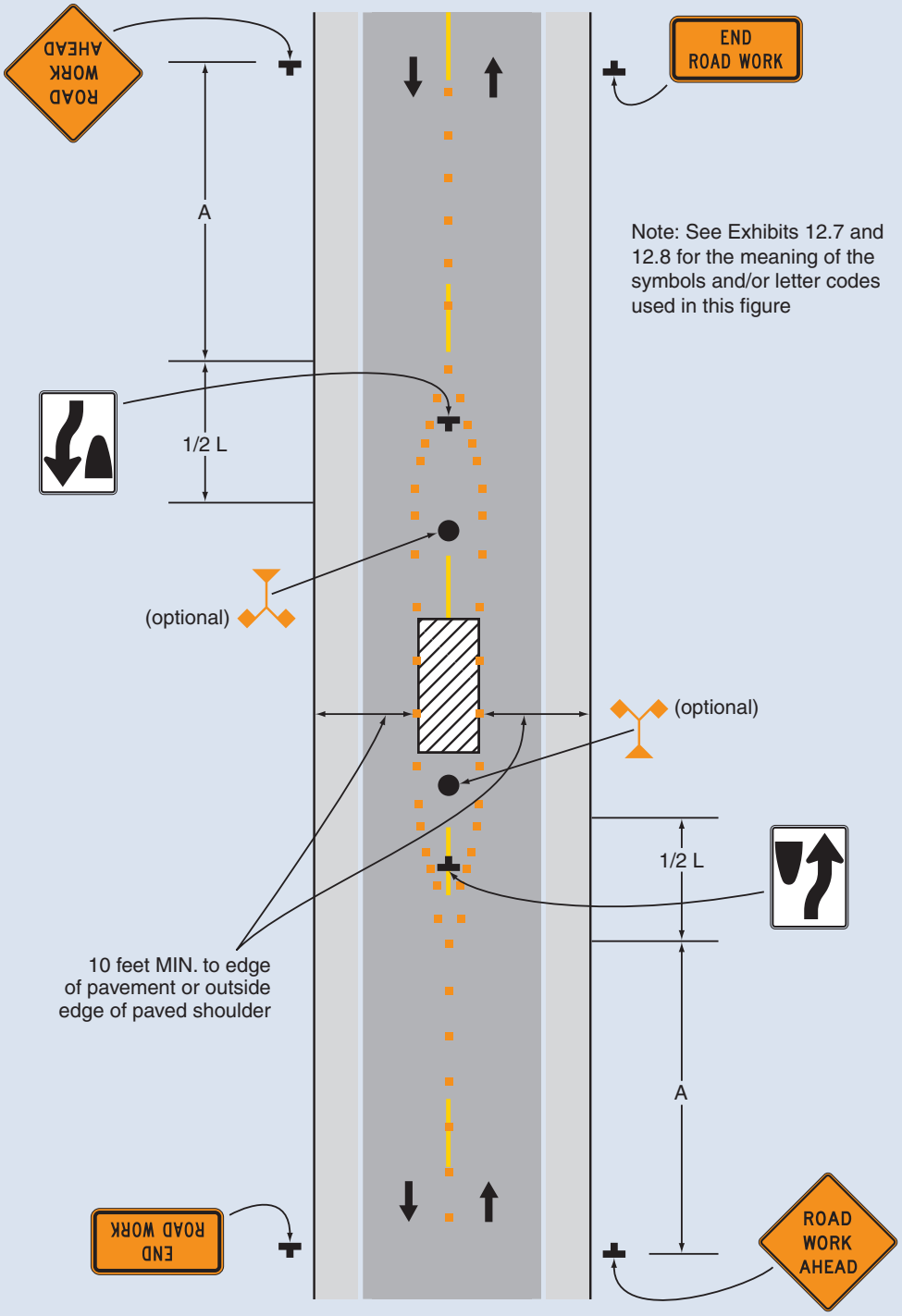
Flag Transfer Method – Vehicles at each end of closure are given a flag to signify the upcoming flagger that the lane is clear.

Stop or Yield Control – If sight distance permits, STOP or YIELD signs can be used to coordinate traffic through the single lane.



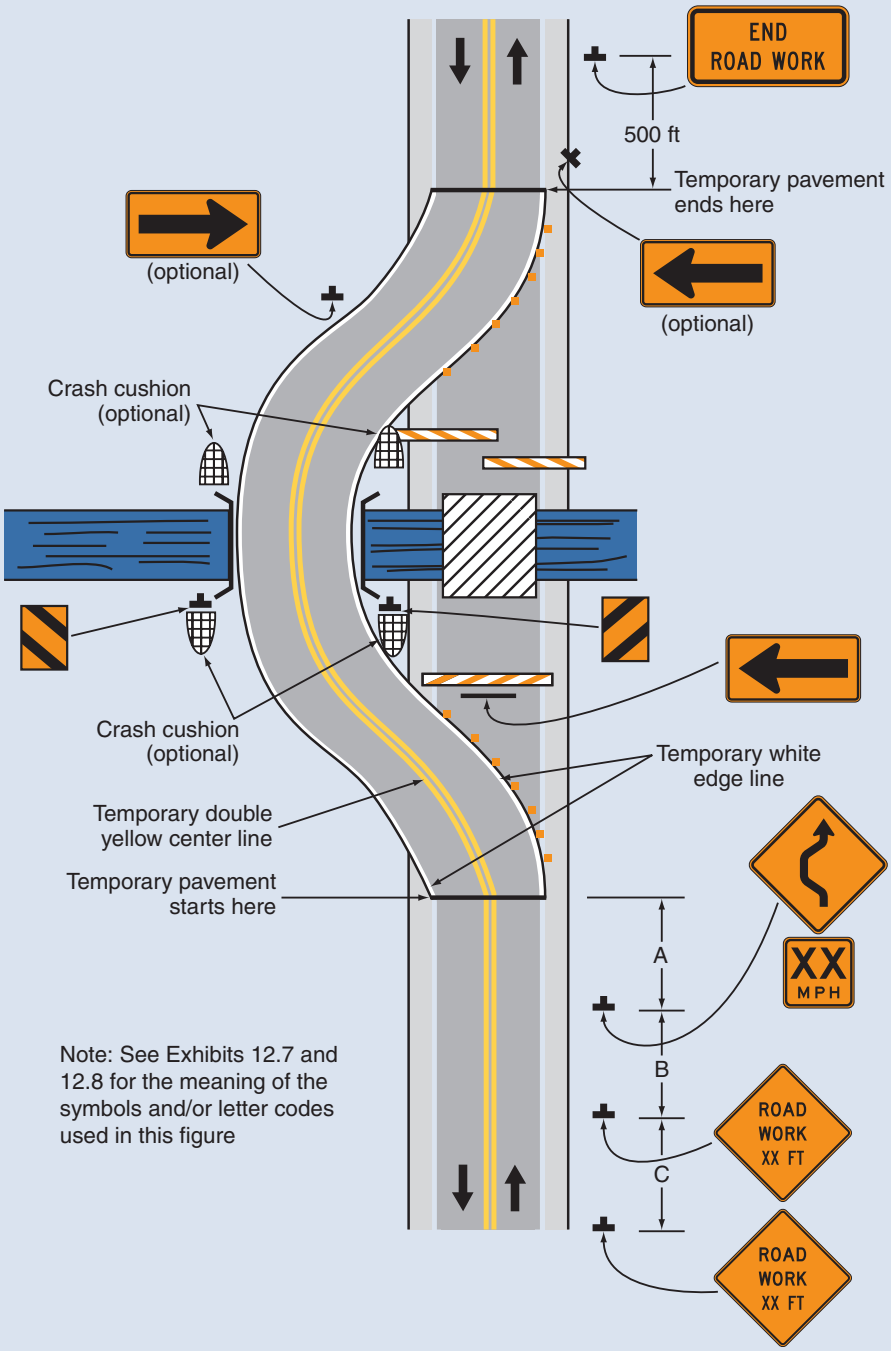
Source: MUTCD *Figure 6H-11*

Work in center of road – A minimum of 10-foot lanes shall be maintained around the work zone.



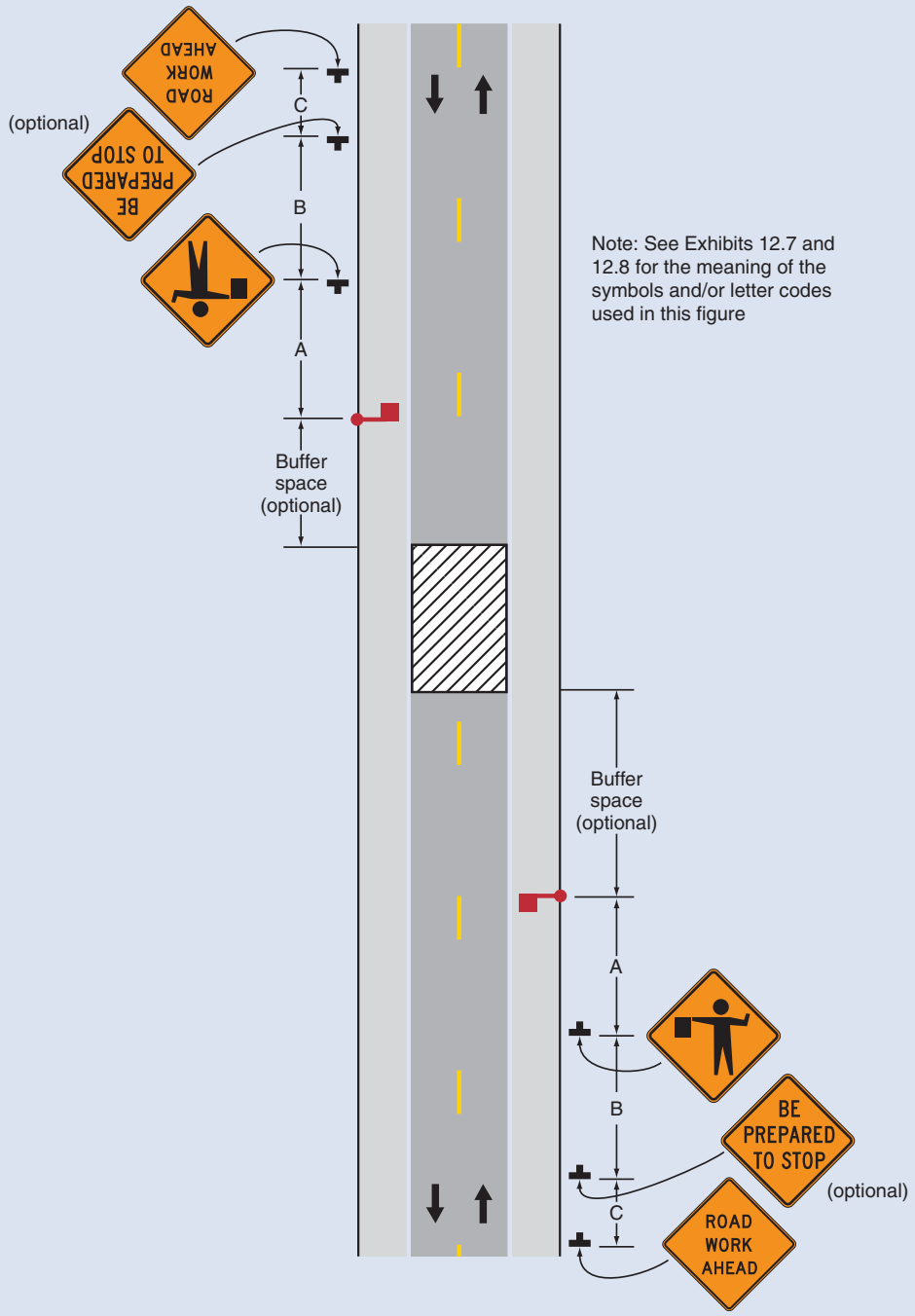
Source: MUTCD *Figure 6H-15*

Temporary Diversion – Temporary alignment used to divert road users around TTC zone. Pavement markings that do not apply shall be removed, and temporary barriers and end treatments shall be crashworthy.



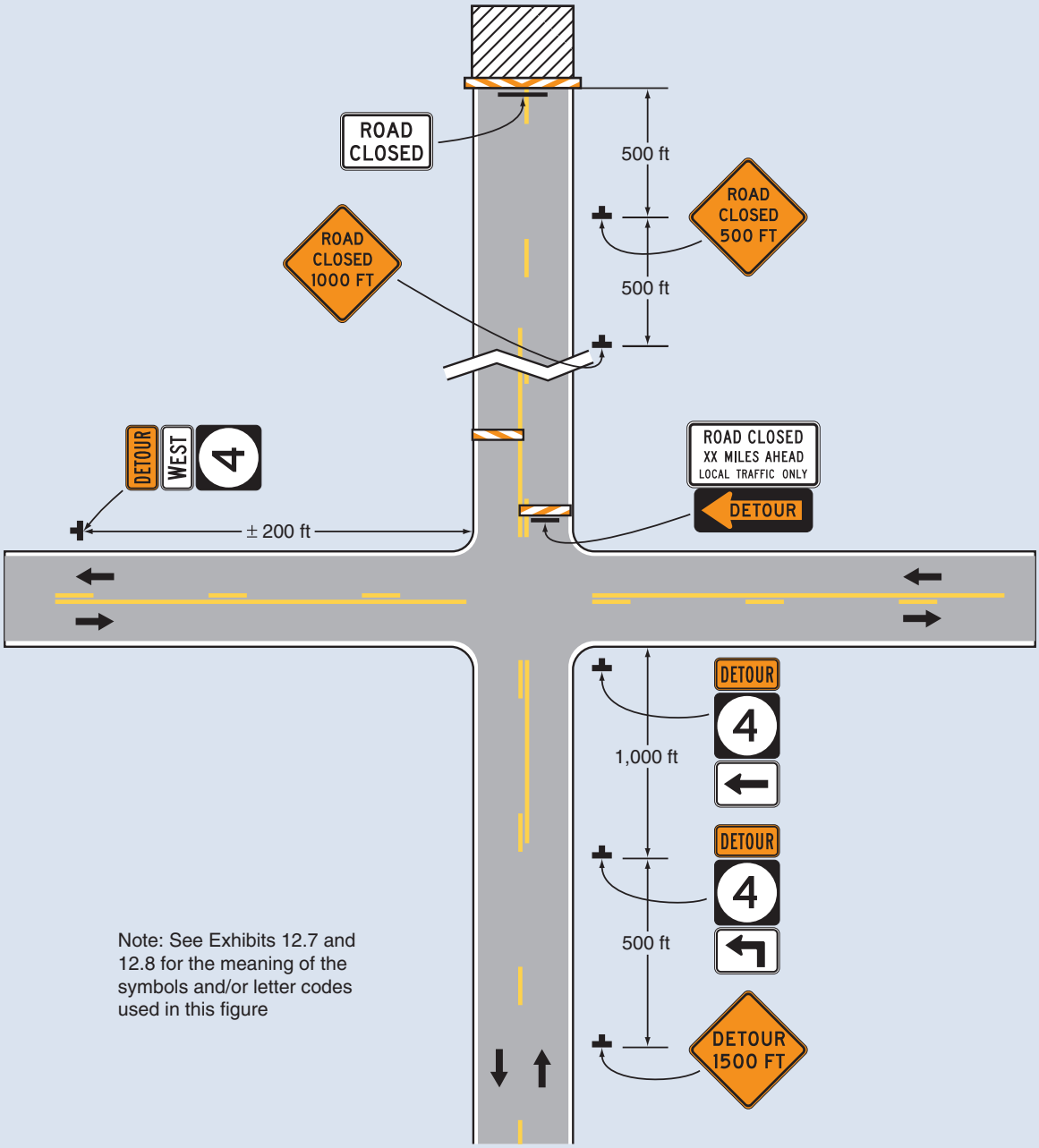
Source: MUTCD *Figure 6H-7*

Temporary Road Closure – Complete closure of the roadway. A flagger or other enforcement officer shall be used for this application.



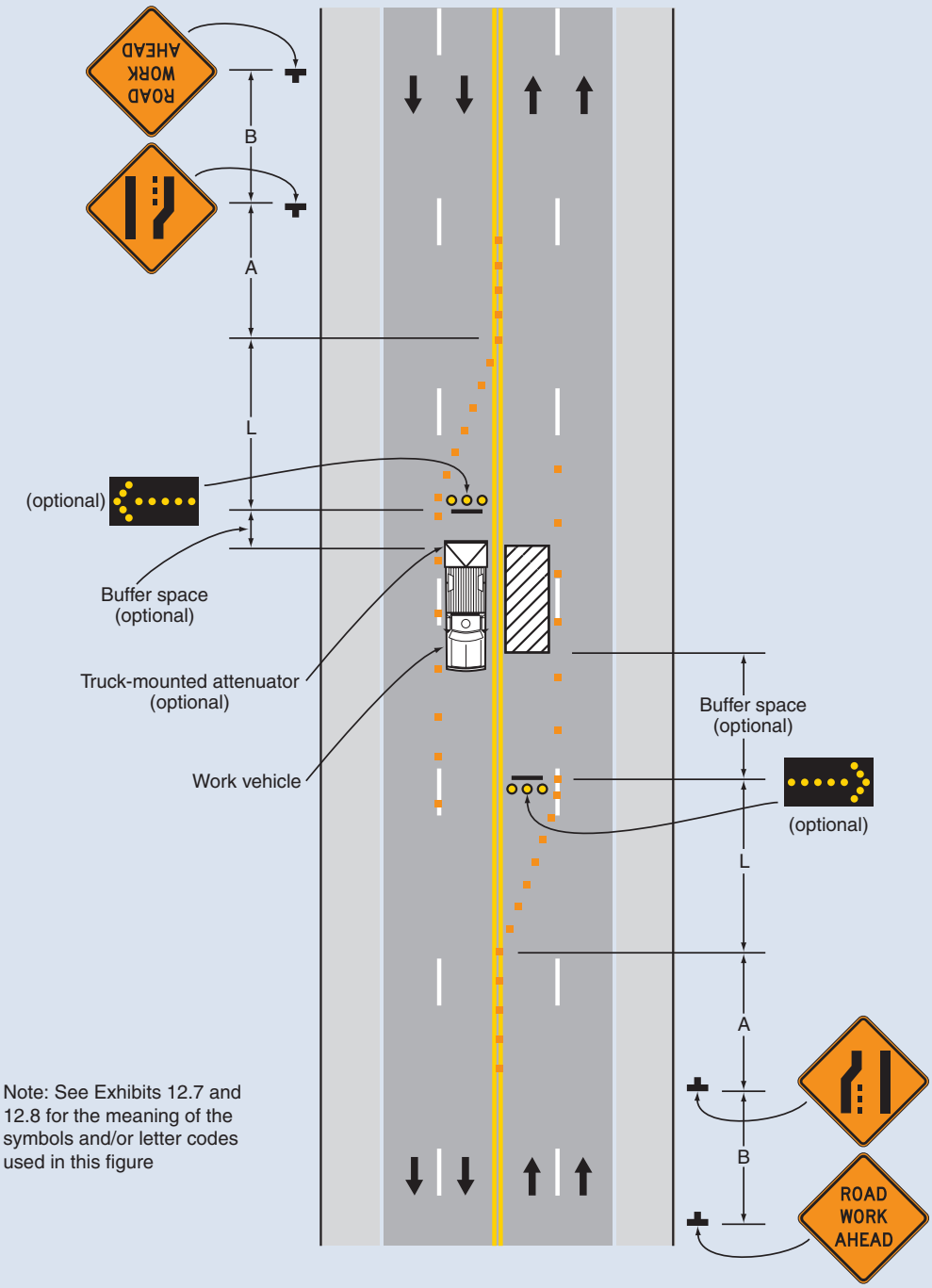
Source: MUTCD *Figure 6H-13*

Detour Route – Used to temporarily reroute roadway users around a TTC zone onto existing roadways. Detour routes should be clearly marked to allow the road users to safely traverse the route, and return to the original roadway.



Source: MUTCD *Figure 6H-8*

Closure on Multi-Lane Street – Additional signing may be needed then what is shown if there is a high speed limit or traffic volume.



Source: MUTCD *Figure 6H-30*

12.8. TTC DEVICES

The *MUTCD* defines traffic control devices as all signs, signals, markings, and other devices used to regulate, warn, or guide road users, placed on, over, or adjacent to a roadway open to public travel.

All traffic control devices used within TTC zones on a street, highway, or private road open to public travel shall comply with the applicable provisions of the *MUTCD*. This section summarizes the typical TTC devices utilized on military installations.

12.8.1. Signs

TTC zone signs convey both general and specific messages by means of words, symbols, and/or arrows and have the same three categories as all road user signs: regulatory, warning, and guide.

The colors for regulatory signs shall follow standards for other regulatory signs. Warning signs in TTC zones shall have a black legend and border on an orange background (except for the Grade Crossing Advance Warning, W10-1 sign) and except for signs that should have fluorescent yellow-green backgrounds. Colors for guide signs shall follow the standard colors identified in the *MUTCD*. Refer to Part 6 of the *MUTCD* for a comprehensive listing of signs, installation and location criteria, sign size, and maintenance requirements.

R11-4

Regulatory Sign

W20-1*

Warning Sign

M4-10

Guide Sign

12.8.2. Additional TTC Devices

Portable Changeable Message Sign – Can be used to display a variety of messages including information about an upcoming detour or road or lane closure. These shall only display traffic operational, regulatory, warning, or guidance information. Never use these for advertising messages.

Arrow Boards – Shall be a sign with a matrix of elements capable of either flashing or sequential displays.

Channelizing Devices – Used for delineation of traffic patterns, or to channelize pedestrians. These include drums; tubular markers; vertical panels; cones; and Type I, II, or III barricades.

Temporary Pavement markings – Can consist of temporary painted pavement markings or temporary raised pavement markers

Lighting Devices – Can be used to supplement retroreflectorized signs, barriers, and channelizing devices.

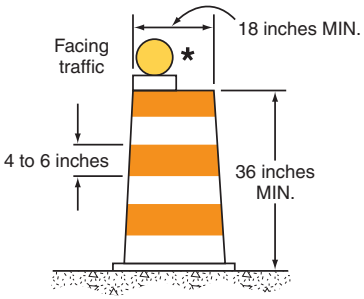
Floodlights – Can be used when night work is required. Floodlighting shall not produce a disabling glare condition for approaching road users, flaggers, or workers.

Warning Lights – Consist of Type A, B, C, and D and are portable, powered, yellow, lens-directed, enclosed lights. These are mounted on channelizing devices or signs in a manner that, if hit by an errant vehicle, they will not be likely to penetrate the windshield.

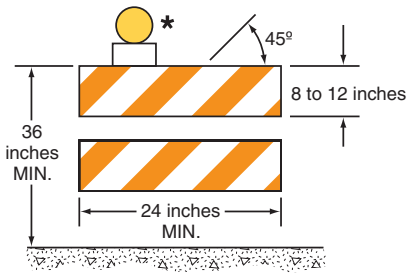
Temporary Traffic Control Signals – Can be used to control road user movement through TTC zones.

Temporary Traffic Barriers – Shall be supplemented with standard delineation for improved visibility if used for channelizing. Temporary traffic barriers and their end treatments shall be crashworthy.

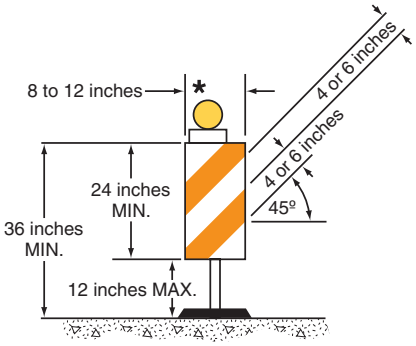
Crash Cushions – Shall be crashworthy and designed for each application to stop or redirect errant vehicles under prescribed conditions. They should be inspected periodically, and if damaged, shall be promptly repaired or replaced.



Drum



Type 2 Barricade



Vertical Panel

Temporary barrier, crash cushion, drums, and temporary pavement markings

12.9. FLAGGER CONSIDERATIONS

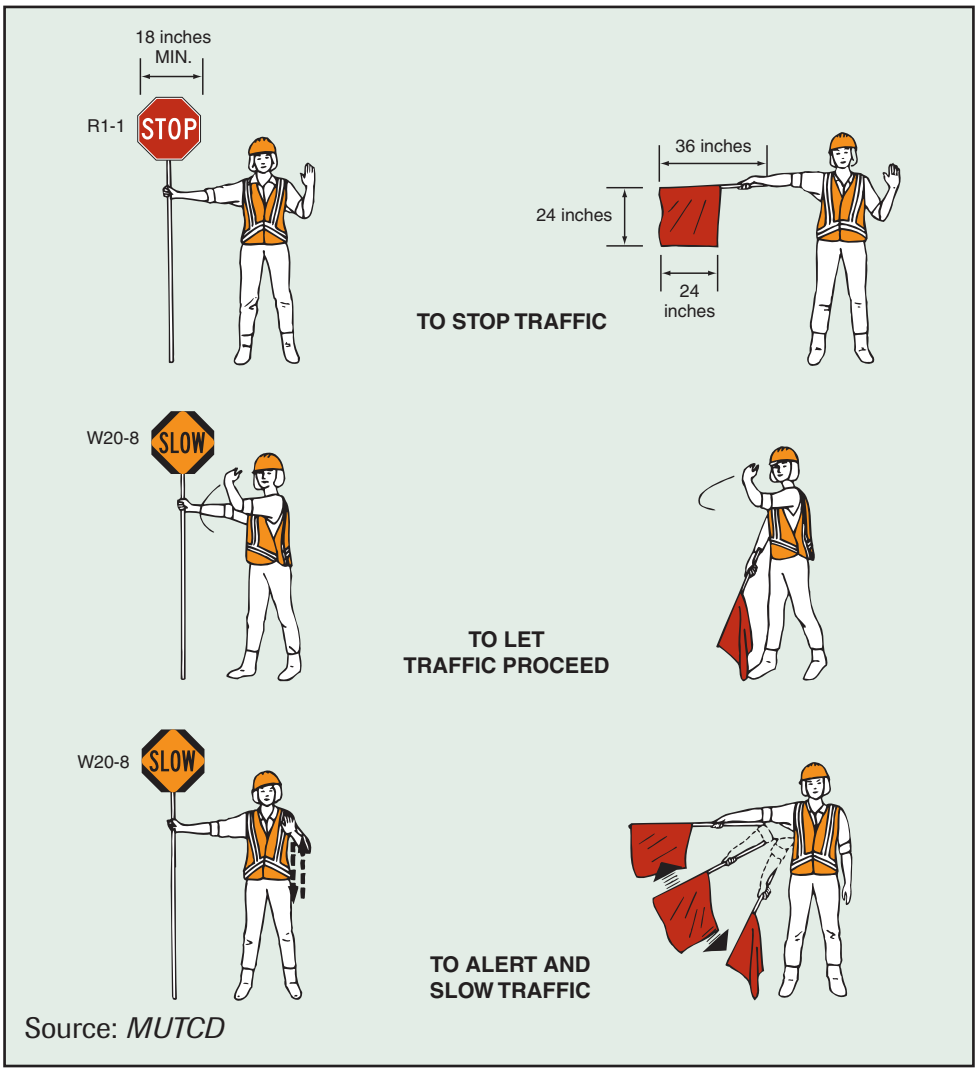
Daytime and nighttime flaggers shall wear high-visibility safety apparel (meets ANSI 107-2004, Class 2 or 3 risk exposures).

It is important that flaggers have the proper training and qualifications due to their responsibility for public safety and because they have the most exposure to vehicles than other roadway workers. Flaggers should have the ability to receive and communicate specific instructions clearly, to move and maneuver quickly from danger, to control signaling devices, to understand and apply safe traffic control practices, and to recognize dangerous traffic situations and warn workers in time to avoid injury.

12.9.1. Flagger Devices

The most common device used by flaggers is a Hand-Signaling Device, such as a STOP/SLOW paddle. When used at night, the paddle shall be retroreflectorized. The *MUTCD* Part 6 describes other less common automated devices, and the detailed procedures for safely controlling traffic. Exhibit 12.9 shows common flagger hand signals.

Exhibit 12.9: Flagger Hand Signals



Source: *MUTCD*

12.9.2. Flagger Stations

Flagger stations shall be located such that approaching road users will have sufficient stopping distance (see Section 12.4.3 for distance requirements based on speed and stopping sight distance). Except in emergency situations, flagger stations shall be preceded by an advance warning sign or signs and should be illuminated at night.

W20-7

W16-2P

12.10. WORKER SAFETY CONSIDERATIONS

The safety of the workers within the TTC zone is equally as important as maintaining safety to the travelling public. The workers are vulnerable due to their close proximity to roadway users traversing through a change in traffic patterns. The elements shown in Exhibit 12.10 should be considered in order to improve worker safety.

Exhibit 12.10: Worker Safety Elements

TRAINING	All workers should be trained on how to safely work next to motorized traffic.
TEMPORARY TRAFFIC BARRIERS	Should be placed along the work zone depending on factors such as lateral clearance or workers from adjacent traffic, speed of traffic, duration and type of operations, time of day and traffic volume.
SPEED REDUCTION	Reducing the speed of vehicular traffic, mainly through regulatory speed zoning, funneling, lane reduction, or the use of flaggers should be considered.
ACTIVITY AREA	Minimize exposure to risk by planning internal work area to minimize backing-up maneuvers of construction vehicles.
WORKER SAFETY PLANNING	A trained person should conduct a basic hazard assessment for worksite and job classifications required in the activity area.
SAFETY APPAREL	All workers, including emergency responders, who are exposed to traffic or work vehicles/construction equipment within the TTC zone shall wear high-visibility safety apparel that meets proper classification for day and night work.
ROAD CLOSURE	If a detour route is available, the road may be closed temporarily which will reduce worker vulnerability.
LIGHTING	For nighttime work, the TTC zone may be lighted.

Workers within an active work zone

12.11. PEDESTRIAN CONSIDERATIONS

If pedestrian traffic will be interrupted by a TTC zone, then adequate temporary pedestrian access and walkways shall be provided. This includes maintaining accessibility and detectability if it exists at the affected area. When planning for pedestrians in a TTC zone, consider the following:

- ✓ Pedestrians should not be led into conflicts with vehicles, equipment, and operations including vehicles moving through or around the worksite.
- ✓ Pedestrians should be provided with a comparable temporary pathway to the existing condition, including width of walkway.
- ✓ A smooth, continuous hard surface should be provided throughout the entire length of the temporary facility.
- ✓ If pedestrians with disabilities are expected, then blocked routes, alternate crossings and sign and signal information should be communicated through devices such as audible information devices, accessible pedestrian signals or barrier or channelizing devices that are detectable to the disabled.
- ✓ If channelization is used to delineate a pathway, a continuous detectable edging should be provided for the disabled.
- ✓ Signs mounted lower than 7 feet should not project into the pathway by more than 4 inches.

Temporary pedestrian accommodations

CHAPTER 13 – SPEED LIMITS

13.1. SPEED LIMIT BASICS 13-1
13.2. WHAT IS SPEED ZONING? 13-2
13.3. SPOT SPEED STUDIES 13-3
13.4. SPEED LIMIT SIGNS 13-4
13.5. TRANSITIONAL SPEED LIMIT REDUCTIONS 13-6
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13.7. OTHER SPEED MANAGEMENT TECHNIQUES 13-8

Speed limit signs are one of the most common types of traffic signs, but research shows that speed limits have little effect on the actual speed that motorists drive their vehicles. Moreover, the presence of an inappropriate speed limit increases the probability of crashes.

13.1. SPEED LIMIT BASICS

KEY POINT

Research shows that the safest speed limit approximates the 85th-percentile speed.

Most motorists select a speed that will allow them to arrive at their destination in the shortest time possible but without endangering themselves and others. As drivers, we select our speed by considering the roadway width and alignment, presence of intersections and driveways, roadside conditions, parked vehicles, pedestrian traffic, mix and density of vehicular traffic, weather, and other conditions. However, drivers pay almost no attention to posted speed limits, and studies have repeatedly proven that raising or lowering the speed limit has little effect on most drivers. All states have a law that requires a driver to operate his or her vehicle at a speed that is reasonable and prudent for existing conditions, regardless of the presence of a posted speed limit.

Speed differences between vehicles increase crash potential, and the greater the speed differences, the greater the damage when vehicles collide with one another. In a perfect world, everybody would drive at exactly the same speed at any given location.

Research shows that the safest speed limit approximates the 85th-percentile speed, which is the speed that 85 percent of the free-flowing vehicles are traveling at or below. In reality, it is necessary to round the speed limit to the nearest 5-mph multiple at or below the 85th-percentile speed.

Studies repeatedly show that establishing the speed limit below the 85th-percentile speed increases the number of crashes. The cause of this increase in crashes may be the direct result of a few drivers who actually attempt to obey the speed limit, which in turn frustrates other drivers, causes traffic queues and congestion, and contributes to increased tailgating and passing.

The basic reason to have a posted speed limit is to encourage speed uniformity and to provide a means to prosecute the few drivers that travel at excessive speeds and jeopardize the safety of others.

Speed limit sign example

13.2. WHAT IS SPEED ZONING?

KEY POINT

Consult your state's vehicle code to ensure that all posted speed limits are enforceable.

Speed zoning is the process used to determine the proper speed limit. Every state uses the 85th-percentile speed as a major factor in selecting the appropriate speed limit; however, other factors such as roadside conditions, crash experience, and design speed are often considered.

All states have at least one statutory speed limit that may or may not require speed limit signs to make them enforceable. For example, a state may have statutory speed limits such as:

- ✓ 25 mph in urban business districts.
- ✓ 35 mph in residential districts.
- ✓ 70 mph on rural freeways.
- ✓ 55 mph on all other roadways.

However, agencies generally may revise these speed limits if they perform traffic-engineering studies that document that the speed limit should be higher or lower than the statutory provisions. Therefore, it is essential that installations know the specifics for their state to ensure that all posted speed limits are enforceable under your state's vehicle code. For example, you should know:

- ✓ Statutory speed limits.
- ✓ Required engineering and traffic studies.
- ✓ Maximum spacing intervals for speed limit signs.

Information regarding speed laws for your state is available via the Massachusetts Institute of Technology at http://www.mit.edu/~jfc/laws.html. Generally, most states require engineering and traffic studies to determine the following:

- ✓ Prevailing vehicle speeds.
- ✓ Physical features of the roadway.
- ✓ Crash locations and crash rates.

Any special safety concerns that may not be readily apparent to drivers; for example, limited sight distance.

DEFINITIONS

Advisory speed – A recommended safe speed at a given location such as a curve, where the speed is shown on a warning sign.

85th-percentile speed – The numerical speed at which 85 percent of the sampling of free-flowing vehicles are traveling at or below. This speed should be determined by conducting a spot speed study during ideal conditions; (i.e., daylight, dry roads, straight sections, and so on).

Posted speed limit – The numerical speed limit noted on regulatory signs placed along the roadway to which it applies.

Speed zoning – A structured process used to determine the proper speed limit, usually based on an engineering and traffic study.

Statutory speed limit – A speed limit established by law that applies to a specific class or category of road; such as, rural freeway, residential streets, business district, and so on, and in some cases does not even require speed limit signs to make it legally enforceable. Statutory speed limits are specific to each state.

13.3. SPOT SPEED STUDIES

KEY POINT

Use a spot speed study to determine the 85th-percentile speed.

Spot speed studies determine the speed distribution of vehicular traffic at a specific location. The most common method to determine vehicle speeds is with a radar speed gun.

To establish a regulatory speed limit, perform the spot speed studies on straight sections of roadway, away from intersections where congestion may slow traffic. Design the study to avoid influencing the speeds; for example, technicians with radar guns should not be visible to passing motorists, if possible. Perform speed studies under ideal weather, road and traffic conditions, and without the presence of police vehicles or any restriction that could influence speeds.

As a rule-of-thumb, spot speed studies should include a minimum of 100 free-flowing vehicles; however, if traffic volumes are very light you may reduce the sample to about 50 vehicles or a 2-hour sample. If there is a platoon of traffic, record only the speed of the first vehicle in the platoon since other vehicles are not free-flowing vehicles.

Use a data sheet, as shown in Exhibit 13.1, to annotate the spot speed information. One advantage of recording the speeds of exactly 100 vehicles is the simplicity of determining the 85th-percentile speed. By examination, the 85th-percentile speed in Exhibit 13.1 is between 35 and 36 mph because 83 vehicles exceeded 35 mph and 90 vehicles exceeded 36 mph.

Exhibit 13.1: Radar Spot Speed Data Example

SPEED (MPH)	RECORD	NO.	CUMULATIVE TOTAL
23			
24			
25	//	2	2
26			
27	//	2	4
28	////	4	8
29	//	2	10
30	~~////~~ ~~////~~ //	12	22
31	~~////~~	5	27
32	~~////~~ ~~////~~	10	37
33	~~////~~ ~~////~~ ~~////~~ ////	19	56
34	~~////~~ ~~////~~ ~~////~~	15	71
35	~~////~~ ~~////~~ //	12	83*
36	~~////~~ //	7	90*
37	~~////~~	5	95
38	///	3	98
39			
40	//	2	100
41			
42			
TOTALS		100	

** Note: The cumulative total column indicates that the 85th-percentile speed is between 35 and 36 mph.*

The *MUTCD* indicates that the speed limit should be within 5 mph of the 85th-percentile speed. However, some states make provisions for reductions below the 85th-percentile speed if crash rates are abnormally high or if special safety concerns exist that may not be readily apparent to drivers. For example, drivers may be unaware of limited stopping sight distance or restricted sight distance from a side road.

KEY POINT

A 25 mph speed limit is the lowest speed limit that is enforceable, except in a school zone.

Although installation personnel can collect spot speed data, only a qualified traffic engineer can actually set speed limits based on analyses of the data and through personal observations. If there are no extenuating circumstances, establish the speed limit to the nearest 5-mph increment at or below the 85th-percentile speed. For our example in Exhibit 13.1, establish the speed limit at 35 mph.

Speed limits should generally apply to all vehicles, but under unusual situations, it is possible to establish a separate speed limit for trucks or large vehicles. However, as noted, the perfect scenario is to have all vehicles travel at the same speed.

Some locations such as ECFs do not lend themselves to spot speed studies. However, based on engineering and traffic studies at many installations, it was determined that a 25-mph speed limit is appropriate in both directions within an ECF.

Although many installations desire to post speed limits at speeds less than 25 mph due to safety and security concerns, the consensus of traffic engineers is that lower speed limits do not improve safety. In addition, many state vehicle codes do not permit these limits, thus making such speed limits unenforceable. Therefore, a 25-mph speed limit is the lowest speed limit that should be used.

13.4. SPEED LIMIT SIGNS

The standard Speed Limit (R2-1) sign is 24 by 30 inches. On roads with more than one travel lane in the same direction, it is beneficial to use a larger size such as 30 by 36 inches. You may also use larger sizes for additional emphasis at other locations.

Place speed limit signs at every location where the speed limit changes, and at intermediate locations as necessary to comply with any state requirements. Additional signs must be installed beyond major intersections and at other locations where it is necessary to remind the road users of the applicable speed limit. However, try to avoid placing a sign immediately in advance of a curve or turn. SDDCTEA Pamphlet 55-14 section 2.2.5 has additional information regarding the use of speed limit signs. SDDCTEA Pamphlet 55-14 section 2.2.5 has additional information regarding the use of black on white speed limit signs; section 2.3.2 has information on the use of black on yellow advisory speed signs, and appropriate uses for each.

The *MUTCD* does not contain any maximum spacing requirements for Speed Limit signs, but many states have unique requirements that must be followed in order to enforce speed limits. In the absence of any specific state spacing requirements, installations are encouraged to use maximum 1-mile spacing for speed limits of 35 mph or lower, and maximum 3-mile spacing for higher speed limits.

There may often be the desire to post lower speed limits for certain types of vehicles. These vehicle types may be trucks or any other slow-moving heavy vehicles. When this different speed limit is desired, use the Truck Speed Limit Plaque (R2-2P) to display the lower speed limit. This plaque would be mounted beneath a regular speed limit sign displaying the speed limit for the remainder of traffic. If trucks are not the appropriate vehicle to which the lower speed limit would pertain, the legend can be modified as appropriate.

Most states require advance signs to inform drivers of speed reductions, especially if the reduction is over 10 mph. The type of sign may vary from state to state, but the trend is to use the new Speed Reduction (W3-5) sign as shown below. Therefore, it is important to know the specific requirements for your state.

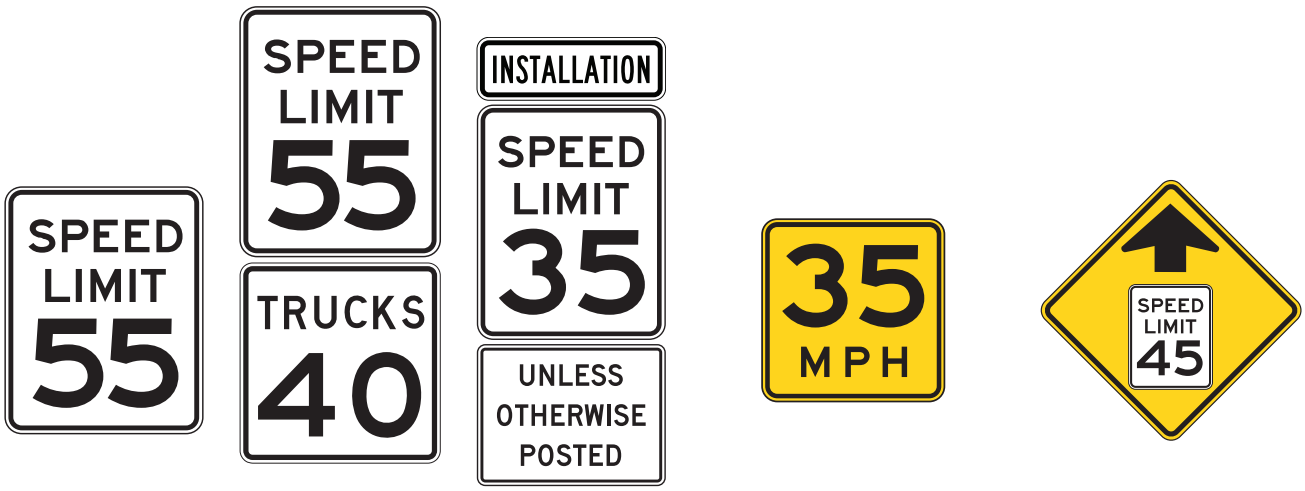
Many installations post blanket speed limits. This is permitted based on the 2009 *MUTCD*. This could either be posted at the entrance of the installation after the ECF area, or at more localized areas such as at the entrance to a housing area. If this type of speed limit is used, it should be signed as shown below:

✓ One of the following:
- R2-5iP-TEA, INSTALLATION, as shown in SDDCTEA Pamphlet 55-14
- R2-5cP, RESIDENTIAL

✓ R2-1, SPEED LIMIT XX

✓ R2-5P, UNLESS OTHERWISE POSTED

SPEED LIMIT | **ADVISORY SPEED** | **SPEED REDUCTION**



R2-1 | R2-1 and R2-2p | R2-5iP, R2-1, R2-5P | W13-1 | W3-5

Common speed-related signs

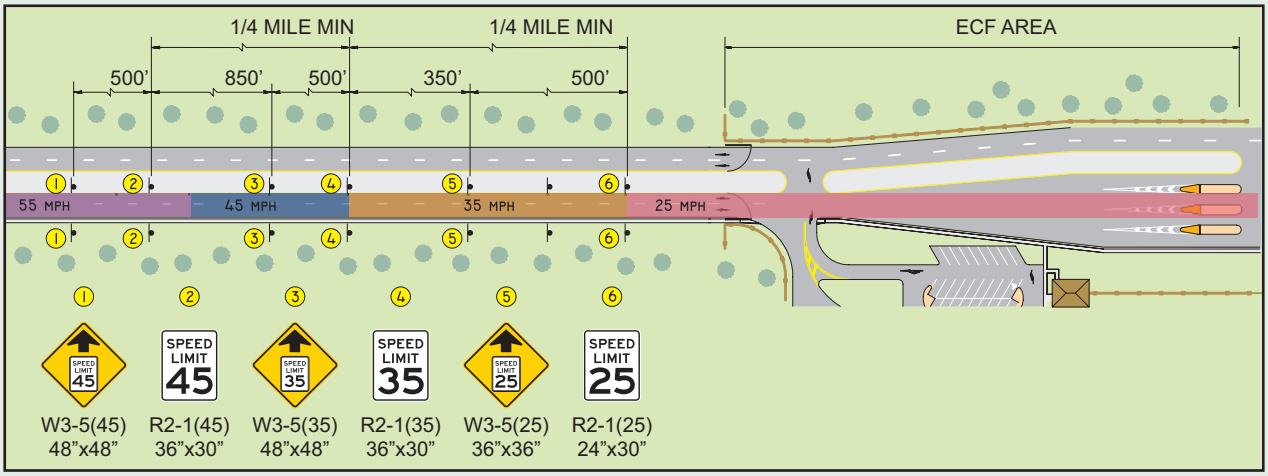
13.5. TRANSITIONAL SPEED LIMIT REDUCTIONS

Often there is the need to change the speed limit on a roadway. Often, the speed limit changes by 10 miles per hour. Sometimes, however, there is the need to transition by speed limits greater than 10 miles per hour. When the speed limit transition is no more than 10 miles per hour, no additional signing is required. If the difference in speed limits is greater than 10 miles per hour, additional transitional signing should be used.

- ✓ Speed reductions of greater than 10 miles per hour should be avoided.
- ✓ Speed zones of less than ¼ mile should be avoided.

A frequent example of the need to reduce speed limits by more than 10 miles per hour is approaching ECF areas. An installation may have a long approach corridor posted at a high speed limit, 55 miles per hour for example, and have an ECF posted at 25 miles per hour. In this case, a transitional speed reduction from 55 mph to 25 mph should occur in three zones (55-45; 45-35; 35-25) each being no less in length than ¼ mile (3/4 mile total). Each zone should be introduced with a W3-5 sign ideally placed at least 500 feet in advance of the zone.

TRANSITIONAL SPEED LIMIT REDUCTIONS



13.6. ADVISORY SPEEDS

KEY POINT

An advisory speed is a recommended safe speed for a specific condition.

An advisory speed is a recommended safe speed. However, this speed is relative, since a speed that is safe or comfortable for a driver of a car may not be safe or comfortable for a truck driver; and the safe or comfortable speed for a driver of a sports car may not be safe or comfortable for the driver of a family sedan. Therefore, an advisory speed is only a recommendation.

The most common application of an advisory speed is with the Advisory Speed (W13-1) plaque installed below the Turn (W1-1) sign or Curve (W1-2) sign (shown below), but you may install a W13-1 plaque below any warning sign. Another option for displaying warning speeds on Turn or Curve signs is to include it on the actual Turn or Curve sign legend (W1-1a).

If a regulatory speed limit, as displayed by black and white signs, is not appropriate at a turn or curve, the appropriate advisory speed may be determined from the 85th-percentile speed on the curve. The advisory speed should be the nearest multiple of 5 mph that is at or below the 85th-percentile speed.

On the recommendation of a qualified traffic engineer, advisory speed plaques may be used at other locations such as below intersection signs like the Cross Road (W2-1) sign or the Side Road (W2-2) sign, or whenever the engineer determines that there may be a limited sight distance problem.

Regardless of the application or methodology, do not use an advisory speed unless it is at least 5 mph less than the posted speed limit or the statutory speed limit.

W13-1 and W1-1

Turn sign with an Advisory Speed plaque

W1-2

Curve sign

W1-1a

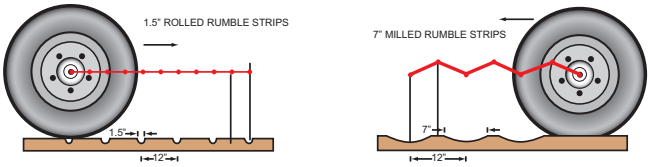
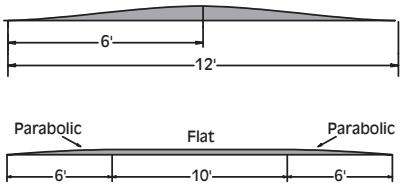
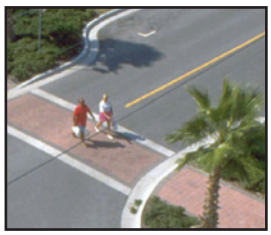
Combination Turn/Advisory Speed Sign

13.7. OTHER SPEED MANAGEMENT TECHNIQUES

Exhibit 13.2 shows several applications which will typically reduce speeds.

However, the best approach is to design roads for the intended speed limit. For example, if there will be a lot of pedestrian activity, design the road for a 25-mph speed limit rather than a 55-mph speed limit. Narrow roads and roads with curves tend to reduce speeds.

Exhibit 13.2: Speed Management Techniques

RUMBLE STRIPS.	
SPEED HUMPS AND RAISED CROSSWALKS.	
TEXTURED CROSSWALKS.	
ELECTRONIC SPEED WARNING SIGNS; I.E., "YOUR SPEED IS 49 MPH."	
FLASHING WARNING DEVICES ON WARNING SIGNS.	

CHAPTER 14 – TRAFFIC CALMING

14.1. TOP FIVE RECOMMENDED TRAFFIC CALMING DEVICES 14-1

14.2. MULTI-WAY STOP CONTROL. 14-2

14.3. SPEED BUMPS VS. SPEED HUMPS. 14-3

14.4. SPEED HUMP APPLICATIONS 14-4

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14.6. TRAFFIC CALMING PLANNING AND DESIGN CONSIDERATIONS 14-17

14.7. LEGAL ISSUES 14-17

KEY POINT

Traffic calming increases vehicle and pedestrian safety by reducing vehicle speeds.

Traffic calming is the use of physical measures to address speeding and high-volume cut-through traffic on neighborhood streets.

Speeding and cut-through traffic can create an atmosphere in which non-motorists are intimidated, or even endangered, by motor vehicle traffic. By addressing high speeds and cut-through volumes, traffic calming can improve both the real and perceived safety of pedestrians and bicyclists, and improve the quality of life within a neighborhood.

Generally, traffic calming measures are not appropriate on higher speed and higher volume streets such as arterial roadways. Traffic calming measures may be appropriate on the following roadway types:

- ✓ Local residential streets
- ✓ Collector streets with predominantly residential land uses
- ✓ Arterial roads within downtown districts or commercial areas (with posted speeds of 40 mph or less)

Bulb-out example

14.1. TOP FIVE RECOMMENDED TRAFFIC CALMING DEVICES

Speed humps – low cost and effective at reducing vehicle speeds.

Roundabouts – used to reduce vehicle conflicts at intersections with balanced approach volumes. They can be aesthetically pleasing, but are costly.

Raised crosswalks – elevated crosswalks that bring added attention to mid-block pedestrian crossings. They are also effective at reducing vehicle speeds. Often these devices are combined with bulb-outs to enhance pedestrian crossings.

On-street parking – reduces vehicle speeds in residential areas by psychologically narrowing the roadway. When used for traffic calming, it is important that roadway width and intersection sight distance requirements are satisfied. On-street parking on high volume, high-speed roadways can have a negative effect.

Diverters – devices that partially or completely prohibit traffic movements. They are excellent for eliminating residential "cut-through" movements. However, diverters also adversely impact emergency vehicle access and the access needs of local residents.

TRAFFIC CALMING OBJECTIVES INCLUDE:

- ✓ Achieving lower speeds for motor vehicles
- ✓ Reducing collision frequency and severity
- ✓ Increasing the safety and the perception of safety for non-motorized users
- ✓ Reducing the need for police enforcement
- ✓ Enhancing the street environment (e.g., street scaping)
- ✓ Increasing access for all modes of transportation (motor vehicles, bicycles, pedestrians, etc.)
- ✓ Reducing cut-through motor vehicle traffic

14.2. MULTI-WAY STOP CONTROL

KEY POINT

Multi-way stop control should never be used to reduce vehicle speeds.

A common request made by the general public is to use multi-way stop control as a means of reducing vehicle speeds. The *MUTCD* states that STOP signs should not be used for speed control. The decision to install multi-way stop control should be based on an engineering study. The following problems may occur if multi-way stop control is used where not warranted:

- ✓ Traffic will rarely come to a full stop.
- ✓ Motorists will increase their speed between STOP signs to make up for lost time.
- ✓ Residents will gain a false sense of security. The unwarranted control breeds disrespect for other multi-way stop-controlled intersections that are warranted.

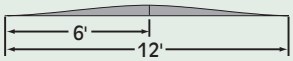
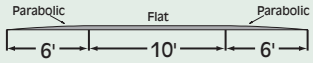
When implemented after a proper engineering study, multi-way stop control is an excellent tool to reduce right-angle crashes, but is not an effective tool at reducing vehicle speeds along a corridor.

Multi-way stop control example

14.3. SPEED BUMPS VS. SPEED HUMPS

Exhibit 14.1 identifies reasons why speed humps are preferred over speed bumps.

Exhibit 14.1: Speed Bumps vs. Speed Humps

TYPE OF DEVICE	SPEED BUMP	SPEED HUMP (WATTS PROFILE)	SPEED HUMP (SEMINOLE PROFILE)
			
SIZE	✓ 1- to 3-feet long ✓ 3- to 6-inches high	✓ 12-feet long ✓ 3- to 4-inches high	✓ 22-feet long ✓ 3- to 4-inches high ✓ Also called speed tables
APPLICATION	✓ NOT RECOMMENDED ✓ Prohibited on Army installations	✓ Recommended only for local streets having an ADT of less than 3,500 vehicles, and a speed limit of 30 mph or less ✓ Not recommended for major emergency service routes	✓ Appropriate for streets with ADT volumes of up to 6,500 vehicles ✓ Many jurisdictions also permit the use of Seminole speed humps on emergency response routes
DESIGN SPEEDS	✓ NOT RECOMMENDED ✓ At low speeds, vehicle occupants feel a jolt ✓ At high speeds some vehicles can traverse speed bumps easily since the vehicle's suspension quickly absorbs the impact	✓ Designed to slow vehicles to 15-20 mph at each hump and 25-30 mph in between properly spaced humps ✓ Smoother to traverse when traveling at lower speeds than at higher speeds	✓ Because of its gentler profile, the Seminole speed hump has a design speed of 25-30 mph at the hump, and approximately 35 mph in between humps ✓ Smoother to traverse when traveling at lower speeds than at higher speeds
SPEED REDUCTION	✓ Dependent upon vehicle type and speed	✓ Reduces vehicle speeds by about 8 mph in the vicinity of humps	✓ Reduces vehicle speeds by about 6.5 mph ✓ Studies show that vehicle speeds at the hump and in between the humps are not significantly different
VOLUME REDUCTION	✓ Unknown	✓ Volumes are reduced, on average, by about 18%	✓ Volumes are reduced, on average, by about 12%

Note: Army Regulation 420-1 Section 2-17 states: "Hazardous features such as transverse ridges, speed bumps, or dips on pavement surfaces will not be installed or maintained as a means of controlling or reducing the speed of traffic." This regulation applies to speed bumps on Army installations. Speed humps can still be used.

14.4. SPEED HUMP APPLICATIONS

As detailed in Exhibit 14.2, there are several special considerations for speed hump applications.

Exhibit 14.2: Special Considerations for Speed Hump Applications

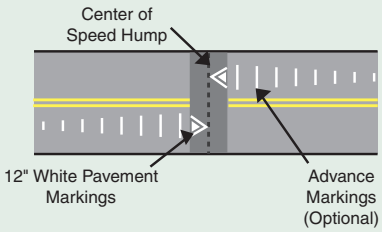
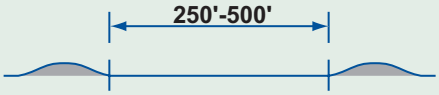
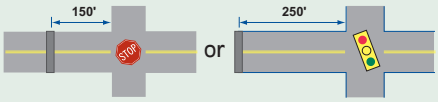
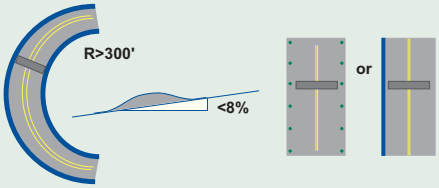
SIGNING 	✓ The SPEED HUMP (W17-1) sign should be used to give warning of a vertical deflection in the roadway that is designed to limit the speed of traffic. If used, the SPEED HUMP sign should be supplemented by an Advisory Speed plaque (W13-1). If a series of speed humps exists in close proximity, an Advisory Speed plaque may be eliminated on all but the first SPEED HUMP sign in the series.
PAVEMENT MARKINGS  	✓ Speed hump markings consist of 12-inch white markings as illustrated. Two other allowable configurations exist as shown in the *MUTCD*. Advanced speed hump markings, which shall be white, may be used in advance of a speed hump where added visibility is desired or where deflection is not expected.
NUMBER AND SPACING  	✓ A single hump will act as point speed control. To reduce speeds along an extended section of street, a series of humps is usually needed. Humps should be placed 250 to 500 feet apart. One study shows that placing speed humps at intervals of 275 feet resulted in 85th-percentile speeds of 25 mph; intervals of 550 feet resulted in 85th-percentile speeds of 30 mph.
PROXIMITY TO INTERSECTIONS  	✓ Normally, humps should not be placed within 150 feet of an unsignalized intersection, or 250 feet of a signalized intersection.
GEOMETRIC ISSUES  	✓ Curves – Speed humps should only be used on curves if the radius is greater than 300 feet. ✓ Grade – Humps should be installed on streets with a grade less than 8 percent. ✓ Curbing – Humps should only be installed on streets with curbing unless obstructions such as signing or flexible delineator posts prevent drivers from driving around a hump.

Exhibit 14.2: Special Considerations for Speed Hump Applications (continued)

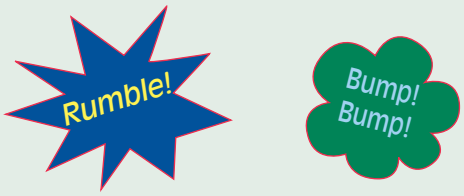
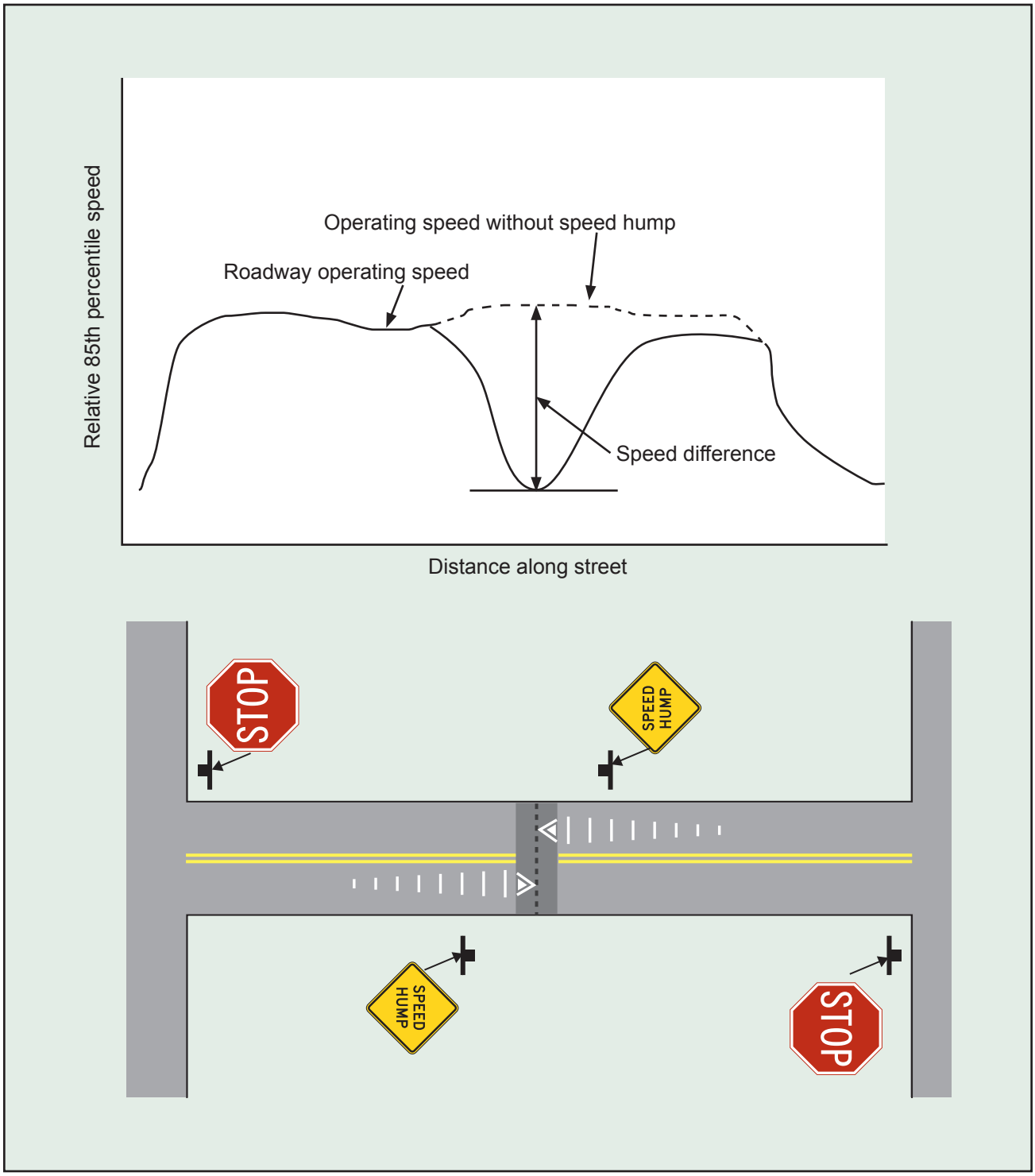
BICYCLES AND DRAINAGE	✓ Ideally, speed humps should extend across the roadway from curb to curb. Bicyclists generally prefer this design, and it prevents motorists from driving with one wheel in the gutter. However, if drainage cannot be accommodated in the preferred design, the hump can be altered to allow drainage around the hump and to the nearest inlet.
EMERGENCY VEHICLES	✓ Watts humps delay emergency vehicles anywhere from 1 to 10 seconds, with most delays in the range of 3 to 7 seconds. ✓ Seminole humps delay emergency vehicles by approximately 1 second.
NOISE 	✓ Although speed humps may create noise from vehicles passing over them, the overall noise levels on the street may be reduced because of reduced vehicle speeds.

Exhibit 14.3 shows a typical speed profile for a speed hump, as well as the speed differential if the speed hump was not used. Although this depicts a speed hump, it is similar to any traffic calming device.

Exhibit 14.3: Speed Profile for Speed Humps



14.5. TRAFFIC CALMING TECHNIQUES

KEY POINT

FHWA has additional web resources on traffic calming: http://safety.fhwa.dot.gov/speedmgt/traffic_calm.cfm

Traffic calming techniques can be grouped into four major areas: horizontal deflection, vertical deflection, physical obstructions, and signing and pavement markings. These are detailed in the following sections.

Raised median island

Roundabout

Curb extension

Horizontal deflection examples

14.5.1. Horizontal Deflection

Horizontal Deflection refers to two types of traffic calming measures. The first type hinders the driver's ability to drive in a straight line by creating a horizontal shift in the roadway. The shift forces drivers to slow their vehicles in order to safely navigate the measure. The second type of horizontal deflection measure is designed to narrow the width of the travel lane. Doing so reduces the usable surface of the roadway causing drivers to slow the vehicles to maintain an acceptable comfort level. Examples of the various techniques are outlined in Exhibit 14.4.

Bulb-out/Curb Extension - Areas of expanded curbing that extend across a parking lane, resulting in a narrower travel lane.

Chicane - Series of three bulb-outs, staggered at mid-block locations on alternating sides of the street.

Gateway - Entrance treatment, typically using physical and textural changes, which provides identity to an area.

On-Street Parking - Provisions for on-street parking reduce roadway width.

Raised Median Island/Pedestrian Refuge - Narrow islands, at mid-block or intersections, located between travel lanes with breaks in landscaping and curbing for pedestrians.

Roundabout - Raised island in the center of an intersection that requires vehicles to travel counterclockwise around the circle (in countries where vehicles travel on the right-hand side of the road).

Exhibit 14.4: Horizontal Deflection Techniques

■ Significant Effect ◣ Moderate Effect ☐ Minimal or No Effect

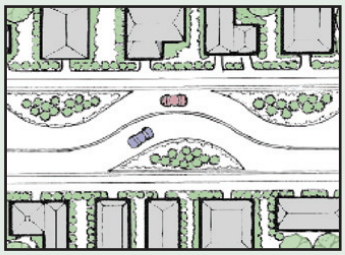
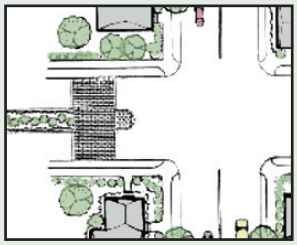
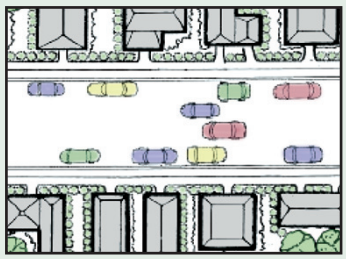
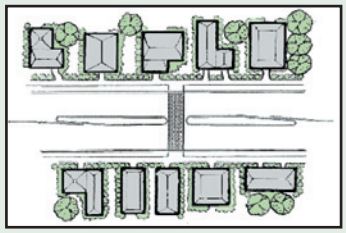
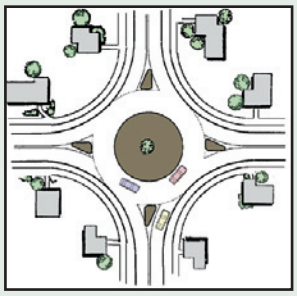
		VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
BULB-OUT/CURB EXTENSION		☐	◣	◣	◣	$7K-10K
CHICANE		◣	◣	☐	◣	$6K-14K
GATEWAY		☐	☐	☐	◣	$5K-20K

Exhibit 14.4: Horizontal Deflection Techniques (continued)

■ Significant Effect ◣ Moderate Effect ☐ Minimal or No Effect

		VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
ON-STREET PARKING		☐	◣	☐	◣	Varies
RAISED MEDIAN ISLAND/ PEDESTRIAN REFUGE		☐	◣	◣	☐	$5K-15K
ROUNDABOUT		◣	◣	■	■	$20K-120K

14.5.2. Vertical Deflection

KEY POINT

AR 420-1 prohibits the use of speed bumps to control or reduce vehicle speeds on Army installations. Although other services do not have a similar regulation, speed bumps are not recommended for use in any case.

Vertical deflection refers to traffic calming measures that create a change in the height of the roadway. When designed properly, vehicles must slow down over these measures in order to avoid unpleasant bumping sensations. Vertical deflection techniques are shown in Exhibit 14.5.

Raised Intersection - Intersections, including crosswalks, raised 3- to 6-inches above street grade.

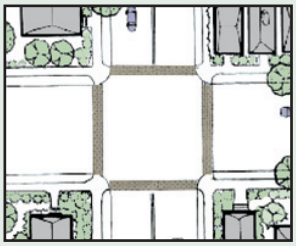
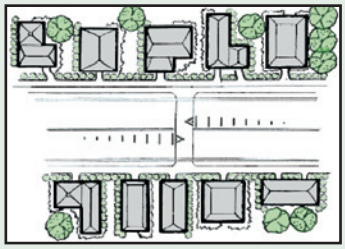
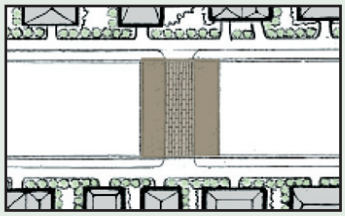
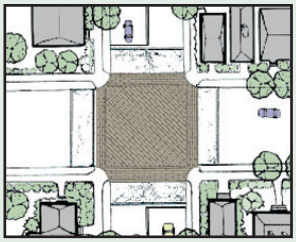
Textured Crosswalk - Use of pavers or other materials to define crosswalks and alert motorists that they are entering a pedestrian-friendly area.

Speed Humps - Raised humps in the roadway, typically 3-inches high and 12- to 22-feet long.

Raised Crosswalk - Marked pedestrian crossing elevated 3- to 6-inches above street grade at intersections or mid-block.

Exhibit 14.5: Vertical Deflection Techniques

■ Significant Effect ◣ Moderate Effect ☐ Minimal to No Effect

		VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
TEXTURED CROSSWALK		☐	☐	☐	☐	$50-150/ sq. yd.
SPEED HUMPS		◣	■	◣	■	$1.5K-3.5K
RAISED CROSSWALK		◣	■	◣	■	$2K-10K
RAISED INTERSECTION		☐	◣	◣	■	$15K-60K

14.5.3. Physical Obstruction

Physical obstruction refers to measures that prevent specific vehicle movements, thereby discouraging or eliminating cut-through traffic. The overall traffic volume reduction depends upon the nature of the traffic calming measure and the number of movements obstructed. Physical obstruction techniques are illustrated in Exhibit 14.6.

Semi-Diverter - Directional closure created by physically blocking half the street.

Diagonal Diverter - Physical barrier placed diagonally across a four-leg intersection to create two unconnected roadways.

Right-in/Right-out Island - Use of raised islands to prevent left turns and through movements, to and from side streets, at intersections with major streets.

Raised Median Through Intersection - Median barrier through an intersection that discourages through traffic in a residential area by restricting movements.

Street Closure - The use of a cul-de-sac to close a roadway by extending a physical barrier across the entire width, obstructing all traffic movements.

Exhibit 14.6: Physical Obstruction Techniques

■ Significant Effect ◣ Moderate Effect ☐ Minimal or No Effect

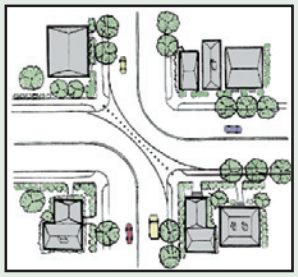
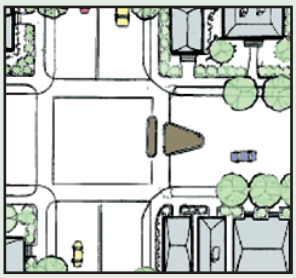
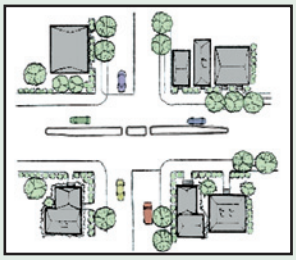
		VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
SEMI-DIVERTER		■	◣	◣	◣	$1K-20K
DIAGONAL DIVERTER		■	◣	◣	◣	$7K-20K

Exhibit 14.6: Physical Obstruction Techniques (continued)

■ Significant Effect ◣ Moderate Effect ☐ Minimal or No Effect

		VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
RIGHT-IN/RIGHT-OUT ISLAND		◣	☐	◣	◣	$3.5K-7.5K
RAISED MEDIAN THROUGH INTERSECTION		■	☐	◣	■	$1.5K-20K
STREET CLOSURE		■	◣	■	■	$1.5K-25K

14.5.4. Signing and Pavement Markings

Signing and pavement markings can be used as traffic calming measures that regulate traffic movements in lieu of physical changes to the roadway. In certain applications, these measures may produce the same effect as the physical traffic calming measures. However, police enforcement is often required to ensure motorist compliance. Exhibit 14.7 shows the benefit of signing and pavement marking techniques.

Speed Limit Signing - Field investigations of citizen complaints of speeding on residential streets often reveal that very few, if any, speed limit signs are in place. While most states have statutory speed limits which can be enforced in the absence of speed limit signs, any other speed cannot be enforced. Statutory speed limits typically vary by state. Examples include: 25 mph in urban business districts, 35 mph in residential districts, 70 mph on urban freeways, or 55 mph on all other roadways. Therefore, residential streets must include speed limit signing if a speed limit other than the statutory speed limit is to be enforceable. However, a speed study must be conducted to establish the speed limits.

Turn Prohibitions - Turn prohibitions are an excellent "quick fix" that can be used for both 24-hour or part-time applications. One drawback is that the residents living in the area must also abide by the posted restriction. If the cut-through occurs only during certain peak hours, part-time applications should be used.

Roadway Narrowing With Edge Lines - A low-cost way of reducing speeds is to narrow the roadway lane through the use of edge lines and center lines. A number of jurisdictions across the country have installed this type of pavement marking application to create 10-foot-wide lanes. This pavement marking application is appropriate on local streets and low-volume minor collectors, but should not be used on major collectors or arterial streets.

Transverse Markings - Double-thick thermoplastic transverse pavement markings have been successful in slowing traffic in diverse areas such as school zones, hospitals, approaches to severe curves, and stop signs.

Exhibit 14.7: Signing and Pavement Markings Techniques

■ Significant Effect ◣ Moderate Effect ☐ Minimal or No Effect

	VOLUME REDUCTION	SPEED REDUCTION	CONFLICT REDUCTION	EMERGENCY RESPONSE	ESTIMATED COST
SPEED LIMIT SIGNING	☐	◣	☐	☐	$250-400/sign
TURN PROHIBITIONS	◣	☐	◣	☐	$250-400/sign
ROADWAY NARROWING WITH EDGE LINES	☐	◣	☐	☐	$0.30/linear foot
TRANSVERSE MARKINGS	☐	◣	☐	☐	$2.00/linear foot

14.6. TRAFFIC CALMING PLANNING AND DESIGN CONSIDERATIONS

KEY POINT

A qualified traffic engineer should identify what traffic calming techniques are appropriate.

Traffic calming measures should typically be considered only after:

- ✓ Education and enforcement efforts have failed to produce the desired results.
- ✓ Existing traffic conditions have been thoroughly analyzed.
- ✓ The necessary approvals have been received by installation authorities and/or by the local DOT if the roadway is not owned by the installation.

A qualified engineer should gather the appropriate traffic data, analyze the data, and identify what (if any) traffic calming techniques are appropriate. Additionally, traffic flow diversions resulting from the installation of traffic calming devices should be studied.

Throughout the study and design process, the community should be engaged as much as possible to identify areas of concern, gather feedback on potential solutions, and provide feedback on the success of traffic calming improvements.

14.7. LEGAL ISSUES

Hundreds of local governments across the country have implemented traffic calming programs. Few have encountered liability issues. Almost all lawsuits that have arisen have been dismissed, denied, or withdrawn. Where lawsuits have succeeded, they have done so not because a traffic calming measure was found inherently unsafe, but because signs or pavement markings were poorly maintained. In order to minimize liability, installations should maintain documentation illustrating that their traffic calming programs are appropriate, and that the installation of traffic calming measures are based upon the recommendation of a qualified engineer.

CHAPTER 15 – ACCESS MANAGEMENT

15.1. WHAT IS ACCESS MANAGEMENT? 15-1

15.2. WHY IS ACCESS MANAGEMENT NEEDED? 15-2

15.3. PRINCIPLES OF ACCESS MANAGEMENT 15-3

15.4. ACCESS MANAGEMENT STRATEGIES 15-5

15.5. ACCESS DESIGN 15-7

15.1. WHAT IS ACCESS MANAGEMENT?

KEY POINT

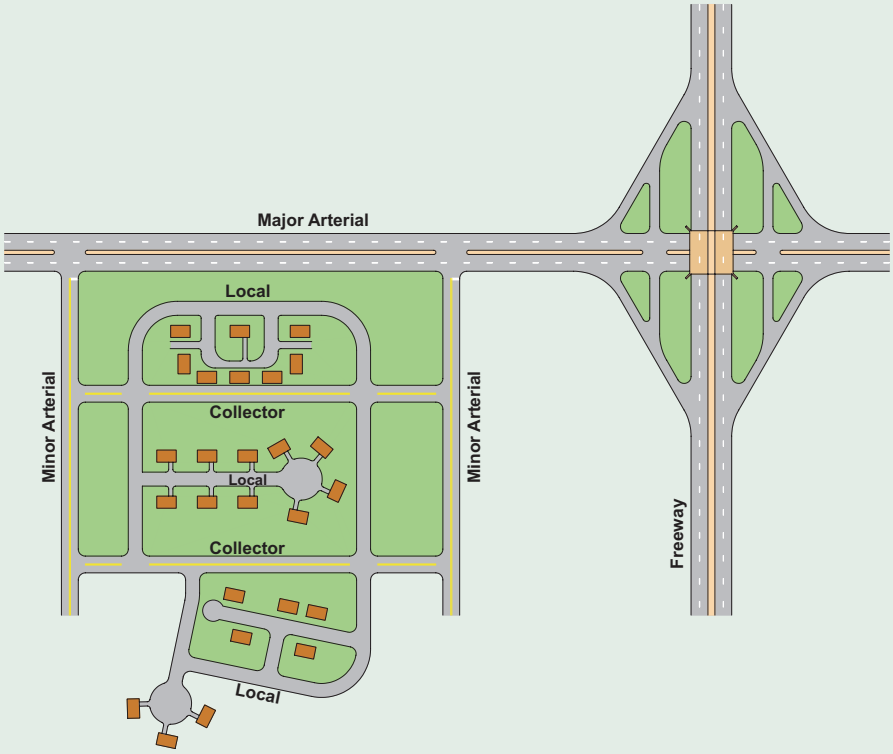
Access management provides reasonable access while minimizing impacts to traffic operations.

The *Access Management Manual*, published by the Transportation Research Board (TRB), defines access management as "…the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway." In simple terms, it is the management of access points along a roadway such that the impact to traffic operations is minimized, while maintaining reasonable access.

By preserving the safety and efficiency of a roadway network, access management procedures balance mobility and access, which are a roadway's two primary functions. This is accomplished by carefully managing the number of conflicts that are introduced by intersecting driveways and streets.

For roadways such as freeways, access is limited to interchanges with the primary function being mobility. At the other end of the spectrum is a local street in a residential neighborhood. This roadway type functions mainly as a means of providing access to homes and serves minimally as a means of mobility. The illustration below shows a hierarchy of roadway classes, each with varying degrees of access and mobility.

HIERARCHY OF ROADWAY CLASSES



15.2. WHY IS ACCESS MANAGEMENT NEEDED?

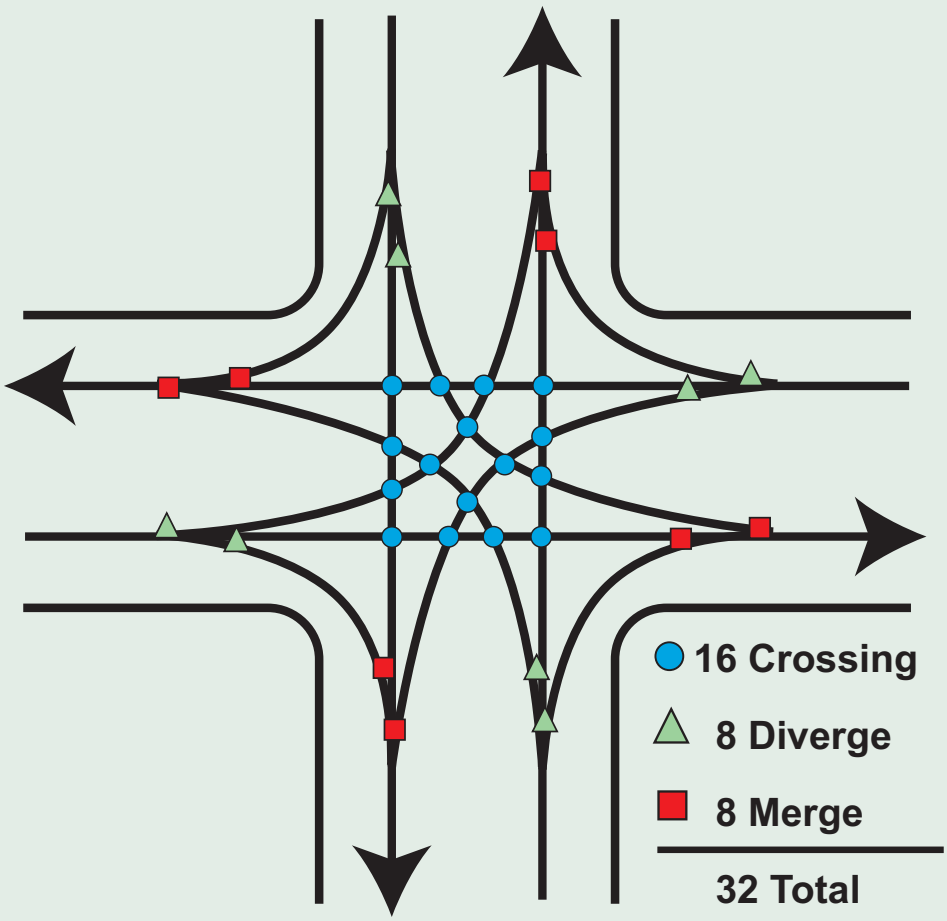
KEY POINT

A standard four-leg intersection has 32 possible conflict points.

Without any type of access control along a roadway, access points will likely increase. Access management is important to minimize traffic conflicts along a roadway. As shown below, traffic conflicts occur when the paths of vehicles intersect.

This results when vehicles are stopping in, crossing, entering, or exiting the traffic stream. At each conflict point there exists a potential collision. As more conflict points are introduced to a segment of roadway, driving becomes more complex and motorists are more likely to make mistakes. Congestion increases and safety deteriorates. Effective access management preserves roadway capacity and reduces crashes.

INTERSECTION TRAFFIC CONFLICTS



15.3. PRINCIPLES OF ACCESS MANAGEMENT

KEY POINT

TRB's *Access Management Manual* identifies goals of access management.

The focus of access management is to limit and consolidate access along major roadways while ensuring that the supporting roadway network can safely and efficiently provide the necessary access. The goals of access management can be realized by adhering to the principles set forth in the *Access Management Manual*. Those principles most applicable to access management on military installations are described below:

- ✓ **Limit direct access onto major roadways** – Roadways serving high-traffic volumes should require a higher level of access control to protect the roadway's intended function of moving through traffic.

  Access to major roadways should be restricted and instead be provided along roadways with a lower classification such as local or collector streets.

- ✓ **Locate signals to favor through movements** – When signalized intersections are located with long, uniform spacing, coordination between the signals ensures minimal interruption to traffic flow. If signals are located close to access that may in the future become signalized, disruption of the coordinated traffic flow will result, thereby creating congestion and greater delays. For this reason, spacing between a signal and access should be as large as possible.

- ✓ **Limit the number of conflict points** – More mistakes and a higher likelihood of collisions result when drivers are faced with a high conflict area, as shown below. These areas create stressful situations that require a high degree of attention. By minimizing conflicts, traffic operations improve and the potential for collisions decreases. This simplifies the driving task, resulting in a lower-stress environment for the driver.

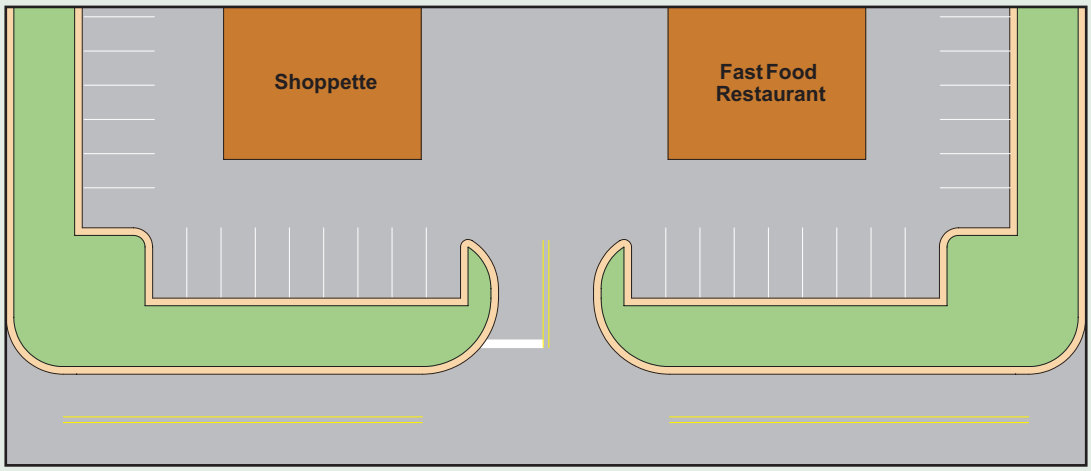
HIGH CONFLICT AREAS

Wide driveway slightly offset from opposite street results in many conflicts.

Driveways too close to a signalized intersection become blocked by stopped vehicles.

- ✓ **Separate conflict areas** – Nearby conflict areas can block movements and increase congestion. Drivers need time to react to each conflict area they are presented with. As travel speeds along a roadway increase, the necessary distance between access points increases because of driver perception-reaction time. Once drivers recognize a potential hazard, they need time to react to that hazard. For this reason, it is important to provide sufficient distance between access points.
- ✓ **Remove turning vehicles from through traffic lanes** – Turning lanes remove lower speed vehicles from the higher speed through lane. Once out of the through lane, turning vehicles can wait safely in a protected lane to complete their turn. This improves the safety and efficiency of an intersection with a street or driveway.
- ✓ **Provide a supporting street and circulation system** – During planning stages it is important to include a supporting network of local and collector streets to accommodate development such as restaurants or a PX/Commissary.
- ✓ **Eliminate the need for multiple driveways** - Joint property access is also key in eliminating the need for each property to have a separate driveway. As illustrated below, this connectivity allows motorists to visit adjacent properties without having to drive separately to each.
- ✓ **Preserve the functional area of intersections** – The functional area of an intersection is the area critical to safe and efficient vehicular movement. This area is where all maneuvering/lane changing takes place for drivers to complete the necessary turning movements. When access is located too close to this critical area, it can cause traffic conflicts that seriously disrupt the function of the intersection.

JOINT PROPERTY ACCESS



15.4. ACCESS MANAGEMENT STRATEGIES

When constructing new access points or upgrading existing access, it is important to consider location and spacing. These components are critical to safe and efficient roadway operation.

15.4.1. Access Location

Proper access location involves several considerations:

- ✓ Sight distance
- ✓ Following hierarchy of roadways
- ✓ Functional area of intersections

Sight Distance

Providing adequate sight distance at a driveway ensures motorists can safely enter or exit a roadway. Adequate sight distance also allows approaching drivers sufficient distance to react to entering or exiting vehicles if necessary. Section 4.7 further discusses sight distance.

Roadway Hierarchy

Avoid connecting a roadway of low functional class to one with a much higher functional class. When possible, connections should be made only between roadways with similar classification. For example, a connection between a minor and major arterial is acceptable, but connecting a local road to a major arterial should be avoided.

Functional Area of Intersections

Constructing access points in the area of an intersection where maneuvering or lane changing takes place should be avoided. This area extends at least to the end of turning lanes and to where stopped traffic typically would queue.

15.4.2. Access Spacing

Wide spacing between successive driveways is the single most important element of access management since each new access introduces numerous traffic conflicts to the roadway. These conflicts reduce travel speeds and contribute to congestion and higher crash potential. The closer these access points are, the more profound are these effects. Minimum access spacing requirements attempt to minimize these impacts.

Various sets of guidelines exist for the spacing of access points. Spacing requirements should be based on number of expected trips, speed limits, and roadway classification among other considerations. General spacing guidelines are published in TRB's *NCHRP Report 348*. Exhibit 15.1 shows unsignalized access guidelines.

Exhibit 15.1: Unsignalized Access Guidelines

OPERATING SPEED (MPH)	SPACING (FEET)
30	100-200+
45	300-500+
TYPE OF FACILITY	**SPACING (FEET)**
Major Arterials	300-500+
Minor Arterials	100-300
Collectors	100-200
Lower values apply to roadways on most military installations. Higher volumes would only apply to high-speed or median-divided roadways.	

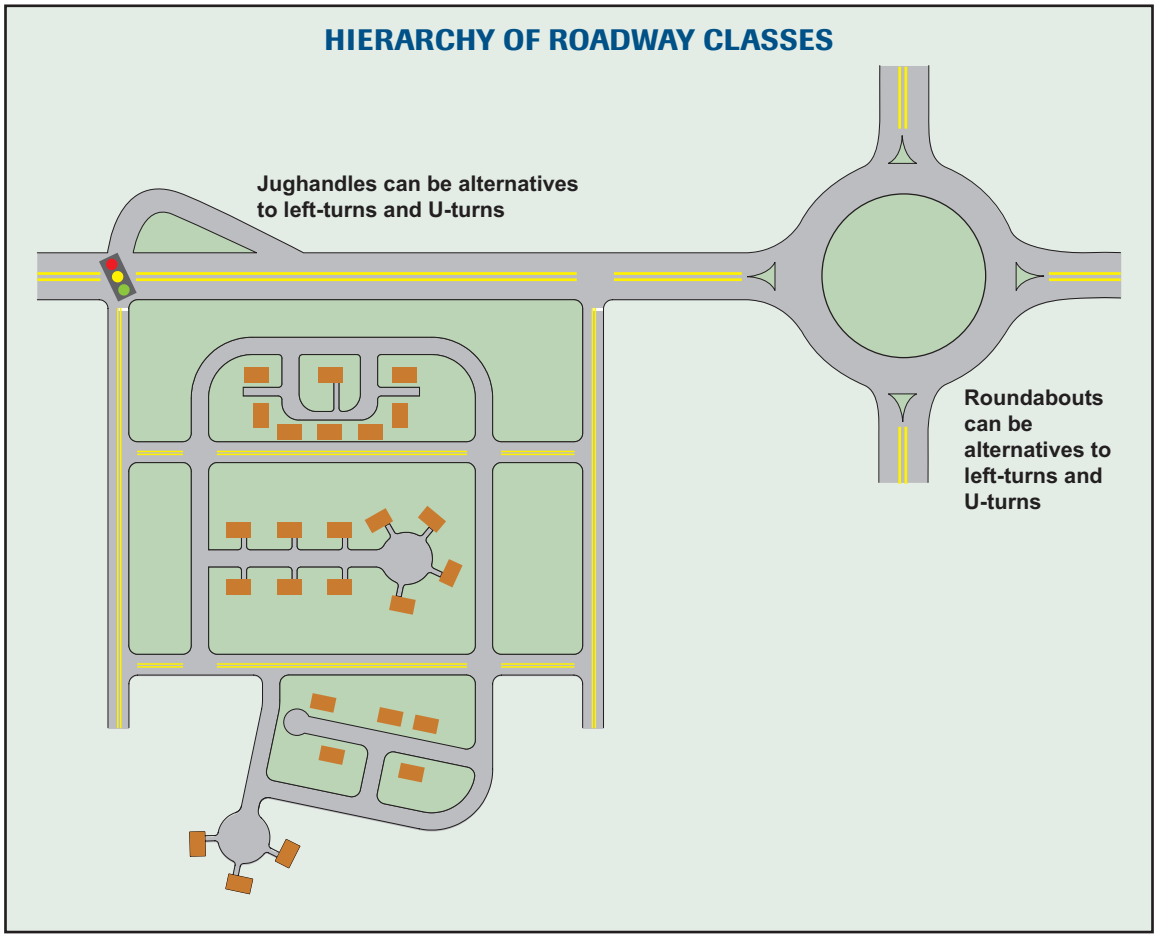
The spacing guidelines shown above provide a range of values. The lower values apply to lower class roads or roadways with raised medians where no left turns are permitted.

15.4.3. Additional Considerations

It is often desired to restrict some turning movements through intersections with accesses. This most often is left-turns to and/or from busier roadways with the access. The benefit of restricting left-turns generally is safety and operations related. When the volume of traffic is so high that it is extremely difficult to turn left out of the driveway, motorists may accept unsafe gaps in traffic to try to turn left. This could make the intersection more crash-prone. Motorists waiting to turn left would also cause unacceptable delays to right-turning vehicles.

When this type of restriction occurs, it may be necessary to somehow accommodate traffic that otherwise needs to make these left-turns. This may be by providing another access from the site to a side street. It could also be by providing U-turn capabilities along the major roadway. U-turn capabilities can be provided by any of the following methods:

- ✓ Provide U-turn capabilities at an adjacent traffic signal.
- ✓ Provide a jughandle at a signalized intersection.
- ✓ Provide a roundabout at an adjacent intersection to allow for U-turns without conflicting with traffic from the opposite direction.



15.5. ACCESS DESIGN

The three basic design components of an access are:

- ✓ Corner radius
- ✓ Width
- ✓ Throat length

15.5.1. Corner Radius

Sufficient corner radius enables a vehicle to enter or exit an access without encroaching into adjacent traffic lanes. The radius should be designed for the largest type of vehicle expected to use the intersection. For passenger cars, this radius is typically 30 feet; for tractor trailers, the minimum radius is 50 feet.

15.5.2. Width

While width must be sufficient to accommodate intended traffic movements, too large a width will result in conflicts spread over a large area. Consequently drivers will be uncertain where to position their vehicles with such a wide access. The recommended width is 12 feet for each lane. Greater widths may be necessary where truck traffic is expected.

15.5.3. Throat Length

The throat of an access is the distance between the adjacent roadway and the point internally where drivers are presented with conflicts. The throat lengths at PX/Commissary complexes are often too short, which leaves little room for vehicles to stack when presented with an internal conflict, as shown in the illustration on page 15-8. Eventually vehicles back out onto the adjacent street, which increases crash potential significantly.

A short throat length also results in insufficient reaction time to the conflicts that a driver will be presented with upon entering the site. Exhibit 15.2 provides some general guidelines for throat lengths. Exhibit 15.3 illustrates the many problems associated with such a short throat length and provides an example of adequate throat length. The drawback to longer throat length is the impact to parking. However, ensuring safe entry into the site is more important.

Exhibit 15.2: Throat Length Requirements

TYPE OF RETAIL ESTABLISHMENT (OR SIMILAR MILITARY FACILITY)	RECOMMENDED THROAT LENGTH	APPROXIMATE NUMBER OF CARS
Small strip mall (shoppette/video store/fast food restaurant)	75-95 feet	5
Small shopping center or large super market (PX/Commissary)	200 feet	11

Source: Access Management Manual, 2003

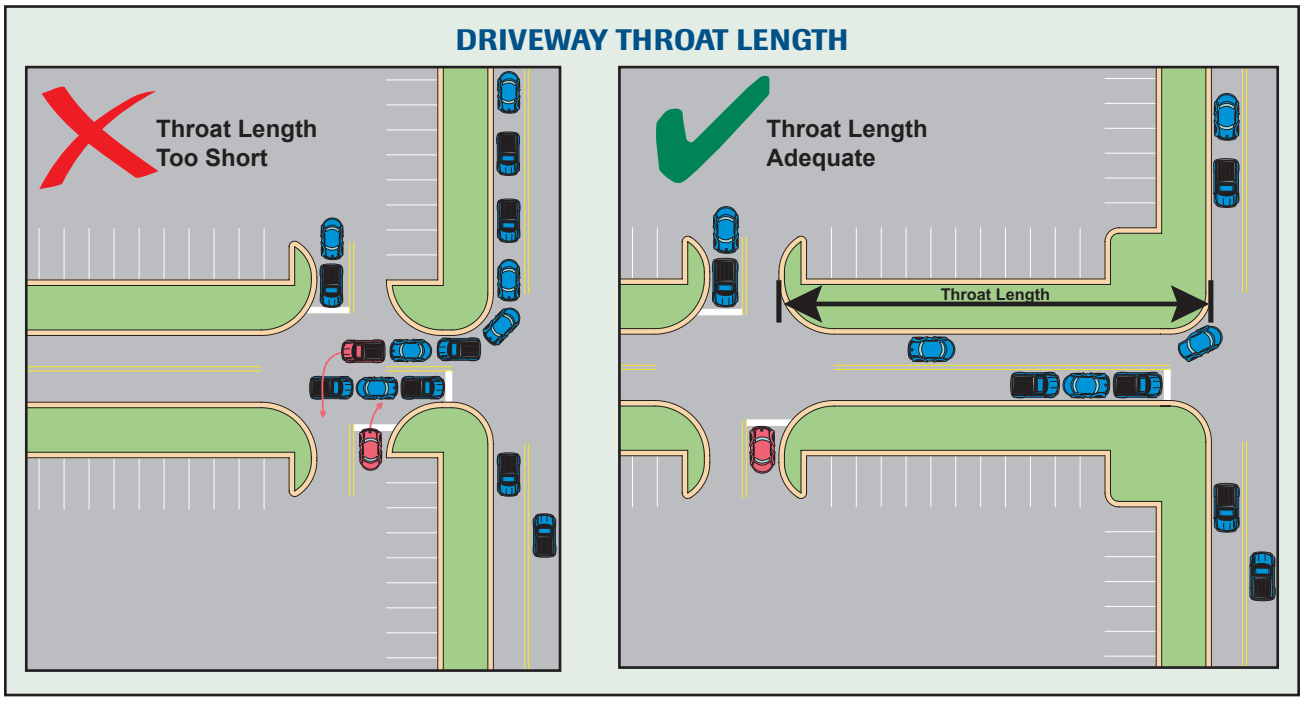
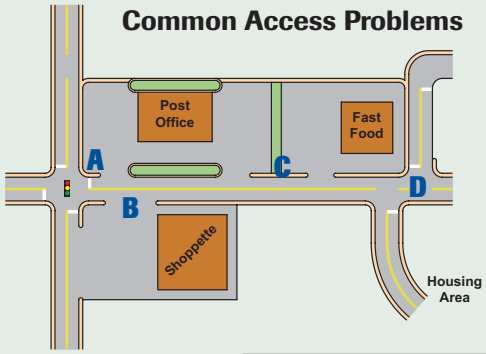
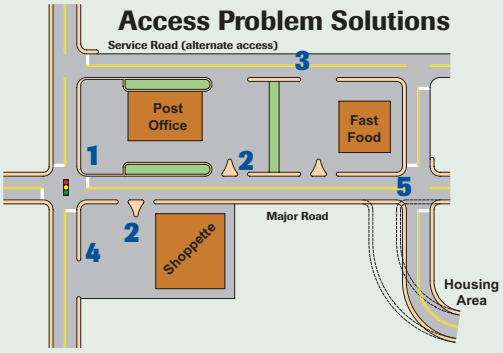


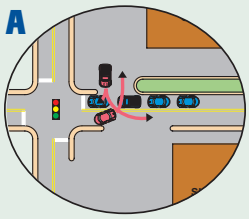
Exhibit 15.3: Access Problems and Solutions

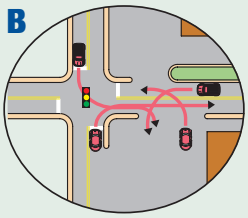
Common Access Problems

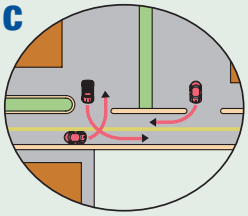


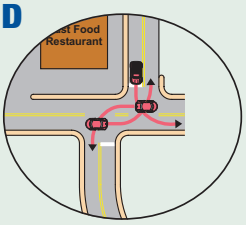
Access Problem Solutions











Common Access Problems \ Access Problem Solutions	1. **Driveway closure** – Eliminating driveways when other alternative access is provided will eliminate points of conflict along the adjacent roadway.	2. **Restrict left-turn movements** – If alternate access can be provided, such as a service road, left turns can be restricted using raised concrete islands.	3. **Construct service road** – Service roads eliminate access from major roadways.	4. **Reduce width of access** – Access width reduction minimizes the length of roadway along which traffic conflicts are present.	5. **Intersection realignment** – Relocate legs of intersections, when possible, to eliminate offset.
A. **Driveways too close to intersections** - When a driveway is too close to an intersection, blocking of turning movements will occur. This can have detrimental effects on the operation of the intersection.	✓	✓	✓		
B. **Wide, uncontrolled access along a property's frontage** - Inadequate access control, especially at the corner of an intersection, will result in a high-conflict area with frequent unpredictable, unsafe turning movements.		✓		✓	
C. **Driveways spaced too close together** - When drivers are simultaneously exiting nearby driveways, uncertainty is involved trying to predict other nearby maneuvers. Left turns from the major street may also block multiple accesses.	✓	✓	✓		
D. **Intersecting roads with a slight offset** - When intersecting roads are slightly offset from one another, blocking of turning movements may result. For vehicles crossing the major roadway a slight jog results instead of a straight-line movement.					✓

CHAPTER 16 – DEMAND MANAGEMENT

16.1. CONGESTION 16-1

16.2. TRAVEL ALTERNATIVES. 16-4

16.3. HIGH OCCUPANCY VEHICLES (HOVs) 16-5

16.4. TRANSIT 16-7

16.5. LAND USE 16-8

16.1. CONGESTION

KEY POINT

Demand Management addresses congestion by reducing the number of vehicles on the road during peak periods.

Congestion is not limited to cities, it also affects many rural areas, smaller communities, and military installations. Congestion takes a toll in driving time, vehicle costs, air pollution, and stress/health issues. Some of the stress is caused by the unpredictable nature of traffic, e.g., "Will I be late for that important meeting?" As a motorist, it is easier to accept consistent delays than it is to accept erratic delays.

Many roads were not designed to handle the current traffic demand. With reference to Exhibit 16.1, except for bottlenecks and poor signal timing, the other sources of congestion are usually temporary.

As illustrated in Exhibit 16.2, congestion can be reduced by:

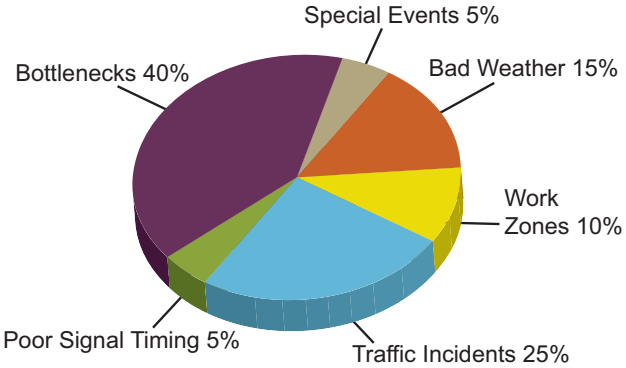
1. Building additional road capacity
2. Improving the roadway efficiency
3. Reducing the number of vehicles

The Cost of Congestion

Congestion is a problem in America's 439 urban areas, and it has gotten worse in regions of all sizes. In 2007, congestion caused urban Americans to travel 4.2 billion hours more and to purchase an extra 2.8 billion gallons of fuel for a congestion cost of $87.2 billion – an increase of more than 50 percent over the previous decade.

Source: 2009 Urban Mobility Report, Texas Transportation Institute

Exhibit 16.1: Source of Congestion

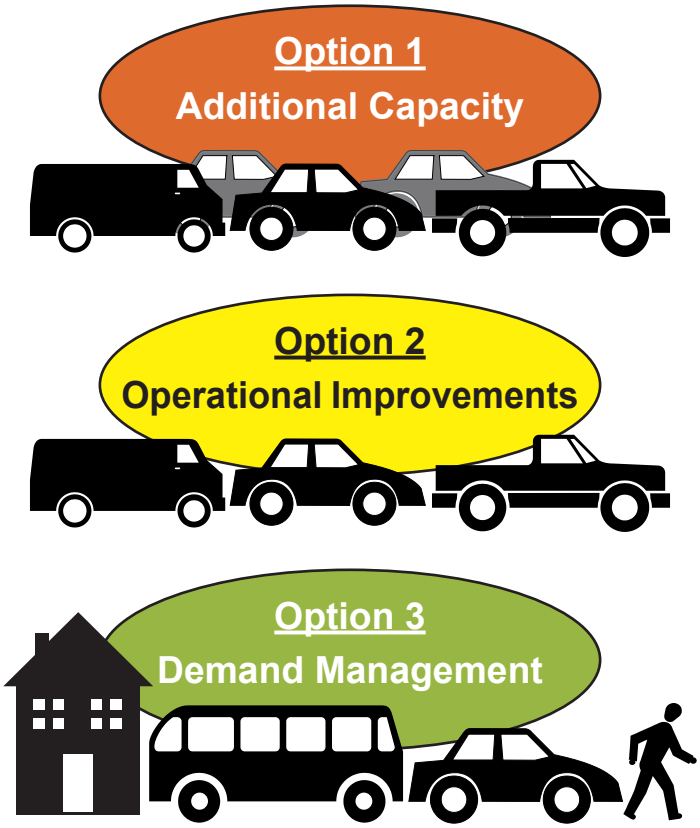


Source: FHWA

Option 1 is the "build option," but experts believe that it is virtually impossible to solely build our way out of congestion. Option 2 includes eliminating bottlenecks, and adding sophisticated traffic signal and intelligent transportation systems that use technology to tweak the capacity. Studies indicate that some of these technologies have a very high return in time and fuel savings. However, the focus of this bulletin is Option 3, which is commonly called either "travel demand management" or simply "demand management." In reality, the best approach is to use all three of these options.

Executive Order No. 13423 (January 26, 2007), entitled "Strengthening Federal Environmental, Energy, and Transportation Management," raises the bar for federal agencies. The order requires federal agencies to reduce their greenhouse gases through a reduction in energy intensity by 3 percent a year through the end of fiscal year 2015, or by a total of 30 percent by the end of fiscal year 2015. Obviously, this puts more pressure on military installations to redouble their efforts to reduce all forms of energy consumption. Although the Executive Order is relative to an agency's energy use, the agency should be cognizant of other ways to reduce energy consumption.

Exhibit 16.2: Congestion Mitigation Options



Demand management programs attempt to address congestion at the root of the problem by reducing the number of vehicles on the road. These initiatives work to modify driver behavior by encouraging people to make fewer single-occupancy trips, travel in off-peak hours when possible, and support land-use policies that reduce the demand for vehicular travel.

Exhibit 16.3 shows six typical demand management strategies used to reduce congestion. Of the six strategies, only the first four have typical applications on military installations; therefore, the first four strategies are discussed in the remainder of this section.

As the owner of the road network and as the employer, military installations have a unique opportunity to make a difference for their employees while also eliminating some of the costs for constructing extra travel lanes and parking spaces.

The next sections identify different demand management techniques. By using these, military installations can assist their employees and other partners in making significant reductions in energy usage, travel time, and air pollution. This truly is a win-win situation for everybody.

Exhibit 16.3: Demand Management Strategies

STRATEGY	EXAMPLES
TRAVEL ALTERNATIVES	✓ Telework ✓ Flexible work hours/alternate work schedules ✓ Pedestrian/bicycle travel
HOV	✓ Carpooling ✓ Guaranteed ride home program ✓ Parking pricing and cash-out programs ✓ Instant ridesharing program
TRANSIT	✓ Enhanced bus quality and transit stops ✓ Internal shuttle service ✓ Guaranteed ride home program ✓ Subsidized fares
LAND USE	✓ "Smart Growth" policies ✓ Pedestrian/bicycle/transit connections
FREIGHT	✓ Truck-only toll lanes (TOT) ✓ Lane restrictions ✓ Delivery restrictions ✓ Availability of rail or barge
PRICING	✓ High occupancy toll lanes (HOT) ✓ Time-of-day pricing ✓ Activity center pricing

16.2. TRAVEL ALTERNATIVES

16.2.1. Telework

Telework is where employees enjoy the flexibility in work location. This is the ultimate in the reduction of travel demand since it allows workers an opportunity to work from home whenever possible. Telework is facilitated by laptop PCs, broadband Internet connections, groupware, conference calling, video-conferencing, and Voice over Internet Protocol (VOIP). Telework can also assist marginalized groups, such as caregivers, employees with disabilities, and people living in remote areas.

Telework tends to be most suitable for jobs that primarily manipulate information, such as software programming, data entry, planning, analysis, and design. In 2008 approximately 2.8 million employees worked from home most of the time, but it has been suggested that 52 million U.S. workers (about 40 percent of employees) could work from home.

Benefits of telework include:

- ✓ Enhances business across multiple time zones.
- ✓ Reduces the spread of diseases, employee turnover, and absenteeism.
- ✓ Eliminates commuting time.
- ✓ Reduces congestion, air pollution, and energy use.
- ✓ Reduces employee and employer costs.
- ✓ Eliminates the effects of weather and terror-related office and road closures.

Most employers believe that teleworkers are more productive than other employees, perhaps because teleworkers will not be part of a group talking around the water cooler or copy machine. Also, teleworkers feel blessed to be able to work from home, and there may be an underlying fear that unless they are super productive, this privilege could be taken away. Because of this indebtedness, teleworkers may be willing to further adjust their schedule to make phone calls earlier or later in the day to talk to individuals in other time zones.

Federal agencies are responsible for formulating their telework policies and procedures in accordance with the U.S. Office of Personnel Management (OPM) guidelines (see http://www.telework.gov). However, OPM's 2009 report indicates that in 2008, only 16,871 DoD employees (2.99 percent) out of an eligible 564,562 employees were teleworkers. Since it is generally estimated that 80 percent of employees who are given an opportunity to telework will do so at least half of the time, the low participation may be because some employees are unaware of the opportunities.

Allegedly, 76 percent of all DoD employees are eligible to telework, and if 80 percent of these would telework half of the time, there would typically be 225,825 teleworkers resulting in a 30 percent reduction in work-related travel.

16.2.2. Flexible and Alternate Work Schedules

Except for jobs where full teams are required at all times, installations should consider allowing employees to establish their own work schedule. In addition to smoothing out the peak-hour traffic volumes, flexible hours allow employees to be more active in family and community activities, to choose the part of the day that they work best, and to facilitate carpools, transit, and educational opportunities.

Alternate work schedules like the compressed work week can also have major implications. For example, working four 10-hour days instead of five 8-hour days reduces commuting-related travel by 20 percent. Installations should refer to OPM's Handbook on Alterative Work Schedules (see http://www.opm.gov/oca/aws/).

16.2.3. Pedestrian and Bicycle Travel

To further reduce vehicular travel and to promote healthy activities, it is highly desirable to have a good network of sidewalks, walkways, and bikeways. These facilities can be used to go to the PX, commissary, credit union, library, gym, etc., instead of jumping in the car, and they can also encourage walking or biking during the lunch hour as recreation. If employees can have a relaxing lunchtime stroll with shade trees and park benches, it is also likely that they will be more productive when they return to work after lunch.

Typical pedestrian concerns include:

- ✓ Lack of continuous walkways.
- ✓ Walkways are too narrow, have a poor walking surface, and are partially blocked by utility poles, signs, etc.
- ✓ Insufficient lighting.

To encourage employees to walk or bike to work, installations should consider a dedicated entry control facility when the number of pedestrians and bicyclists exceeds ten users per 15-minute interval during the morning peak hour.

16.3. HIGH OCCUPANCY VEHICLES (HOVs)

16.3.1. Carpooling

The definition of a high occupancy vehicle (HOV) generally means a vehicle having more than one person, and at the workplace this is generally referred to as carpooling. These ridesharing opportunities are an ideal way to reduce congestion and the number of required parking spaces. It also allows carpoolers an opportunity to reduce their commuting costs and save time by using HOV lanes, while at the same time provide extra time for passengers to catch up on sleep; work or reading; or just relax, unwind, and socialize. Sometimes workers know of someone in their neighborhood whoworks at the military installation and together they can work out their own rideshare arrangements. However, installations can encourage additional ridesharing by developing a web site for individuals to express their willingness to share a ride.

Carpooling has risks such as, what happens if a member of the carpool is required to work overtime, or if someone needs to leave work early for unanticipated personal reasons?

When these risks do materialize, the member can sometimes make a quick call and perhaps other members of the carpool can adjust their schedule or make other carpool arrangements; but this will not always work. One concept to alleviate these fears is a Guaranteed Ride Home (GRH) program.

To encourage HOVs, installations are encouraged to consider the following actions:

- ✓ Allow alternate work schedules and flex time.
- ✓ Provide an appropriate carpool-matching website.
- ✓ Develop a GRH program.
- ✓ Provide priority parking for HOV vehicles.
- ✓ Charge a daily parking fee or provide a daily cash-out payment for employees that carpool or use transit.
- ✓ Provide express lanes for HOVs through busier entry control facilities.

16.3.2. Guaranteed Ride Home (GRH) Program

The GRH program is where the military installation provides a guaranteed ride to accommodate stranded employees. The method of transportation could be in the form of a government vehicle, a taxi, or a rental vehicle.

Most carpoolers and transit riders consider the GRH program to be important in their decision whether to carpool or use transit, but how "emergency" is defined also affects the attractiveness of the program. Therefore, installations are encouraged to start with a very liberal program and make refinements if they believe the program is being abused. Although carpoolers like the reassurance of a GRH program, on an annual basis employers have found that a very low percentage of carpoolers will actually use the program. It is acceptable to charge a fee for the use of the vehicle.

The GRH program can also be used to assist transit riders when unexpected events come up.

16.3.3. Incentives to Encourage HOV

To encourage the use of HOVs, employees could be charged a parking fee or receive a "cash-out" for using HOV or transit. In both cases, the monetary value should theoretically equal the cost of providing parking.

16.3.4. Instant Ridesharing

In addition to maintaining an appropriate carpool-matching website, an emerging technology is instant ridesharing. Instant ridesharing is a ridesharing arrangement that enables the formation of carpools on very short notice. In instant rideshare matching systems, the employee wishing to obtain a ride sends a ride request to a ridesharing operation network or to a centralized database. The database then searches for a match with trips offered by others who have registered for the program. Instant ridesharing is also known as dynamic ridesharing, ad-hoc ridesharing, real-time ridesharing, single trip ridesharing, dynamic carpooling or casual carpooling.

HOV Lane Example

16.4. TRANSIT

Nationally, a very low percentage of all commuting is by public transportation. Some of the common reasons for not using transit, include:

- ✓ Transit connections are not convenient.
- ✓ The buses are old and uncomfortable.
- ✓ The bus stops do not have clean safe shelters.
- ✓ An emergency could happen when bus service is not available.

Installations generally cannot eliminate the first two reasons but they can help ensure that bus stops on the installation have acceptable shelters. And as noted previously, the GRH program can help more employees participate in a ridesharing program by defusing the last reason.

Employees at military installations tend to be younger and more dependent on public transportation than at most other employment centers. In fact, during basic training, recruits generally cannot have privately-owned vehicles on the installation.

There are three transit arrangements to consider:

1. External service provided on the installation with guards riding on the bus during higher force protection conditions. This is the most efficient arrangement, but security may be an issue since some passengers may not be going to or from the installation.
2. External service to a location outside the gate where there is a connection to an internal shuttle service. Although internal shuttle service is expensive, it does provide an opportunity to pick up employees who live locally and walk to the transfer location or who are dropped off from an outside carpool.
3. External service to a location outside the gate, with opportunities to walk to their employment center. Unfortunately, this arrangement only works for small installations or for those people who work in buildings near the drop-off location.

A common problem to all transit and shuttle services is the state of existing bus stops. At bus stops, shelters should be provided, particularly at stops where larger groups of riders are expected. An example of a bright and friendly bus shelter is illustrated, although a bench would be desirable. On busier roads, bus pull-offs should be provided so buses do not block the travel lane.

Some of the larger military installations have an internal shuttle service. Since these shuttle buses are frequently old and uncomfortable, there may be a benefit to upgrading the shuttle fleet with hybrid buses, buses that run on compressed natural gas (CNG), or buses that have the new clean diesel engines. These newer buses will improve passenger comfort, and be more environmentally friendly and cost effective.

A Clean Cities Fact Sheet (the May 2000 issue, as published by the U.S. Department of Energy) says that CNG buses could pay for themselves in just a little more than 3 years, require less maintenance, and emit 97 percent less particulate matter and 58 percent less oxides than conventional diesel buses.

The new clean diesel-powered buses have comparable environment benefits as the hybrids but at a lower annualized cost than either hybrids or CNG buses.

Typical Bus Shelter

If replacing buses, most installations could consider smaller shuttle buses since existing buses sometimes have trouble making tight turns. Upgrading to new smaller buses should also reduce fuel costs.

It is important to publicize any internal shuttle service, providing the specifics as to who can ride, where it goes and when.

For Arrangements 2 and 3, if a new entry control facility (ECF) is being planned, as a minimum, a transit stop should be considered as part of an ECF design with a bus turnout pocket and a subsequent U-turn capabilities before the ID check area.

16.5. LAND USE

16.5.1. Smart Growth

In an effort to reduce internal travel, military installations should plan for "smart growth," which refers to incorporating land-use considerations into transportation planning to minimize environmental impacts and enhance mobility.

The Institute of Transportation Engineers (ITE) has a publication titled *Smart Growth Transportation Guidelines: An ITE Recommended Practice*. This publication provides recommendations that allow a developing community to reduce vehicular dependence by providing more mobility choices.

The following key principles should be considered for future development:

- ✓ Provide extensive street networks, including small grids with intersections spaced every 300 to 500 feet. (Larger grids require more travel for pedestrians, bicyclists, and motorists to reach their destinations.)
- ✓ Provide a well-connected system of facilities for pedestrians and bicycles to promote these types of travel.
- ✓ Mix complementary land uses to reduce trip lengths by putting more origin-destination pairs in close proximity with each other.

Perhaps the central theme is planning for integrated self-contained communities and work areas where everything is within walking distance. In addition, add transit or internal bus loop stops near the center of these "communities."

In addition to the term "smart growth," the term "walkable communities" is also used to indicate how friendly an area is to walking. While the actual evaluation requires the consideration of many subjective factors, the goal is to encourage citizens to rely less on their cars and to choose walking more often as a form of everyday transportation. Well-designed, compact communities where people can walk to school and work, to stores, parks, and restaurants significantly reduce the need to drive.

Obviously, there are many economic, health and environmental benefits of building and sustaining a community that supports walking as a primary mode of transportation.

CHAPTER 17 – PARKING

17.1. COMMON DEFICIENCIES 17-1
17.2. OFF-STREET PARKING FACILITIES. 17-2
17.3. PARKING GARAGES 17-9
17.4. ON-STREET PARKING 17-10

CHAPTER 17 – PARKING

Lack of adequate parking presents a significant problem at many installations. Poorly designed and maintained parking facilities frustrate drivers and can increase crash potential. There are two basic categories of parking: on-street and off-street. This section will discuss common deficiencies with each and provide guidance on proper planning and design.

17.1. COMMON DEFICIENCIES

The ten most common parking deficiencies are discussed below.

- ✓ **On-street parking creates conflicts with traffic flow** – Perpendicular parking in particular is a major hindrance to traffic flow as drivers must slowly back their vehicles out of the parking spaces.

Perpendicular on-street parking

- ✓ **Poor parking lot circulation pattern and layout** – Poorly designed lots create conflicts between vehicles and cause unnecessary travel within parking lots.
- ✓ **Incorrect parking lot dimensions** – Narrow parking spaces and aisle widths make entering and exiting stalls difficult.
- ✓ **Parking areas do not conform to ADA guidelines** – Islands without curb cuts lengthen routes for physically challenged users and force them to circulate with vehicles.
- ✓ **Parking lots not properly maintained** – Broken pavement and excessive vegetative growth discourage driver utilization.
- ✓ **Absence of markings in on- and off-street parking areas** – Without marked parking stalls, inefficient use of space results as motorists park in a random fashion.
- ✓ **Lack of off-street parking areas** – When drivers cannot find an off-street parking space, they may park roadside and unknowingly become a hazard to other motorists.

Undesirable on-street parking

- ✓ **Poor lighting in parking areas** – Without adequate lighting, some drivers feel insecure and will be discouraged from parking.
- ✓ **Poor access design** – Unnecessary vehicular conflicts result when too many access points are provided. Conflicts between parking and circulation result.

Example of too many access points

- ✓ **Not enough buffer zone between parking lots and adjacent land uses** – Adequate buffer is necessary to provide room for landscaping.

17.2. OFF-STREET PARKING FACILITIES

KEY POINT

Because of lower crash rates, off-street parking is preferred over on-street parking.

During the initial planning process, off-street parking should be selected over on-street parking because of the associated lower crash rates.

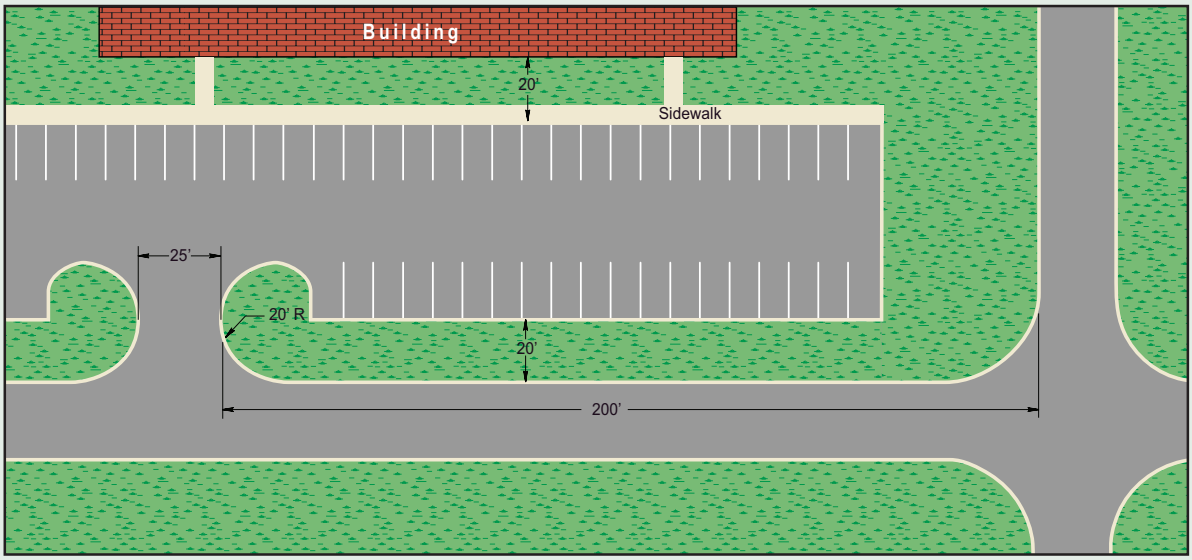
Also important is the assumption that people are generally unwilling to walk more than 1,000 feet from their parking space to reach their destination.

17.2.1. Demand

Future parking demand can be determined by using parking generation rates. A parking generation rate equates parking demand to a predictable characteristic, such as population, number of employees, or floor space. These rates have been developed for many types of facilities, and are published in ITE's *Parking Generation,* 2010. For existing facilities, demand can be measured by performing a parking utilization study. This study compares the highest number of vehicles parked at each facility to the available parking supply. The survey should be conducted at 10:00 a.m. and again at 2:00 p.m. for long-term parking; and every one to two hours for short-term parking.

As a general rule, short- and long-term parking areas should not be more than 85- and 90-percent full, respectively. If the parking utilization exceeds these figures, additional parking may be required.

PREFERRED PARKING LOT DIMENSIONS



17.2.2. Access Points

Factors such as pedestrians, traffic control, turning restrictions, and traffic volumes will affect the design of parking facilities, particularly the location of entry and exit points. As shown below, a minimum driveway turning radius of 20 feet is recommended. A driveway width of 25 feet is recommended for two-way traffic flow. Also, as discussed in Chapter 15, try to locate driveways at least 200 feet from intersections, particularly for larger traffic generators. A qualified engineer should determine the exact spacing and location of access points.

When designing access points to parking lots, be sure to use the same design standards for signing and pavement markings as are used for adjacent roadways.

17.2.3. Setbacks

KEY POINT

See UFC 4-010-01 for information on standoff distances to parking areas.

Parking adjacent to buildings should be avoided to allow a buffer space for plantings and sidewalks. This space, or setback, should be a minimum of 20 feet between the parking area and adjacent buildings. In addition, provide a minimum of 20 feet for the buffer strip separating the parking area from the street. Force protection concerns may require a larger buffer strip.

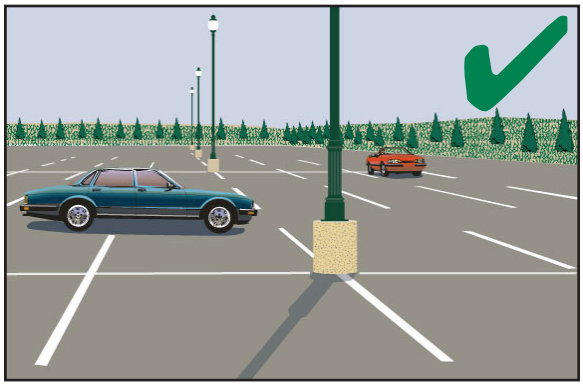
Force protection concerns often require a larger distance separating the parking area from an inhabited building. For parking within a controlled perimeter, which typically would include any installation that has entry control, the standoff distance requirements between a parking area and the building is 33 feet for an inhabited building, or 82 feet to a primary gathering building, billeting, or high occupancy family housing area.

See UFC 4-010-01 for more information on standoff distances to parking areas.

Parking areas themselves are generally not considered to need standoff distance from other areas. For example, if a parking area is located adjacent to an installation perimeter fence, there is generally no need for standoff distance.

17.2.4. Lighting

Locate parking lot light fixtures away from traffic aisles and parking stalls. Light poles are ideally located in center or side islands, and protected by raised curbs. When light poles are within parking rows, locate the poles at the junctions of adjacent stalls as shown below. Poles and fixtures should be in scale, and accommodating to, the setting and surrounding area, while providing the desired level of nighttime illumination. Mounting height and spacing of luminaires should be sufficient to distribute the desired lighting intensity to the entire parking area. A normal lighting level is from 1.0 to 2.0 foot-candles.



Preferred light fixture location

17.2.5. Stall Layout

KEY POINT

For perpendicular parking, stalls for most vehicles should be 9 feet wide by 18.5 feet long.

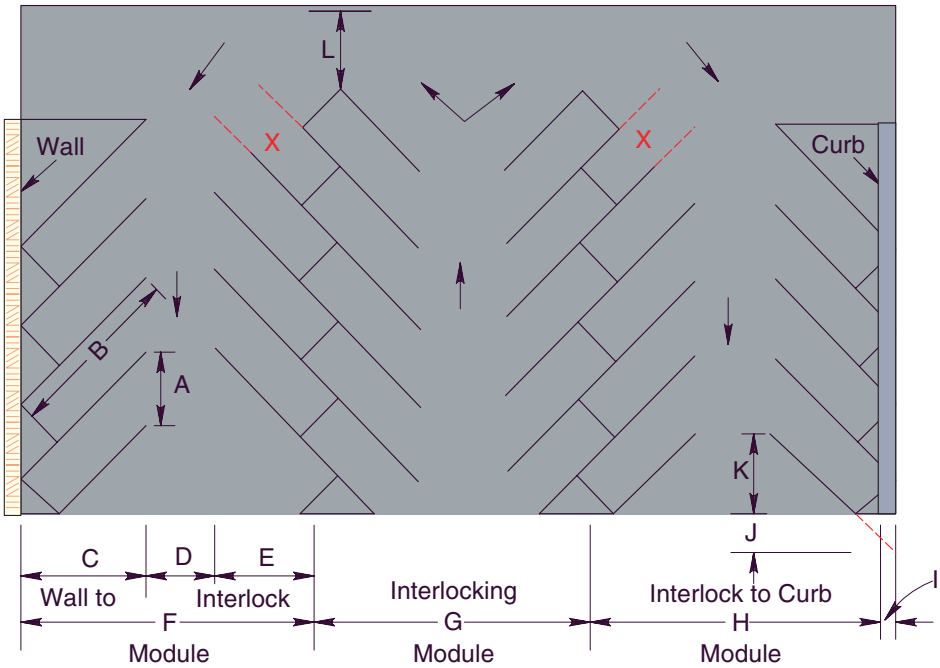
Ideally, parking lots should be rectangular with parking on both sides of access aisles. For two-way traffic flow, parking spaces perpendicular (90°) to the aisles provide the most efficient design. The efficiency decreases as the parking angle decreases. Where a fast turnover rate is expected or where site limitations dictate, 60-degree or 45-degree angle parking with one-way aisles may be used. However, the advantage of easy pull-in and pull-out that angle parking provides is often offset by the inconvenience of one-way aisles, and the tendency of motorists to attempt to pull into a space from the wrong direction. Exhibit 17.1 provides stall layout dimensions for various parking angles.

KEY POINT

For planning purposes, assume an area of 350 square feet per parking space.

Site dimensions, topography, and vehicle type affect the design of parking lots. As a general rule, about 350 square feet is required per car to account for traffic aisles, space between adjacent cars, and entrance and exit lanes.

Exhibit 17.1: Stall Layout Dimensions



X = Stall not accessible in certain layouts

Parking layout dimension (in feet) for 9 ft. stalls at various angles

DIMENSION	ON DIAGRAM	ANGLE			
		45°	60°	75°	90°
STALL WIDTH, PARALLEL TO AISLE	A	12.7	10.4	9.3	9.0
STALL LENGTH OF LINE	B	27.5	23.7	20.9	18.5
STALL DEPTH TO WALL	C	19.5	20.5	20.0	18.5
AISLE WIDTH BETWEEN STALL LINES	D	12.0	16.0	23.0	26.0
STALL DEPTH, INTERLOCK	E	16.5	18.5	18.5	18.5
MODULE, WALL TO INTERLOCK	F	48.0	55.0	62.0	63.0
MODULE, INTERLOCKING	G	45.0	53.0	61.0	63.0
MODULE INTERLOCK TO CURB FACE	H	46.0	53.2	59.5	60.5
BUMPER OVERHANG (TYPICAL)	I	2.0	2.3	2.5	2.5
OFFSET	J	6.4	2.6	0.6	0.0
SETBACK	K	13.1	9.3	4.8	0.0
CROSS AISLE, ONE-WAY	-	14.0	14.0	14.0	14.0
CROSS AISLE, TWO-WAY	L	24.0	24.0	24.0	24.0

17.2.6. Landscaping

The objective of parking lot landscaping is to enhance the lot, provide a buffer zone between adjacent land uses, and to subdivide large parking areas. Landscaping should never obstruct the view of motorists in a parking facility, or interfere with the parking function. Be sure to provide sufficient setbacks for all plants, so that the front or rear overhangs of parked vehicles do not damage or destroy them. Ensure that placing and maintaining shrubbery or other plants near entrances and exits does not restrict sight distance. Also consider the growth pattern of the plant, so that a small plant will not develop into a major sight restriction in the future.

17.2.7. Drainage

Provide adequate grading of surface lots to minimize the possibility of low or flat spots. Accumulation of standing water in a parking lot is a hazard for both vehicle and pedestrian movements, particularly in cold climates where freezing may lead to icy spots. Recommended minimum grades are 1.0 percent for asphalt surfaces and 0.5 percent for portland cement surfaces.

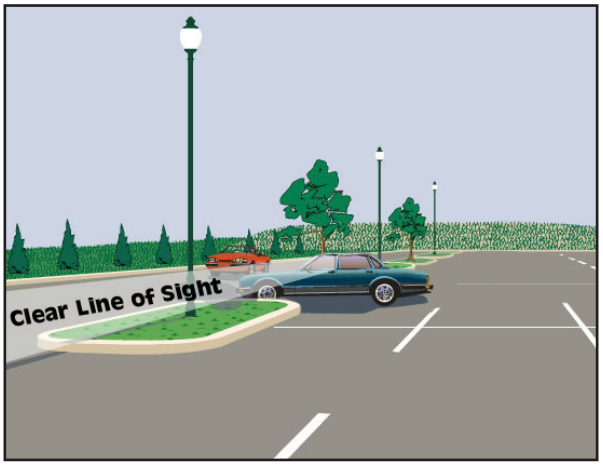
Proper drainage is important!

17.2.8. End Islands

Space at the end of each aisle should be kept clear of parked vehicles to allow turning motorists a clear view down the cross aisle.

Mark this area with either white paint or a raised traffic island. Islands should be designed to accommodate the turning maneuvers of vehicles in the parking lot. A passenger car requires a right-turning radius of 18 feet. Raised end islands can provide a location for signs and light fixtures.

They also provide an aesthetic function by breaking up the “sea of pavement” as well as providing a place for plantings. While these other functions are useful, adequate sight distance for motorists using the parking lot must be maintained.



End aisle configuration

Exhibit 17.2: Other Off-Street Parking Design Considerations

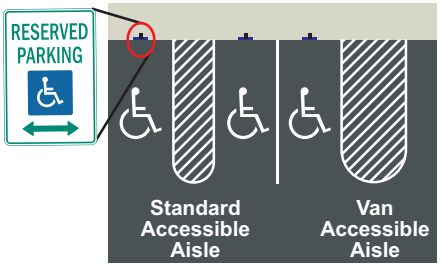
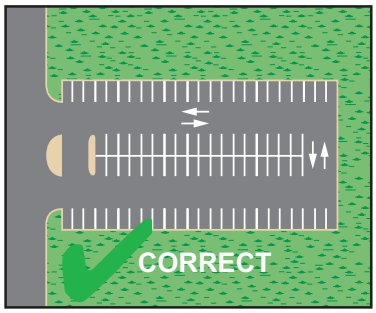
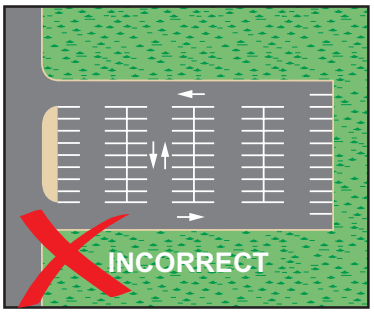
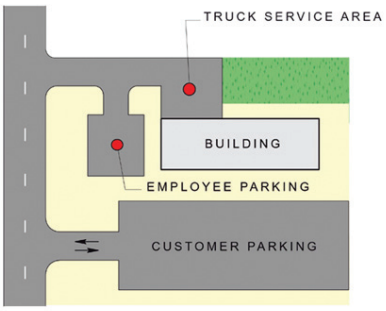
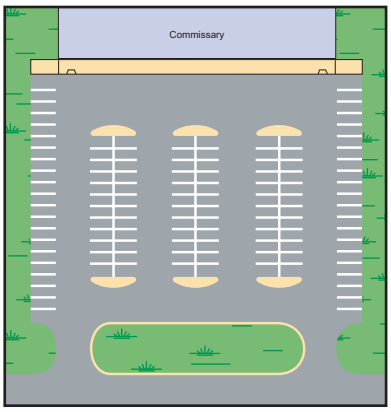
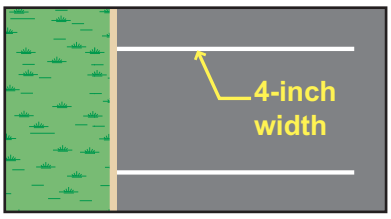
ACCESSIBLE PARKING	
The Americans with Disabilities Act (ADA) requires that a certain number of parking spaces be set aside for accessible parking. Generally, this amounts to about 4 percent of the total number of spaces within a lot for the first 100 spaces; 3 percent for 101-200 spaces; and 2 percent for 200 or more spaces. Medical facilities require additional accessible parking. Handicapped spaces should be located immediately adjacent to the nearest building entrance; or in the case of a remote parking lot or garage, the location where pedestrians exit. Provide a 60-inch access aisle and a ramp. Display the handicapped symbol on a signpost at the head of the stall.	
AISLES	
Provide aisles parallel to the long side of the lot with cross aisles every 30 spaces in large parking areas. This layout results in a 20 percent increase in lot capacity compared to aisles oriented parallel to the short side of the lot.	 
EMPLOYEE PARKING	
The employee parking lot for a facility should be separate from the main parking lot. Providing a separate lot helps to avoid a mixture of all-day parking with short-term customer parking.	 SEPARATE PARKING AREAS

Exhibit 17.2: Other Off-Street Parking Design Considerations (continued)

ENTRANCES AND EXITS	ROWS	
Design entrances and exits to serve as a continuation of traffic aisles. Avoid sharp turns whenever possible. Another good practice is to prohibit stalls so close to the entry/exit point that parking maneuvers would obstruct traffic flow.	Parking rows should be perpendicular to buildings for the safety and convenience of pedestrians; however, perpendicular rows less than 130 feet long are not practical. In this case, rows parallel to the front of buildings are recommended.	
PAVEMENT MARKINGS		
White is normally the best color for marking stall lines. All lines should be 4 inches wide.		
WHEELSTOPS		
Wheelstops are often used along the site boundaries of uncurbed lots, where large landscaped areas extend beyond the edge of pavement. Wheelstops in the interior of a parking lot have a few disadvantages: they may hinder people walking between cars; they are often a hazard when hidden from view by parked cars; they tend to trap blowing debris; and they adversely impact snow removal.		
SURFACE TREATMENT		
Paved parking areas are desirable for many reasons including controlling drainage, reducing mud and dust, improving walking surfaces, reducing maintenance costs, and providing a pleasing appearance. Paved parking lots should be marked to provide safe, efficient, and enforceable parking lot operations.		
MAINTENANCE		
For good visibility, repaint markings as needed, and replace old signs. Clean light fixtures at least annually, and replace bulbs before burnouts occur. A properly designed lot is great, but a good maintenance plan is necessary to keep it that way.		

17.3. PARKING GARAGES

Parking garages are often used where there is a considerable demand for parking with a significantly low amount of available space. From a master planning standpoint, parking garages can provide the same amount of parking spaces while using only a fraction of land when compared to surface lots.

The primary drawback to parking garages is the cost. Parking garages often cost in excess of $15,000 per parking space. Therefore, parking garages are often not the first alternative when running out of available space for parking. When there is no space available for parking, consider possible alternatives:

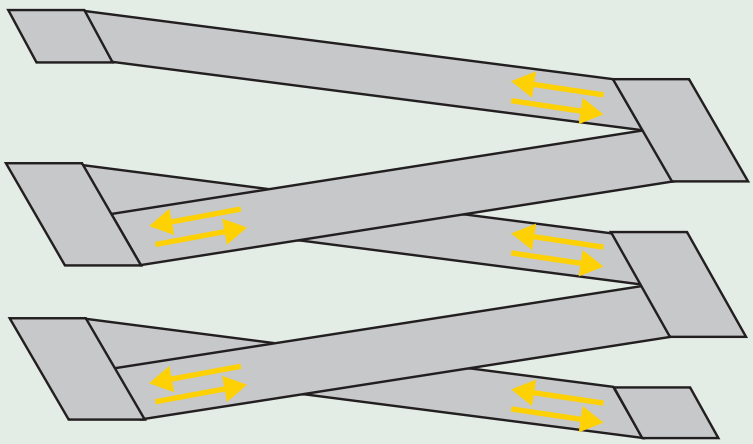
- ✓ Implement a shuttle system. Parking for buildings can be located at a location farther away from the building it serves, and a shuttle can transport people to and from their buildings.
- ✓ When planning the location of a building, if there is no available space for parking, consider relocating it to a more open area where there is plenty of available land for the building and its parking area.
- ✓ Utilize demand management strategies to reduce parking demand. Encourage the use of public transportation, carpooling, or working from home.

When these alternatives are not viable, a parking garage can often be considered.

When planning a parking garage, keep entrances spaced at about 100 feet minimum to maximize the available space between the access and the adjacent street. Exits should be located on low-volume streets to reduce delay to traffic leaving the garage. The most common circulation pattern used in the United States is the continuous ramp, where sloping floors with aisles and parking spaces along both sides of the aisle provide access to the parking spaces themselves and the garage's circulation route. If stairs are the only means of pedestrians changing floors in the garage, as would typically be if there are only two to three floors, at least one stairway should be provided facing major destinations. Generally, one elevator serving a parking garage should be provided for every 250 spaces when the garage is multilevel.

Standoff distance for parking garages is not considered to be needed since they are not considered to be inhabited. Standoff distance is needed between the parking garage and inhabited buildings.

CONTINUOUS RAMP - TWO-WAY TRAFFIC



17.4. ON-STREET PARKING

About 20 percent of all crashes in built-up areas involve vehicles parked along the roadway. On-street parking is not desirable on arterial or collector roads that are designed to move high traffic volumes at moderate or high speeds. On lower speed roadways, such as residential streets, on-street parking is acceptable because it "calms" traffic and thus reduces vehicle speeds.

17.4.1. Angle Versus Parallel Parking

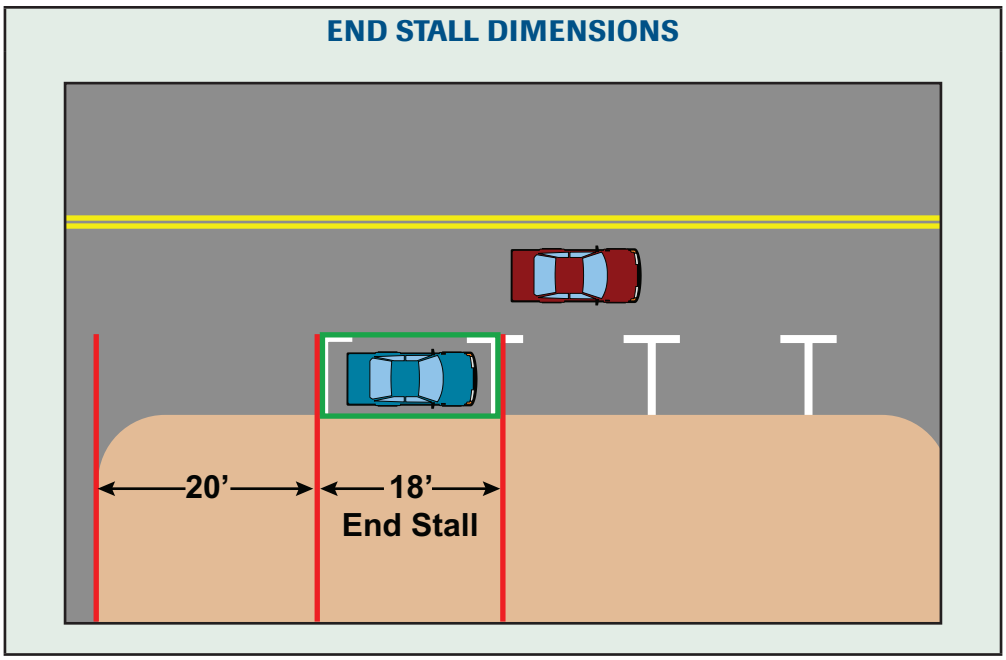
Angle on-street parking provides more parking per unit of curb length than parallel parking. However, angle parking increases the hazard of starting, stopping, and turning in moving traffic and, therefore, is discouraged. The principal hazard of angle parking is the driver's lack of adequate visibility during backing maneuvers, especially when a large vehicle is parked upstream.

Because empty parking stalls are difficult to see with angle parking, motorists who are seeking a place to park create another hazard. They must either proceed slowly in order to find an empty stall, or stop abruptly when they come to an empty stall. Angle parking is generally unsafe and its use should be discouraged.

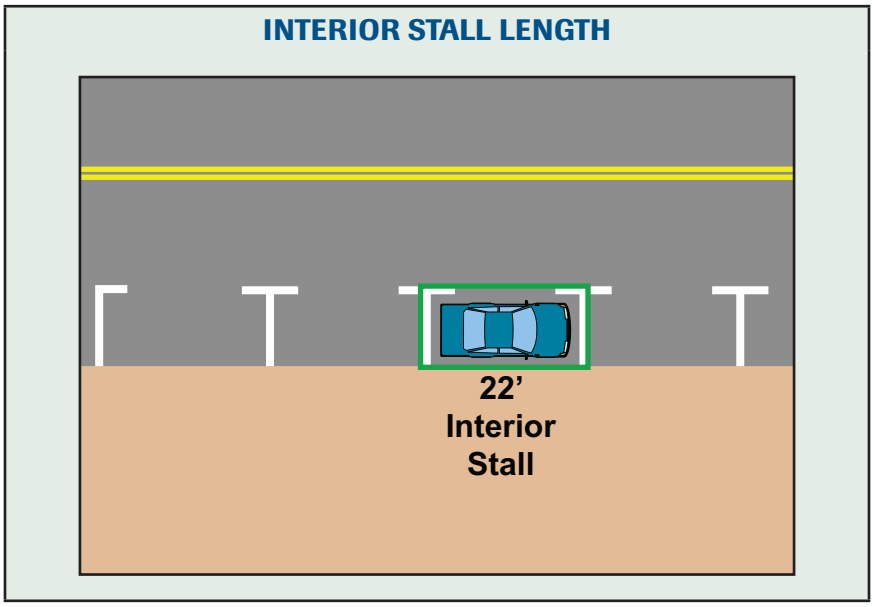
Angle parking

17.4.2. Layout of On-Street Parking Stalls

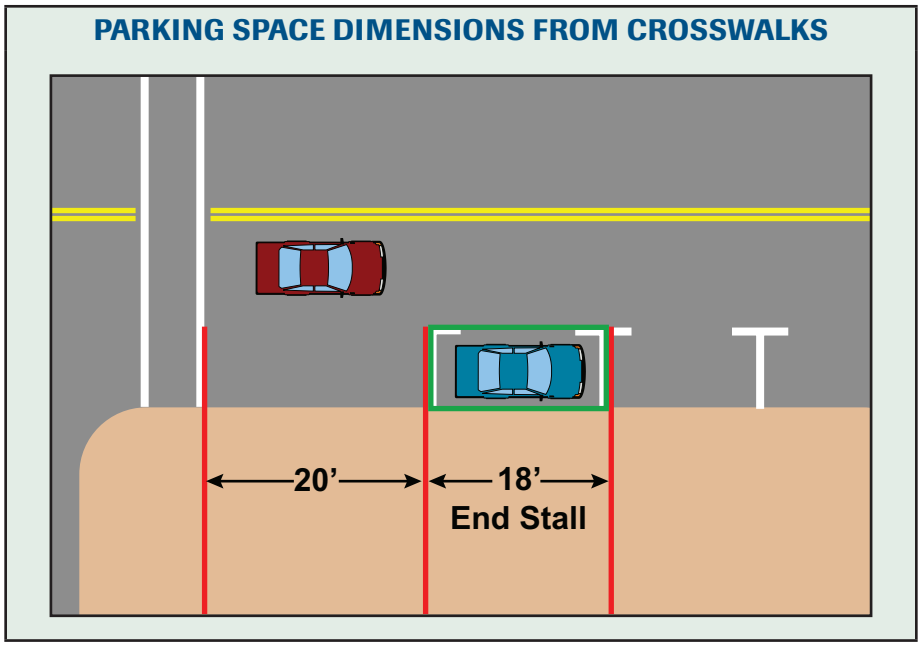
There are two types of stalls to consider when designing on-street parallel parking: the end stall and the interior stall. An end stall is used where a vehicle can be driven directly into or out of the parking space. End stalls require a length sufficient enough to accommodate a passenger car, typically 18 feet. Maintain a minimum of 20 feet between an end stall and a curb opening or intersection.



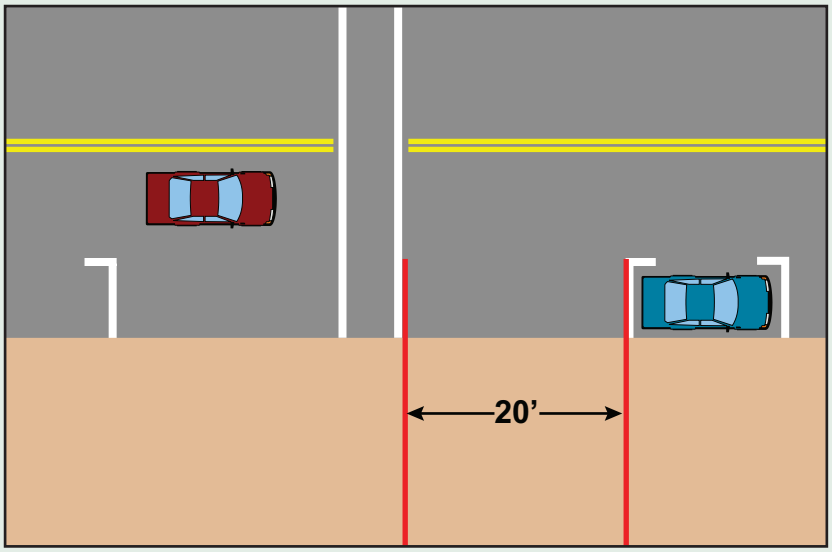
An interior stall requires room for maneuvering into and out of the parking space; therefore, a 22-foot-long stall is recommended.

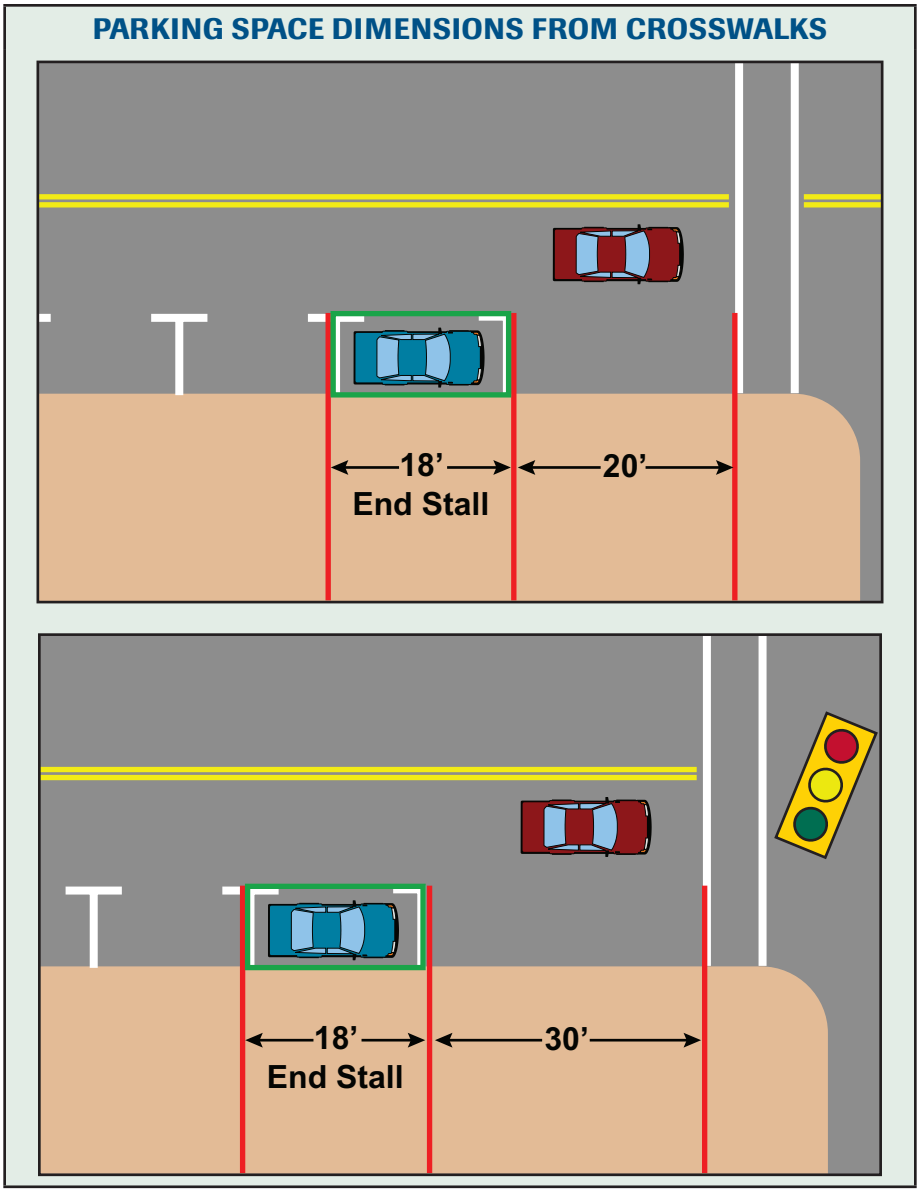


When on-street parking is located near a crosswalk, leave a buffer strip of 20 feet between the crosswalk and the parking space to maximize visibility between pedestrians and motorists. This applies to crosswalks located at intersections, as well as for midblock crosswalks. When crosswalks are located on the approaches to a signalized intersection, use a spacing of 30 feet.



PARKING SPACE DIMENSIONS FROM MIDBLOCK CROSSWALKS

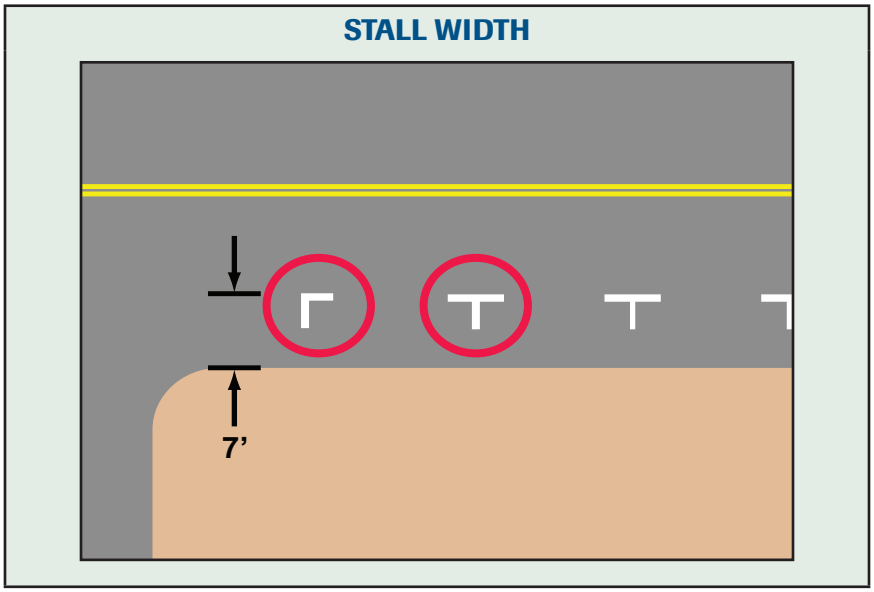




For all of the dimensions discussed in this section, note that they are minimum distances. When laying out actual distances, field-verify all parking spaces to ensure that acceptable sight distance is provided.

17.4.3. On-Street Delineation

Parallel parking stalls should be defined by white lines extending perpendicular from the curb, for a distance of 7 feet. Generally, end stall lines are L-shaped and interior stall lines are T-shaped.



17.4.4. Parking Restrictions

Control of on-street parking is accomplished through signing, markings, and enforcement. Signing and marking regulations are discussed in the *MUTCD*. Standard parking restrictions are set forth in the National Uniform Vehicle Code. Some common parking restrictions are:

- ✓ In front of a public or private driveway
- ✓ Within an intersection
- ✓ Within 15 feet of a fire hydrant
- ✓ Within 20 feet of a crosswalk at an intersection
- ✓ Within 50 feet on the approach to any flashing beacon, STOP sign, or traffic control signal located at the side of a roadway
- ✓ Within 50 feet of the nearest rail of a railroad crossing
- ✓ On any bridge or other elevated structure on a highway.

CHAPTER 18 – CONVOYS

18.1. CONVOY BASICS 18-1

18.2. CONVOY VEHICLE CONSIDERATIONS 18-2

18.3. CONVOY ROADWAY CONSIDERATIONS 18-2

18.4. FLAGGER SAFETY APPAREL 18-3

KEY POINT

Field Manual 55-65 has additional information on Convoy deployment operations.

Convoys are an extremely critical method of deployment on land. Convoy operations generally are comprised of larger and heavier vehicles which tend to travel slower than the regular traffic stream. Due to this, their operations on public roadways must be given special consideration. Field Manual (FM) 55-65 describes procedures to follow when operating convoys. The intent of this section is to expand on some of the information contained in FM 55-65, particularly with respect to convoy operation, and considerations relating to the mix of convoy traffic with public traffic on public roadways.

18.1. CONVOY BASICS

Typically, as a convoy travels, the slowest vehicle is used to set the speed of the convoy. This vehicle is referred to as the pacesetter. A guide is used to ensure that the convoy travels the correct route, particularly when signing is poor. Guides do not have priority over civilian traffic, and must follow all traffic signals and other traffic control devices.

Civilian police should be used to assist in the following areas:

- ✓ Major intersections
- ✓ Entrances to and exits from expressways and main routes
- ✓ Densely populated and industrial areas
- ✓ Entrances to and exits from rest halt areas
- ✓ Intersection areas near the installation where the convoy originates.

Different municipalities may have different policies regarding police utilization. For example, some may require compensation for assistance, particularly if officers require overtime.

Communication between convoy vehicles is accomplished through several modes. Radio is the primary mode of communication, but visual communications are often used. Visual communications generally occur through the use of hand and arm signals from either vehicles or flaggers. Audible communications, such as horns or whistles, may also be used.

If a flagger assists in directing traffic, they should use high visibility safety apparel, similar to apparel used in work zones. This is critical to maximize their visibility by both the convoy drivers, as well as by public motorists driving near the convoy.

18.2. CONVOY VEHICLE CONSIDERATIONS

Vehicles in a convoy may generally be apparent due to their appearance. In lieu of this, the front and rear vehicles of each convoy must clearly indicate the presence of the convoy. This is accomplished by:

- ✓ Front vehicle displays a sign with the legend "CONVOY FOLLOWS." It also must use a blue flag, 12 by 18 inches, mounted on the left-front of the vehicle.
- ✓ Rear vehicle displays a sign with the legend "CONVOY AHEAD." It also must use a green flag, 12 by 18 inches, mounted on the left-rear of the vehicle.

Additionally, all vehicles should travel with their headlights on low beam.

18.3. CONVOY ROADWAY CONSIDERATIONS

The roadway itself should be considered in determining the appropriate route for a convoy.

For oversize or overweight vehicles, a special hauling permit is required in order to request permission to use public roads.

Also, the number of travel lanes should be considered. If the travel speed of the convoy is considerably lower than the freeflow speed of the roadway, the convoy will delay public traffic. If this occurs on roadways with one lane per direction, consider finding pull-off areas to allow traffic to pass so as to not delay traffic unnecessarily. This would reduce the chances for a vehicle to attempt to pass the convoy by leapfrogging through the vehicles in the convoy. If a convoy travels a multilane arterial or freeway, vehicles would pass in the second lane. In general, having a large speed differential between vehicles by lane is not ideal, but the convoy uses attention-getting devices to maximize visibility by vehicles. Civilian police can also assist with controlling traffic.

18.4. FLAGGER SAFETY APPAREL

KEY POINT

People working in traffic should always at a minimum wear a reflective vest.

Flaggers are critical components of convoy operations. Flaggers have uses beyond convoy operations, such as in work zones or incident management applications. This section discusses flagger apparel and equipment that should be used.

For daytime and nighttime activity, flaggers shall wear high-visibility safety apparel that meets the Performance Class 2 or 3 requirements of the ANSI/ISEA 107–2004 publication entitled "American National Standard for High-Visibility Apparel and Headwear" and labeled as meeting the ANSI 107-2004 standard performance for Class 2 or 3 risk exposure. The apparel background (outer) material color shall be fluorescent orange-red, fluorescent yellow-green, or a combination of the two as defined in the ANSI standard. The retroreflective material shall be orange, yellow, white, silver, yellow-green, or a fluorescent version of these colors, and shall be visible at a minimum distance of 1,000 feet. The retroreflective safety apparel shall be designed to clearly identify the wearer as a person.

Class 2 versus class 3 risk exposure refers to the amount of retroreflective material the person needs to wear. Class 2 typically can be provided by a single retroreflective vest. Class 3 requires a retroreflective vest and pants. Class 2 is typically used during daylight hours, and Class 3 should be used at night. Work zone flaggers should use Class 3 apparel by day and night.

The newer style of reflective vests, with the fluorescent yellow-green color and more color area is recommended. The older style with less color area is not recommended since it does not delineate from all directions, mainly the side of the person.

A fluorescent hat or hard hat is also recommended for head gear for additional visibility. Hard hats are usually needed in work zones.

Suggested vest style

18.4.1. Flagger Equipment

Flaggers directing convoys should use special equipment to supplement hand signals. This can include a STOP/SLOW paddle, a flag, or a lighted baton. Typically, flaggers use a STOP/SLOW paddle, or flag, as shown below.

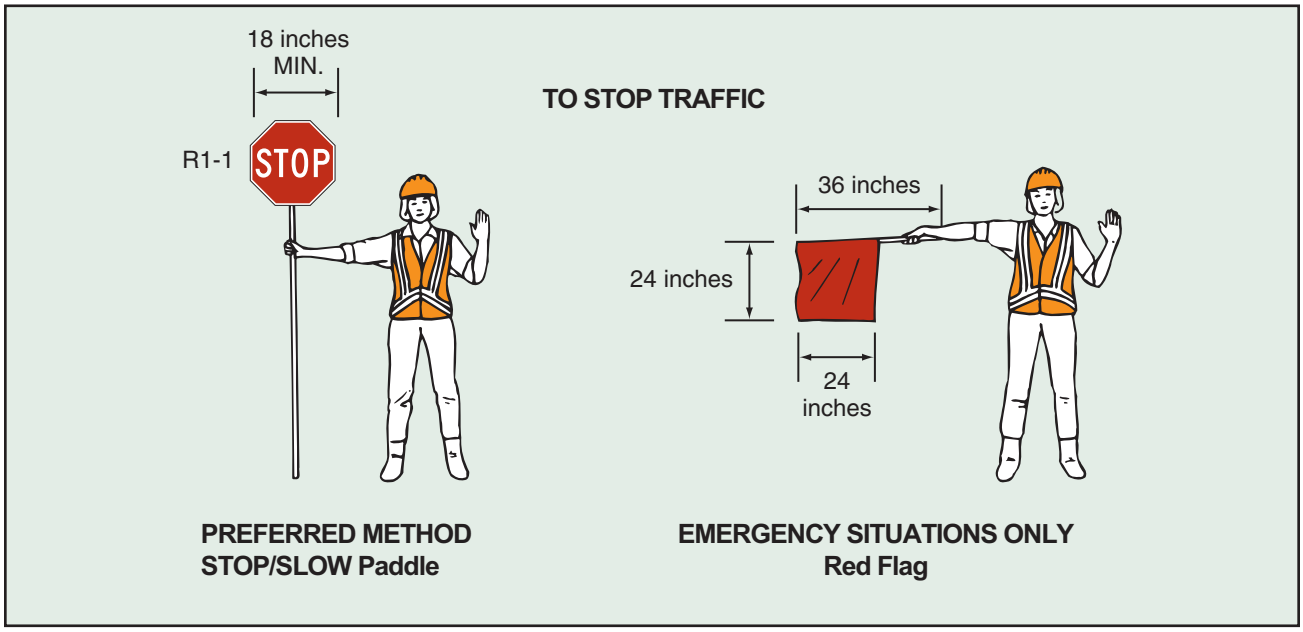
A disadvantage of the paddle is that the messages are limited to those which are contained on the paddle. If other messages are desired, such as would be the case if someone was directing the convoy to turn at a certain location, these messages would not suffice. Another disadvantage of the paddle is that it is bulky, and not as easily stored in a vehicle.

The flag offers more versatility compared to the STOP/SLOW paddle, but does not have reflectivity. Flags are made of a fluorescent orange vinyl material. This offers good visibility during daylight hours, but without retroreflectivity, it cannot be used at night. The actual flag can vary in size. Larger sizes are preferred for maximum visibility.

A lighted baton offers the advantage of nighttime visibility. Since it is not reflective, and does not have as much surface area visibility, it is not as effective during the day. For this reason, the use of a baton should be limited to nighttime.

In order to assist with audio signals, a flagger could have a whistle for use as needed.

Exhibit 18.1: Use of Hand-Signaling Devices by Flaggers



CHAPTER 19 – ENTRY CONTROL FACILITIES

19.1. ECF BASICS 19-1

19.2. ECF STUDIES AND EVALUATIONS 19-8

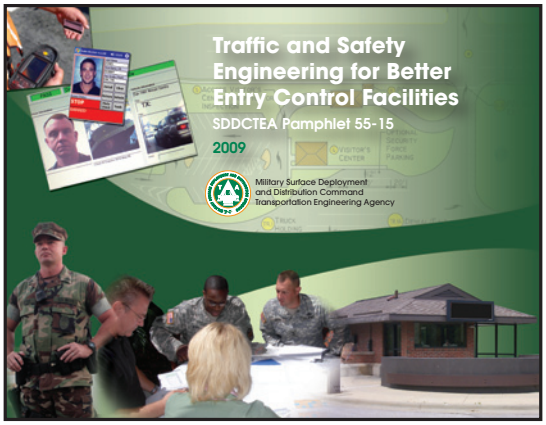
19.3. ECF COMPONENTS 19-16

19.4. ECF SIGNING AND MARKINGS 19-17

19.5. FORCE PROTECTION COMPONENTS 19-22

19.1. ECF BASICS

Mandatory vehicle access control to military installations is a DoD requirement. The term "Entry Control Facility" encompasses the overall layout, organization, infrastructure, and facilities of an access point. The term ECF is synonymous with Access Control Point (ACP); others commonly refer to ECFs as gates. Generally, the purpose of ECFs is to provide security by monitoring traffic entering installations. The degree of security required depends on the sensitivity level of the mission and the level of force protection at any given time.



SDDCTEA's *Traffic and Safety Engineering for Better Entry Control Facilities*, Pamphlet 55-15 covers ECFs in more depth than this pamphlet.

19.1.1. Service Requirements

UFC 4-022-01 is the applicable UFC for ECFs. In addition to this, each branch of the military has specific guidance regarding access to installations. The guidance is referenced in Exhibit 19.1.

19.1.2. Purpose of an ECF

KEY POINT

ECFs must combine security, safety, capacity, and aesthetics.

ECFs ensure the proper level of access control for all DoD personnel, visitors, and truck traffic to an installation. The objective of an ECF is to secure the installation from unauthorized access and to intercept contraband while maximizing traffic flow for both vehicles and pedestrians. Several components are required for an ECF to perform this function properly. ECF priorities are detailed in Exhibit 19.2.

Exhibit 19.1: ECF Service Design References

SERVICE	DESIGN REFERENCE
DEPARTMENT OF AIR FORCE	*Entry Control Facility Design Guide,* but *UFC* governs
DEPARTMENT OF ARMY	*Standard Definitive Design; Access Control Points for U.S. Army Installations*
DEPARTMENT OF NAVY	OPNAV 5530.14D, *Navy Physical Security Manual*
DEPARTMENT OF NAVY – MARINE CORPS	MCO P5530.14, *Marine Corps Physical Security Program*
COMBATANT COMMANDER REQUIREMENTS	Some combatant commanders have issued requirements for entry control procedures for installations within their area of responsibility. Ensure any such requirements are incorporated in addition to the requirements found in the *UFC*. Resolve any differences in the requirements for the design for an ECF by applying the most stringent requirement.

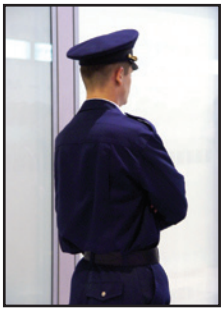
Source: The UFC

Throughout the planning of an ECF, remember that often the priorities in Exhibit 19.2 conflict with one another. For example, an increase in force protection condition level may result in more delays and congestion that may lead to congestion-related crashes. The change or elevation of one condition must always consider the impact to other priorities and, where appropriate, corrective action must take place.

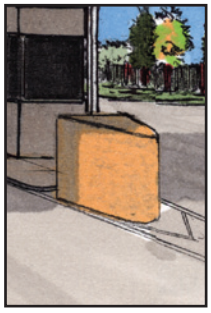
Exhibit 19.2: ECF Design Priorities

SECURITY	The first objective of an ECF is to maintain perimeter security for the installation. An ECF must be able to operate at all FPCONs.
SAFETY	Security Forces safety includes provisions for personnel protection against attack, errant drivers, and considerations for climate, location, and orientation. Safety measures such as reflectorization, impact attenuators, lighting, and properly placed pavement markings are an integral part of providing a safe approach for drivers entering or exiting the installation.
CAPACITY	The ECF needs to be capable of meeting the traffic demand with little or no delay under FPCON BRAVO+.
AESTHETICS	The ECF should provide a sense of arrival for the approaching individual. At a minimum, the ECF should impart an immediate impression of professionalism and commitment to facilities excellence.

SECURITY



SAFETY



CAPACITY

AESTHETICS

19.1.3. ECF Classifications and Functions

The UFC classifies ECFs into four use classifications: primary, secondary, limited use, and pedestrian access. As summarized in Exhibit 19.3, the UFC's ECF classifications are based on the intended function and anticipated usage of the ECF.

Exhibit 19.3: ECF Classifications

USE CLASSIFICATION	TRAFFIC VOLUMES	TYPICAL HOURS OF OPERATION	HIGHEST FPCON OPERATION	SERVICES PROVIDED	VISITOR PASSES	RANDOM INSPECTION	AUTHORIZED VISITORS	TRUCK PROCESSING
PRIMARY	High	24/7 - Open Continuously	Delta	Optional designation as truck and delivery ECF	✔	✔	✔	✔
SECONDARY	Moderate	Established Operating Hours	Closed at or above Charlie	Optional designation as truck and delivery ECF		✔	✔	✔
LIMITED USE	Low	Open for special purposes	N/A	Tactical vehicles, HAZMAT, special events, etc.				
PEDESTRIAN ACCESS	Varies	Varies	Closed at or above Charlie	Personnel only. Could be located near installation housing areas, near schools, or as part of a Primary ECF	✔		✔	

An ECF can have many functions. ECF functions include:

- ✓ Visitor processing
- ✓ ID Checks
- ✓ POV Inspections
- ✓ Truck Inspections

Not all functions are required at every ECF. Functions for each ECF are based on the installation's mission, antiterrorism (AT) plan, ECF use classification, and land area. Functions may change to meet the demands of higher FPCON levels.

A large installation may designate one ECF for truck inspection and truck access only.

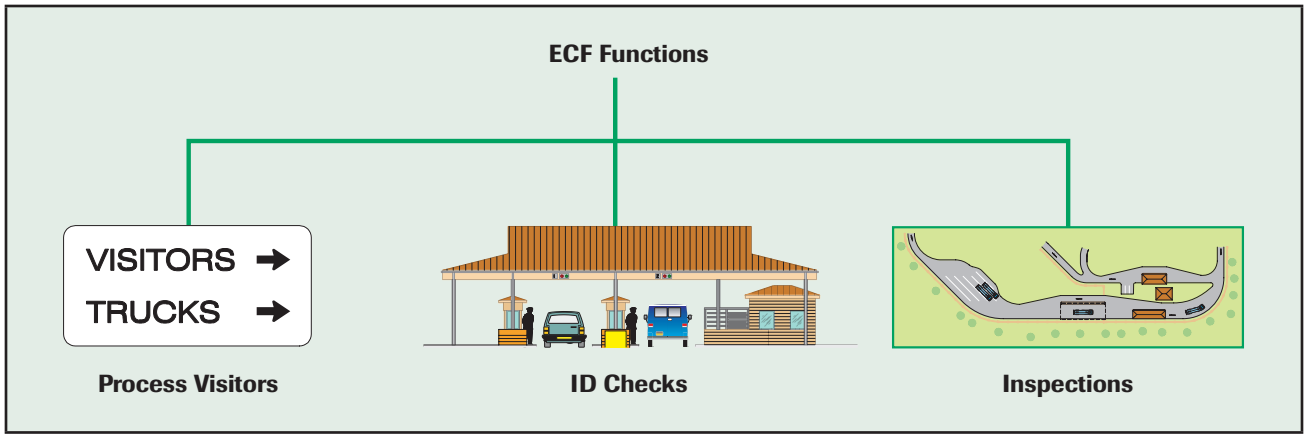
When an installation has a limited number of access points, functional requirements may need to be combined at an ECF. For example, an installation with only one ECF may combine functions or may use a separate truck inspection facility that is removed from the installation. In the latter case, special security arrangements must be provided.

Not requiring support for all functions at each ECF will reduce the infrastructure requirements. The UFC illustrates three functional relationships:

- ✓ Condition 1 – ECF with visitor processing
- ✓ Condition 2 – ECF without visitor processing
- ✓ Condition 3 – Truck ECF processing

Some of these functional relationships can be combined. An ECF with both visitor and truck processing combines conditions 1 and 3.

Exhibit 19.4: Basic ECF Functions

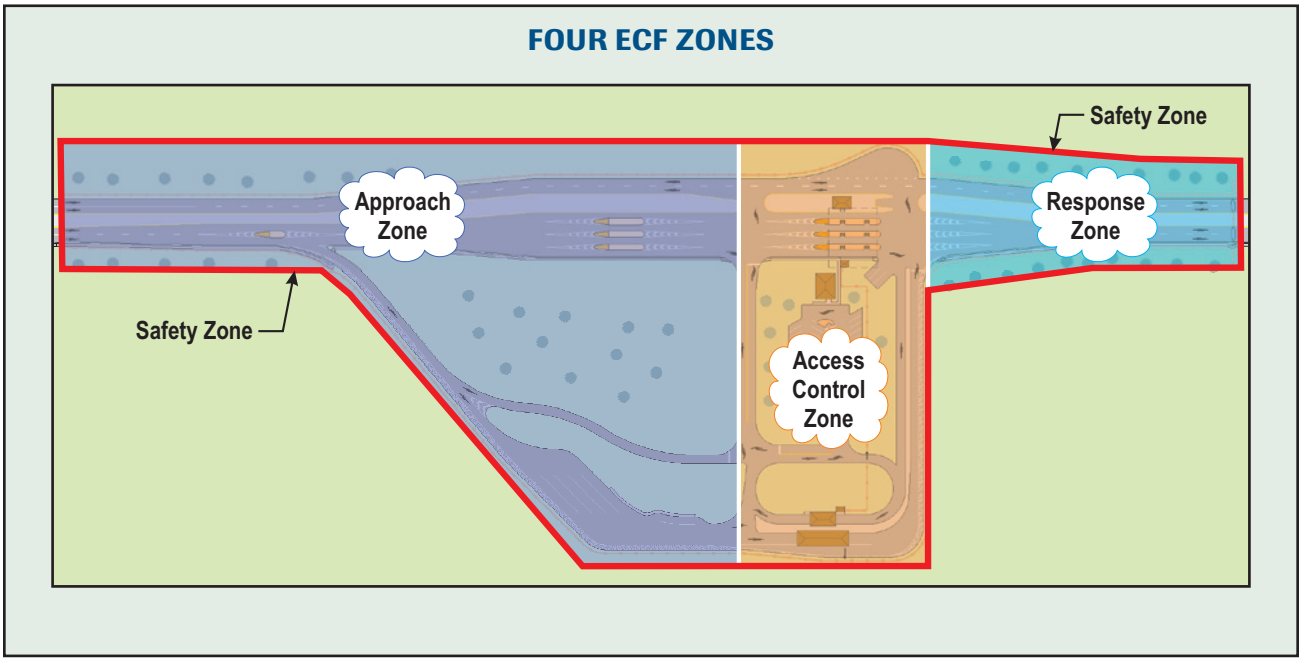


19.1.4. ECF Zones

An ECF consists of four zones, each encompassing specific functions and operations. Beginning at the installation property boundary, the zones include the safety zone, approach zone, access control zone, and response zone. These zones are summarized in Exhibit 19.5.

Exhibit 19.5: ECF Zones

ZONE	LOCATION	GOALS
SAFETY	Extends in all directions beyond passive and active barriers	Protect assets and personnel from explosions
APPROACH	Installation boundary to a point just before the ID checkpoint	Reduce speed, sort vehicles, provide stacking room, identify potential threats
ACCESS CONTROL	A point just before and after the ID checkpoint	Identify vehicles and personnel; provide surveillance, random inspection, visitor processing and rejection capabilities
RESPONSE	A point just after the ID checkpoint to the active vehicle barriers	Provide measures to react to and resist a threat



19.1.5. Applied Designs

Exhibits 19.6 and 19.7 show applied designs that combine design standards with existing site constraints. Frequently, properly designed ECFs use a large amount of land. These are examples of locations that include all proper ECF requirements in areas where there are limitations on available land.

Exhibit 19.6: Applied ECF Designs

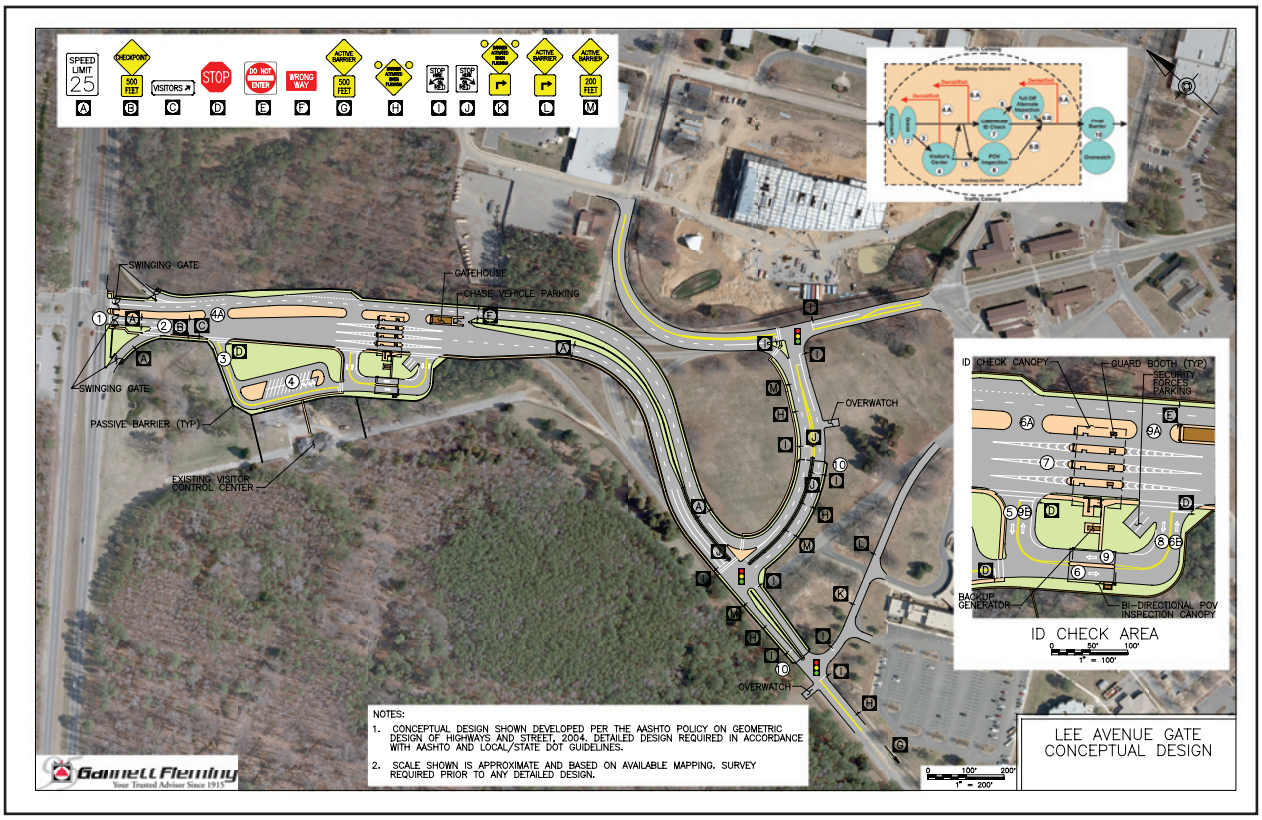
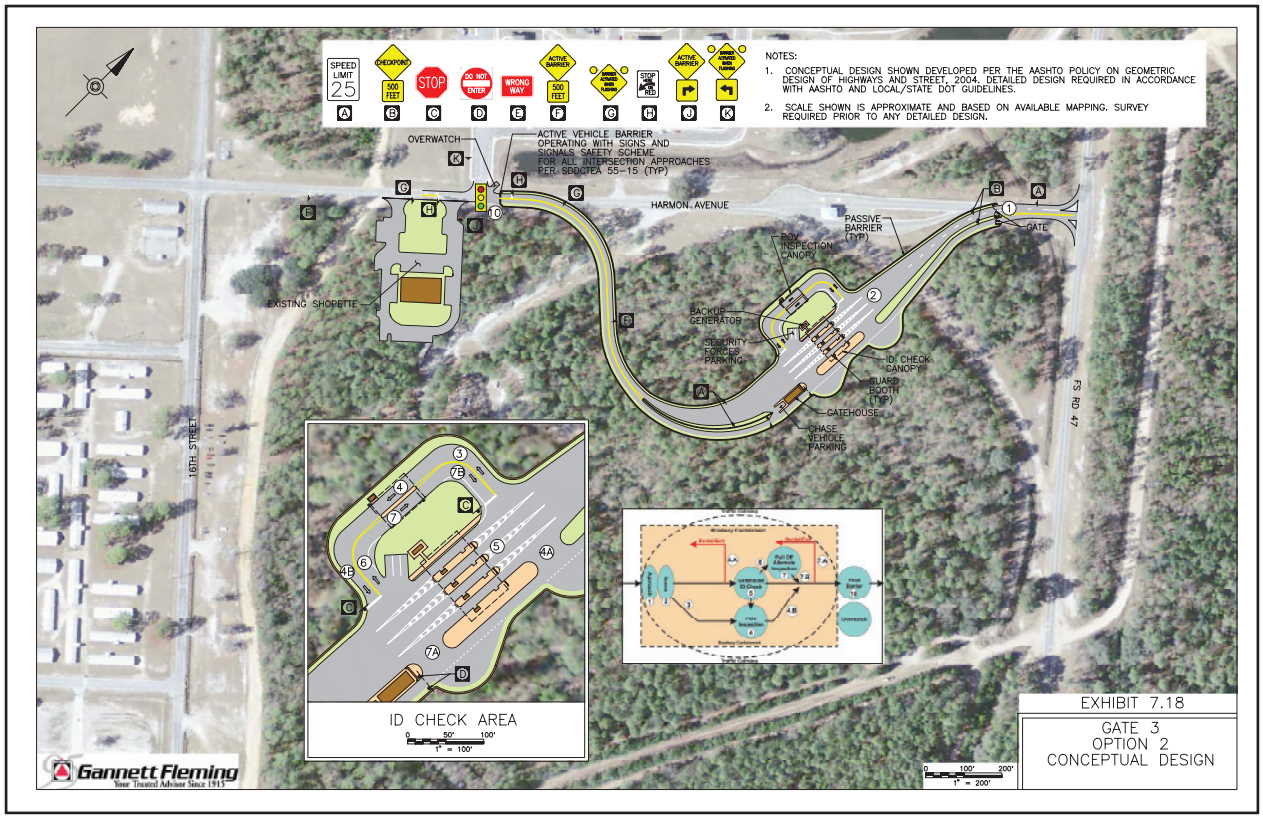


Exhibit 19.7: Applied ECF Designs



19.2. ECF STUDIES AND EVALUATIONS

KEY POINT

When constructing an ECF, plan for the future.

Proper planning will help ensure that ECFs meet an installation's needs, satisfy ECF priorities, satisfy ECF functions, and accommodate future development plans. A systematic assessment of individual ECFs can help identify short- and long-term needs that are required to address security, safety, and traffic flow.

19.2.1. Traffic Engineering and Safety Assessment

In evaluating ECF conditions, consider the following components:

- ✓ **Security and Functional Requirements** – Does the ECF satisfy the UFC functional requirements for ECFs?
- ✓ **Safety** – Is there a documented crash history or any documented safety deficiencies?
- ✓ **Service Requirements** – Does the ECF satisfy service standards and requirements?
- ✓ **Traffic Flow and Congestion** – Does the ECF accommodate existing and future traffic demands?
- ✓ **Aesthetics** – Does the ECF conform to architectural requirements?
- ✓ **Accessibility and Development Plans** – Does the ECF provide suitable access to existing and future land uses?
- ✓ **Installation Wide Needs** – Does the ECF serve the existing and future needs of the installation in its current location?

SDDCTEA can provide a traffic engineering and safety assessment of existing and/or proposed ECFs.

While conducting an ECF assessment, many different areas are studied. During the site visit, the ECF evaluation team should be focused on evaluating the different components of the ECF and how those components compare to current standards.

There are eight broad categories to assess when studying an ECF:

- ✓ Security
- ✓ Crash history
- ✓ Road safety
- ✓ Guard safety
- ✓ Traffic flow and congestion
- ✓ Operations and manpower
- ✓ Accessibility and development
- ✓ Aesthetics

Once existing data has been gathered and field conditions assessed, solutions and alternatives can be generated by applying engineering standards and analyses. Exhibit 19.8 is a checklist for the entire ECF evaluation process.

Exhibit 19.8: ECF Evaluation Checklist

- ✓ Early Coordination with Stakeholders Command
  - Security forces
  - Department of public works
  - Safety officers
  - First responders
  - External stakeholders (county, external responders, state DOT)
  - Guards
  - Others
- ✓ Information Gathering
  - Previous studies
  - Planning data
  - Electronic mapping
  - Force protection information
  - Signalized intersection data
  - Crash data
  - Staffing levels
- ✓ Traffic Data Gathering and Collection
  - Automated traffic recordings of inbound and outbound traffic volumes
  - Peak hour ECF volumes
  - Maximum ECF queuing during peak times
  - Peak hour turning movement counts at adjacent intersections
  - 24-hour and peak hour truck volumes
  - 24-hour and peak hour pedestrian and bicycle volumes
  - Visitor's center demands and processing
  - Inspection procedures and processing (POVs and Trucks)
- ✓ Safety Review
  - Guard
  - Motorists
  - Hazards/fixed objects
  - Sight distance
  - Conflicts
  - Signing and markings (layout/retroreflectivity)
  - Lighting review
- ✓ Operational and Manpower Review
  - Interaction with signals (retiming opportunities)
  - Queue mitigation strategies
  - Processing procedures and manpower usage
- ✓ Inspection Procedures
  - Planning considerations
  - Master plan
  - BRAC
  - Deployment
  - Local growth
- ✓ ECF Sizing Analyses
  - Number of lanes (single vs tandem)
  - Visitor's center parking
  - Truck holding
- ✓ Installation-wide Review
  - By ECF (lanes, ingress vs egress)
  - Consolidation scenarios to maximize resources
  - Total needs
- ✓ Short-term, Low-cost Solutions
  - Guard safety
  - Motorist safety
  - Speed management
  - Operations and processing
  - Low-cost facility needs
- ✓ Alternatives Development
  - Possible charrette
  - Pros/cons matrix
    - Land use and development impacts
    - Environmental constraints
    - Utility constraints and needs
    - Force protection constraints (stand-off, etc.)
    - Wind, sun, weather, etc.
    - Traffic constraints
    - Flight line restrictions
  - Preliminary active vehicle barrier assessments
  - Preliminary costs
  - Rationale for dismissal
- ✓ Refined, Preferred Alternative
  - Standards compliance review and rationale
  - Functions/feature review
- ✓ Active Vehicle Barrier Response Zone and Scheme Assessment
  - Threat scenarios and response calculations
  - Stand-off issues
  - Scheme alternatives and selection
  - Traffic and safety layout
  - Intersection design, if applicable
- ✓ Technology Assessment
  - Role of automation
  - Overheight detection
  - ITS opportunities (DMS, CCTV)
- ✓ Special Events Overview (Evacuation, Housing Turnover, Public Event)
- ✓ Cost Estimates
  - By key areas (roadway, facilities, AVB, etc.)
  - Programmatic approach
- ✓ Report

19.2.2. Traffic Flow Considerations

Traffic data collection should be conducted during a typical weekday under normal operations. As necessary, traffic counts can be adjusted to account for military deployments or planned growth. Key elements of a thorough traffic data collection program are shown in Exhibit 19.9.

Exhibit 19.9: ECF Traffic Data Requirements

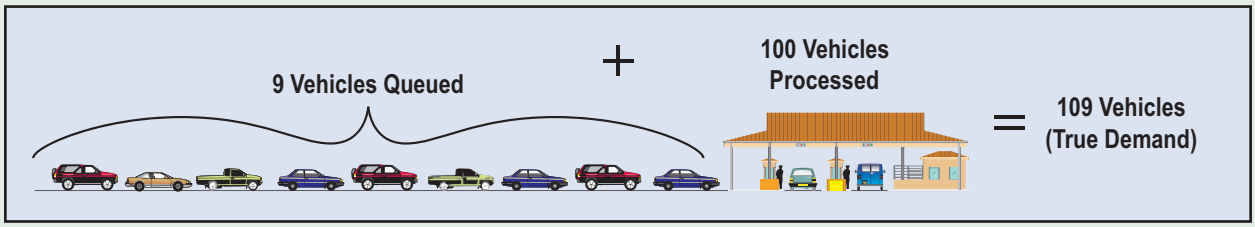
ID CHECK COUNTS	✓ For each inbound lane the amount of traffic processed should be collected in 15-minute increments during peak inbound periods. • During congested conditions, the counts represent the processing capability of the lane. • During non-congested conditions, the counts represent the inbound vehicular demand.
MAXIMUM QUEUE ASSESSMENT	✓ During congested conditions, the maximum number of vehicles queued should be recorded as well as the length of the queue. • The length of the queue will assist planners and engineers in assessing impacts to local roadways and if corrective measures are required.
TURNING MOVEMENT COUNTS AT ADJACENT INTERSECTIONS	✓ TMCs should be collected in 15-minute increments during peak periods. • TMCs provide a better understanding of traffic flow patterns and allow engineers to assess if intersection operations (such as signal timings) need adjusted to complement ECF operations.
PEDESTRIAN AND BICYCLE COUNTS	✓ The number of pedestrians and bicycles entering the installation during the peak period should be recorded. • These counts assist engineers in determining the proper pedestrian and bicycle accommodations.
AUTOMATED TRAFFIC RECORDINGS	✓ ATRs automatically record traffic over a 24-hour period for several days, if necessary. • ATRs provide data in 15-minute increments and permit an evaluation of daily flow patterns.
VEHICLE CLASSIFICATION COUNTS	✓ As part of ID Check Counts, TMCs and ATRs should be collected in order to assess the types of vehicles entering so that the facility can be designed properly.
VISITOR PROCESSING	✓ The number of visitors processed and the typical processing rate at an ECF should be recorded.
INSPECTION AREA	✓ Evaluate inspection elements such as demand and characteristics of vehicles to be inspected.

19.2.2.1. Traffic Adjustments

In calculating traffic demand, consider several other aspects that may influence traffic data.

- ✓ **Future Demands** – In civilian roadway projects, it is common to forecast traffic demands to a design year often 20 or 25 years into the future. The design year forecast is intended to accommodate future growth in roadway traffic. On a military installation, the population is more controlled and is dependent on the installation mission. However, planners and engineers should consider future development plans, possible mission changes, and base realignment and closure.
- ✓ **Local Development** – Planned commercial and residential development serving the installation should be considered in finalizing traffic forecasts. An example of this might be an off-installation residential development just outside an ECF. Some of the residents may be employees of the installation who utilize that ECF and will, therefore, increase traffic through the ECF.
- ✓ **Deployment Adjustments** – Traffic data should be collected at a time when the installation population is at a "normal" level. Periods of significant deployments should also be avoided, if possible; but, military missions around the world may make that unavoidable. When there are significant deployments, normal demand can be calculated by applying a deployment adjustment.
- ✓ **Calculating True Demand** – Depending on the FPCON, the number of vehicles counted in each lane may not represent the true demand. The true demand under congested conditions is the number of vehicles processed plus the queued demand.

QUEUING ADJUSTMENT



19.2.2.2. Lane Processing Rates

To accurately size an ECF, a lane-processing rate must be assumed. SDDCTEA has performed numerous ECF security, safety, and capacity traffic engineering assessments. During these assessments, SDDCTEA has collected significant data, which has been used to establish new criteria regarding capacity and processing rates at ECFs. The processing rate per lane with one ID checker ranges from 800 to 1,400 vehicles per hour for FPCON Alpha. For FPCON Bravo+, this rate drops to a range of 300 to 450 vehicles per hour per lane. Processing rates for different conditions are summarized in Exhibit 19.10.

Exhibit 19.10: ECF Processing Rates

PROCESSING TECHNIQUE	MANUAL CHECKS		CHECKS USING HANDHELD DEVICES		AUTOMATED LANES	
	SINGLE LANE CHECKS	TANDEM LANE CHECKS	SINGLE LANE CHECKS	TANDEM LANE CHECKS	WITHOUT TRAFFIC ARMS	WITH TRAFFIC ARMS (UP/DOWN FOR EACH VEHICLE)
	vphpl	vphpl	vphpl	vphpl	vphpl	vphpl
Vehicle identification only	800 to 1,400	NA	NA	NA	800 to 1,400	550 to 800
Vehicle and occupant identification[4]	300 to 450	400 to 600	275 to 375	350 to 475	400 to 450	325 to 350
Inspection of mission essential vehicles only	20 to 120	NA	20 to 120	NA	NA	NA

Design Conditions

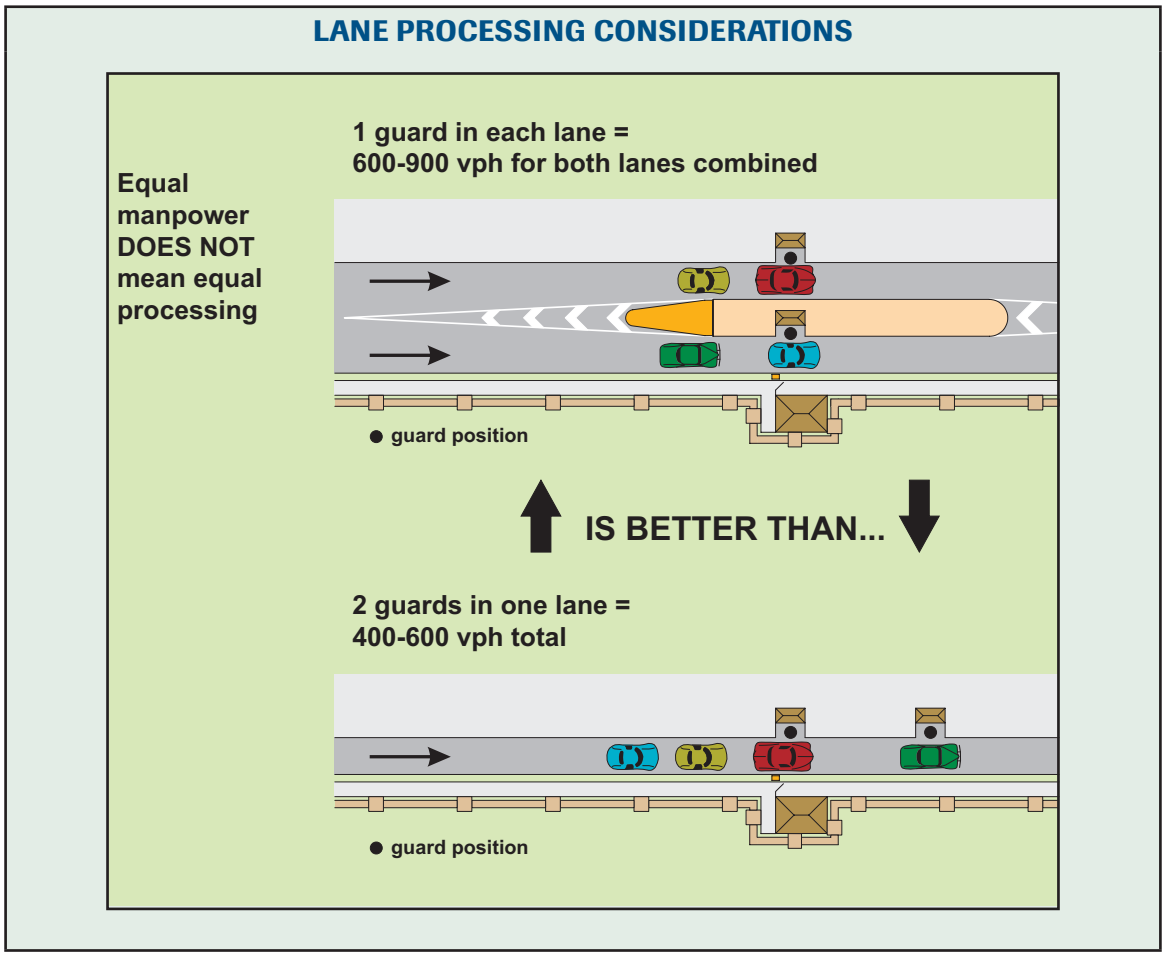
19.2.2.3. Tandem Processing

To reduce congestion at ECFs, many installations use additional guards per lane. Some installations use as many as nine guards to process a single traffic lane. The UFC mandates that all ECFs be designed with tandem processing capabilities. SDDCTEA has concluded that providing more than three ID checkers per lane provides little, if any, benefit and may be a misuse of resources. Furthermore, it is more efficient to use two ID checkers with one in each lane versus using two ID checkers in one lane. Exhibit 19.11 shows Bravo+ processing efficiency.

Exhibit 19.11: Bravo+ Processing Efficiency

ID CHECKERS PER LANE	VEHICLE PROCESSING RATE PER LANE
1	300-450
2	400-600
3	450-675
4	475-700

Source: SDDCTEA, Traffic and Safety Engineering for Better Entry Control Facilities



19.2.2.4. Calculating Lane Requirements

KEY POINT

To calculate the required number of lanes, divide the total peak hour true demand by 375 vehicles per hour per lane for single processing, 500 vehicles per hour per lane for tandem processing, or 325 vehicles per hour per lane for automated processing.

The number of lanes planned for an ECF must be sufficient to handle the expected volume of traffic, especially during times of peak demand. The peak demand typically occurs during the morning peak hour.

Many installations have the goal of reducing manpower at ECFs. Therefore, it may be desirable to calculate the required number of lanes based on single processing instead of tandem processing. In most cases, this would require additional lanes at ECFs and, therefore, a higher initial cost. However, it may save money in the long term with lower staffing requirements.

The incremental threshold for increasing the number of lanes at an ECF is:

- ✓ 375 vehicles per hour per lane for single processing, from the 300-450 range on Exhibit 19.10.
- ✓ 500 vehicles per hour per lane for tandem processing, from the 400-600 range on Exhibit 19.10.

There are other methods of processing available that are intended to reduce manpower. Implementation of these methods may require additional lanes because these methods typically have lower processing rates.

Specific examples include:

- ✓ **Handheld Devices** – These are devices which guards use to scan user ID cards in order to determine whether or not a person is authorized to enter the installation. The processing rates have been studied by SDDCTEA, and tend to range from approximately 275 to 375 vehicles per hour per lane for one guard per lane.
- ✓ **Automated Identification** – These are card reader systems that identify the vehicle and driver. At installations where these systems are used, the processing rate ranges between 400 to 450 vehicles per hour per lane for FPCONs, Bravo, Bravo+, and Charlie when traffic arms are not used. When traffic arms are used, the processing rates are significantly lower; 325 to 350 vehicles per hour per lane.

Even if ECFs are designed based on the lane capacities illustrated, some congestion may still occur due to the random arrival of vehicles and distinct peaking that typically occurs for short periods during the peak hour. Capacity can be increased and congestion reduced by:

- ✓ Setting staggered work hours
- ✓ Encouraging carpooling
- ✓ Adding lanes
- ✓ Redirecting traffic to other ECFs
- ✓ Building new ECFs

It may also be possible to design lanes to be reversible such that outbound lanes can be used for incoming traffic during periods of peak volume. However, priority should be given to maximizing the number of lanes prior to utilizing reversible lanes.

Exhibit 19.12 is a worksheet that can be used for calculating the required number of lanes at an ECF.

Exhibit 19.12: ECF Lane Requirements Worksheet

LINE	FIELD	CALCULATION	VALUE	*EXAMPLE CALCULATION*	*EXAMPLE VALUE*
1	Number of Vehicles Processed in Peak Hour				1200
2	Number of Maximum Queued Vehicles in Peak Hour				150
3	TOTAL EXISTING DEMAND	Line 1 + Line 2		1200 + 150	1350
4	Deployment Adjustment [DA] *Percent of Total Base Population Deployed*	100% / (100% – DA%)		100% / (100% – 10%)	10% deployment = 1.11
5	TOTAL ADJUSTED EXISTING DEMAND	Line 3 x Line 4		1350 x 1.11	1498
6	Local Growth at ECF [LG] *Percent of Estimated Local Growth*	(100% + LG%) / 100		(100% + 5%) / 100%	5% local growth = 1.05
7	Future Growth [FG] *Percent of Estimated Future Growth*	(100% + FG%) / 100%		(100% + 8%) / 100%	8% future growth = 1.08
8	DESIGN DEMAND	Line 5 x Line 6 x Line 7		1498 x 1.05 x 1.08	1699
9	Design Processing Rate *Default 500 vphpl*				500
10	CALCULATED LANE REQUIREMENTS	Line 8 / Line 9		1699 / 500	3.4
11	ROUNDED LANE REQUIREMENTS *Round to Next Highest Whole Number*				**4 LANES**

19.3. ECF COMPONENTS

The UFC and other reference materials provide requirements and guidance on the design of buildings and facilities at ECFs. UFC 4-022-03, *Security Engineering: Design of Security Fencing, Gates, Barriers, and Guard Facilities*, provides guidance on the design of guard booths, gatehouses, and guard towers. The appearance of these facilities should be in accordance with the installation's exterior architectural plan.

The purpose of this section is to highlight issues involving the design of those facilities as they relate to the overall ECF including traffic and safety engineering. Facilities must be adequately sized to accommodate traffic and usage.

Be sure that no facility creates roadside hazards or limits sight distance. Roadways and sidewalks in the ECF area need to be designed to accommodate users while maintaining the desired operational flow patterns.

Facilities at the ECF should provide a comfortable, safe working environment for security personnel. The basic considerations in determining the size of the facility are:

- ✓ Number of personnel assigned during normal operations.
- ✓ Usage.
- ✓ Space required for electronic, electrical, and mechanical equipment, and counter or work space.

SDDCTEA Pamphlet 55-15 discusses many critical components of ECFs. Some of these include:

- ✓ ID Check area
- ✓ Gatehouse
- ✓ Visitor's center
- ✓ Inspection areas
- ✓ Truck inspection area
- ✓ Canopy
- ✓ Active vehicle barrier types and location.

Typical ECF gatehouse

19.4. ECF SIGNING AND MARKINGS

KEY POINT

ECFs require special signing and pavement marking considerations.

Regulatory, warning, and guide signs are all critical to properly direct a motorist through an ECF. As discussed in Chapter 6, regulatory signs inform users of traffic laws and regulations, warning signs call attention to unexpected situations that might not be readily apparent, and guide signs are essential in directing motorists along roadways and streets.

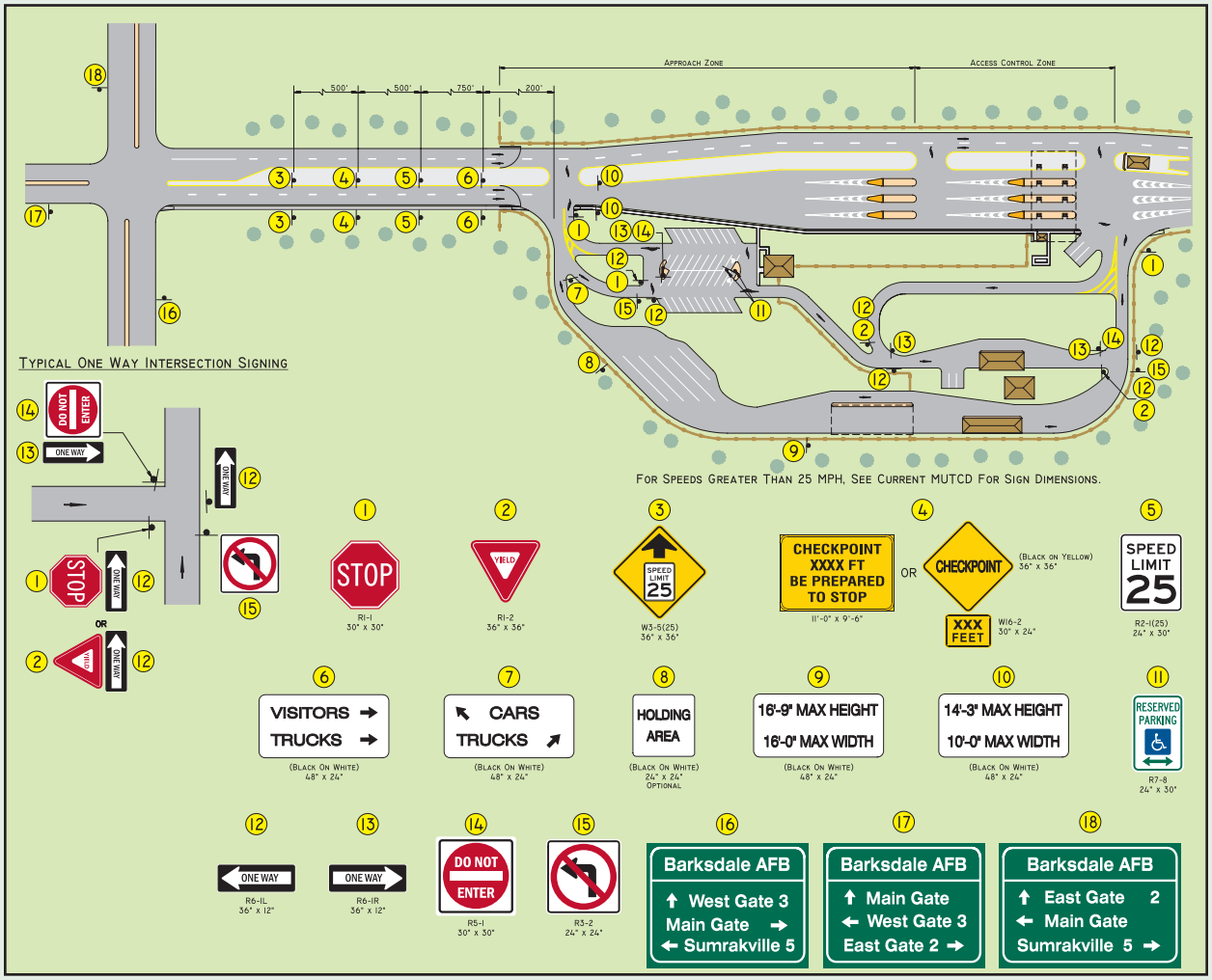
Pavement markings work with signs to help the motorist, providing continuous guidance. A detailed discussion of pavement markings is provided in Section 6.2 of this pamphlet. This section discusses special signing and marking considerations related to ECFs.

EXAMPLE ECF GUIDE SIGNING

19.4.1. ECF Signing

In order to assist motorists who are unfamiliar with the location of an installation, proper guide signing on local roads should be provided. Provide signing for both visitor and truck traffic, particularly when there is more than one ECF. Operational hours or open/closed status should also be posted on this type of sign. The following figure is an example of a sign layout around an ECF.

EXAMPLE SIGN LAYOUT



19.4.2. Outbound Speed Limit Signing

A similar approach to outbound speed limit signing should be utilized even though motorists may not be required to stop.

Outbound speed limits should be set at 25 mph and should be established at least 1/4 mile in advance of the active vehicle barriers (AVBs). If an intersection on the installation side of the ECF is less than 1/4 mile from the AVBs, then the ECF speed limits should be introduced in advance of the intersection.

19.4.3. In-Roadway Barrier Placement and Traffic Control

Concrete or water-filled barrier placements are discouraged on ECF approaches. However, installations often see it as the only temporary means of controlling traffic before a permanent fix can be installed. To date, there has been little guidance on the suitability, layout, spacing, and delineation of barrier placements resulting in potential traffic safety and operational conflicts.

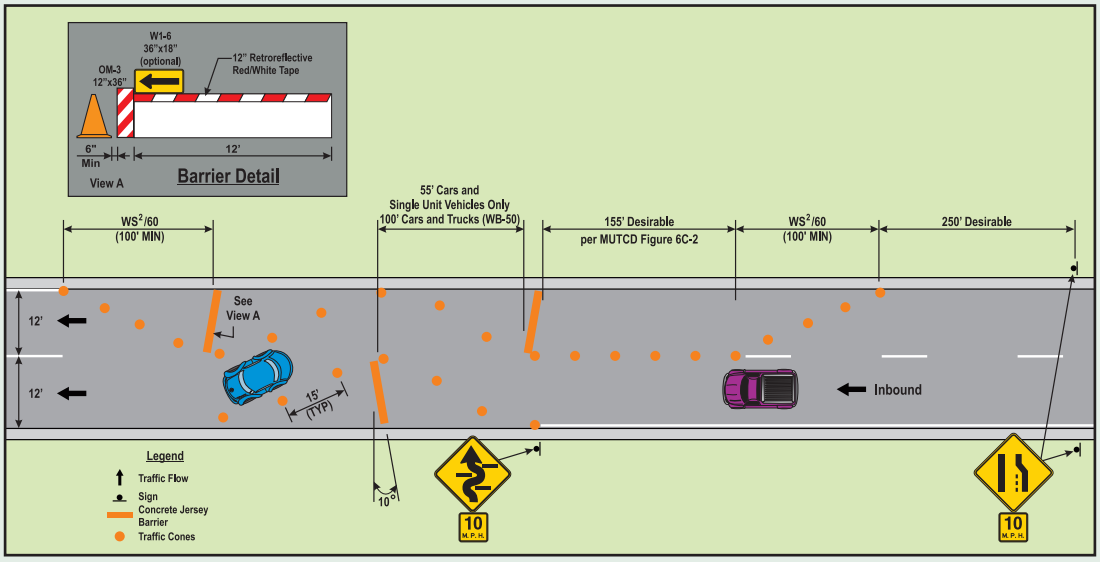
Common problems encountered at many military installations include:

- ✓ No warning signs of speed reduction
- ✓ Exposed barrier blunt ends
- ✓ Barrier openings permitting a “straight-line” path
- ✓ Barriers spaced too close resulting in conflicts with larger vehicle turning paths
- ✓ Little or no delineation of the travel paths.

As illustrated below, proper barrier spacing and orientation will accommodate a WB-50 while still providing the desired level of speed reduction. Delineation of a barrier is often nonexistent, making it particularly difficult to negotiate a vehicle through the configuration at night. Red and white retroreflective tape should be installed, as shown in the barrier detail, to improve barrier delineation.

In-roadway bollard systems are being used at several military installations in order to provide security benefits by limiting vehicular speeds and movements. SDDCTEA does not endorse the use of bollard systems and encourages other design options to address security concerns.

PROPER BARRIER ORIENTATION AND DELINEATION



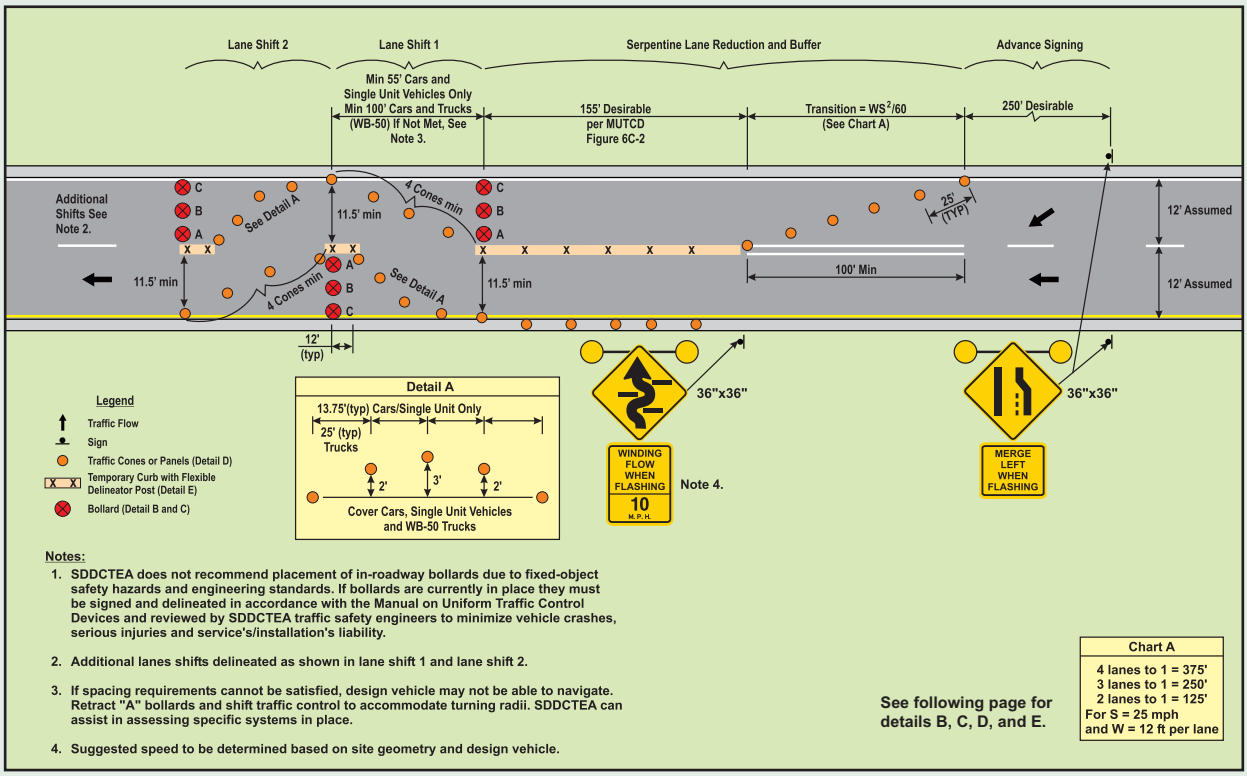
Since a bollard is a fixed object like a tree or utility pole, existing standards such as the *MUTCD* and AASHTO *Roadside Design Guide* discourage their use. Also, bollards are not continuous like other barrier systems. Vehicular impacts may result in significant penetration increasing the severity of the crash. In some vehicles, bollards may penetrate the passenger compartment depending on the vehicular speed on impact.

If existing systems are in use and must remain in use, they should be delineated. The bollards themselves should have retroreflective red and white markings and the roadway alignment should be delineated using signs, traffic cones, and panels. To satisfy AASHTO requirements, use temporary curbing to shield bollards from vehicles in the travel way. Proper spacing is critical to allow vehicles to navigate the system safely.

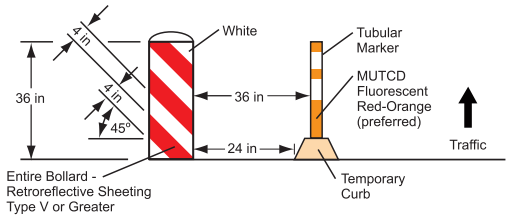
When systems are not used for all time periods, flashers can be used to advise motorists of when serpentine bollards are in place. When bollards are removed for a short-term period, temporary curbing can remain provided it is delineated and does not impede the travel way. When bollards are removed for longer periods, temporary curbing should be removed as well.

SDDCTEA does not endorse or recommend in-roadway bollards; however, we are available to provide guidance regarding existing systems in order to make their operation safer to the road user. The preferred layout is shown below.

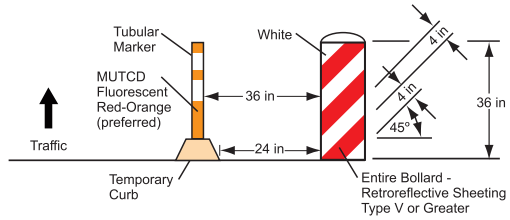
TRAFFIC CONTROL FOR EXISTING BOLLARD SERPENTINES



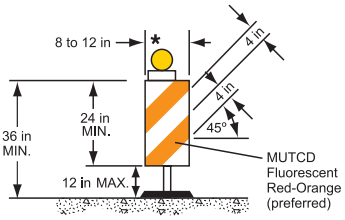
TRAFFIC CONTROL FOR EXISTING BOLLARD SERPENTINES (CONTINUED)



Detail B BOLLARDS TO LEFT OF TRAFFIC

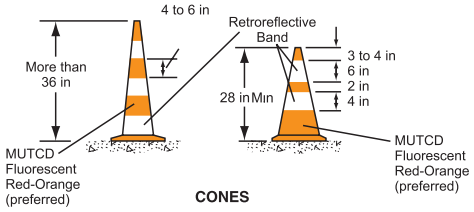


Detail C BOLLARDS TO RIGHT OF TRAFFIC



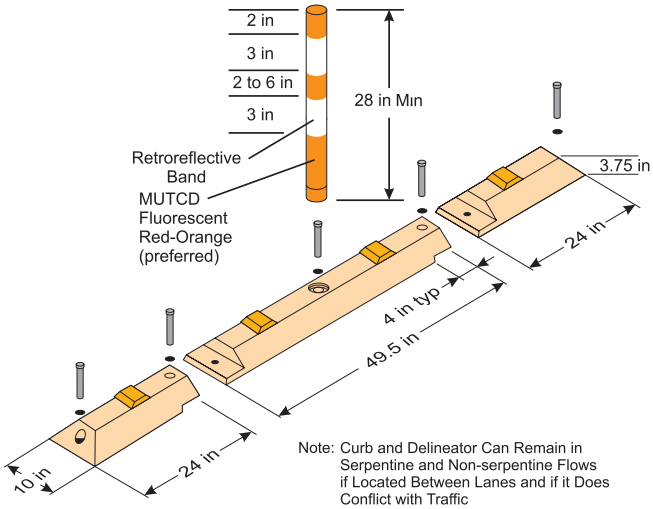
VERTICAL PANEL

* Warning lights (optional)



CONES

Detail D



Note: Curb and Delineator Can Remain in Serpentine and Non-serpentine Flows if Located Between Lanes and if it Does Conflict with Traffic

CURB AND FLEXIBLE DELINEATOR DETAIL

Detail E

19.5. FORCE PROTECTION COMPONENTS

A primary function of an ECF is to secure the installation from vehicular threats. To properly provide this security, there are several different aspects that must be provided, as discussed in depth in SDDCTEA Pamphlet 55-15.

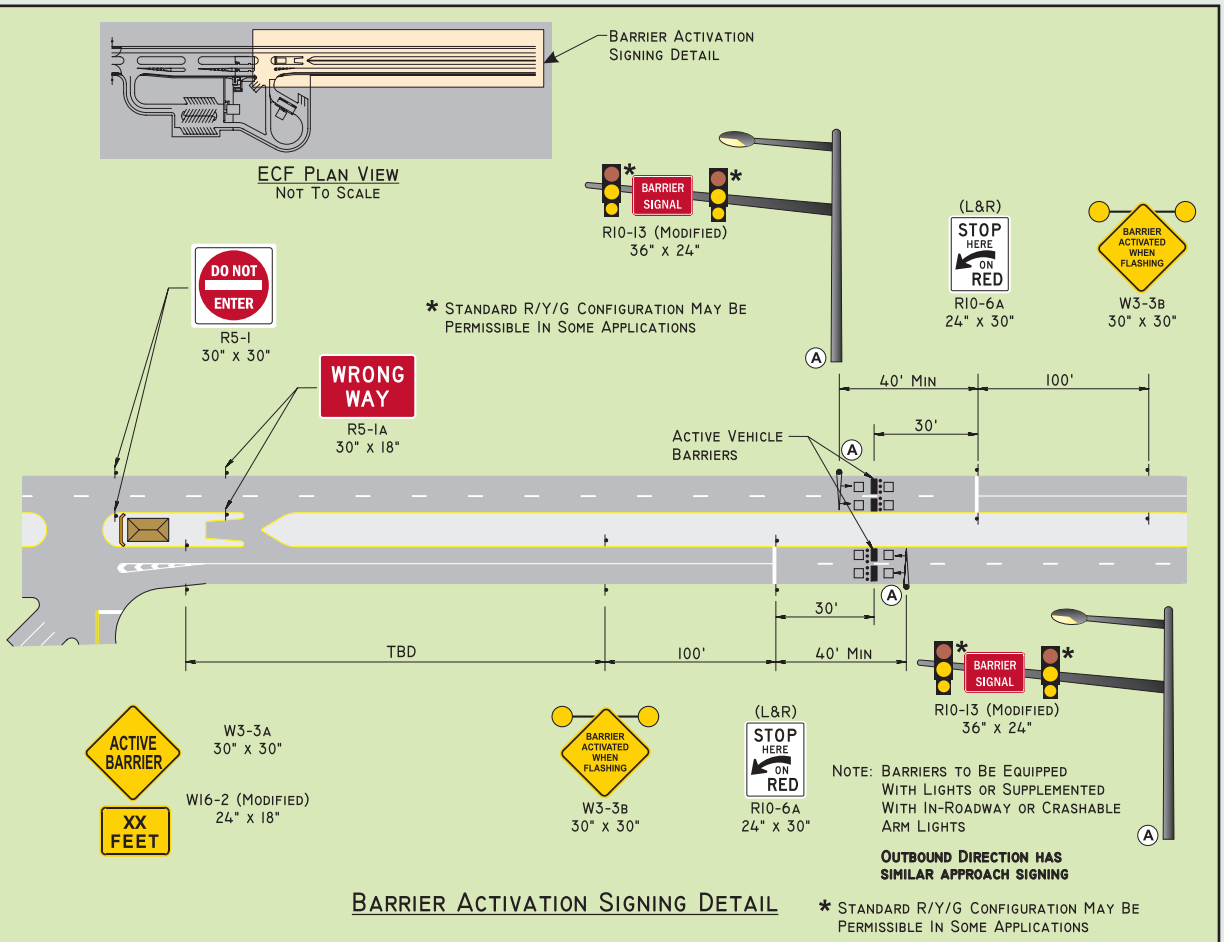
Standoff Distances: provide sufficient distance to buildings and other facilities in order to protect against potential explosive-laden vehicles.

Screening: provide screening to limit casual observation to critical parts of the ECF.

Passive barriers: these essentially make a continuous perimeter to keep vehicles within the ECF area. There are several different types of passive barriers. Passive barriers are often located at a certain offset from a roadway. Be sure that regular roadside safety principles are used when locating them.

Active vehicle barriers: active vehicle barriers (AVBs) are barriers that are activated to close off an approach lane to stop a threat vehicle. AVBs must be located with sufficient distance to provide 9 seconds of response time, measured from the point at which a threat vehicle is initially detected. It is extremely important that AVBs have the proper traffic control, as shown on the following page.

PREFERRED AVB TRAFFIC AND SAFETY CONTROL SYSTEM



Traffic Control and Safety at Active Barriers	Operational Sequence Per Second (Min for Safety - 25 MPH Design Speed)											
	Traffic Control	-	1	2	3	4	5	6	7	8	9	10
		Normal Ops	Guard Perception and Reaction Time to Threat (Button)			Yellow Clearance (MUTCD Minimum)			All Red	Deploying Barrier		Threat Contained
Sign and Signal Warning System	Warning Sign with Beacons	BLANK	BLANK	BLANK	BLANK	ALT FY	ALT FY	ALT FY	ALT FY	ALT FY	ALT FY	ALT FY
	Traffic Signal	FY	FY	FY	FY	Y	Y	Y	R	R	R	R
	In-Roadway Lights or Barrier	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	BLANK	FR	FR	FR	FR
	Active Barrier	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN	DOWN	ACTIVATED	ACTIVATED	DEPLOYED

CHAPTER 20 – LIGHTING

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20.2. ENTRY CONTROL FACILITIES 20-7

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Lighting for security purposes is very important on DoD installations, especially at entry control facilities (ECFs), at sensitive locations within the installation, and around the perimeter of the installation.

Most of the exterior lighting on DoD installations is currently high-pressure sodium (HPS). Although today's color-improved HPS lighting is more efficient than earlier types of lighting, pulse start metal halide (MH) lamps are the preferred lamp on military installations because they are more efficient, require less maintenance, and provide better visibility.

There have been major advancements in lighting technology and the understanding of uniformity, contrast, glare, and the color of the light and how they affect nighttime visibility. UFC 3-530-01, entitled *Design: Interior and Exterior Lighting and Controls*, incorporates current design concepts.

Sustainability is also an important design consideration. As a result, installations should:

- ✓ Use the most effective, energy-efficient light source available.
- ✓ Avoid over-lighting, and ensure that lights are only on during the hours they are needed.
- ✓ Promote dark skies and reduce light trespass onto adjacent properties by using cutoff luminaires.
- ✓ Recycle lamps containing mercury.

20.1. BASICS

The proper design of the lighting system will increase safety and efficiency, aid security forces, and enhance appearance. Therefore, a qualified lighting engineer should develop a lighting plan that meets lighting requirements within site constraints.

20.1.1. Illuminance

Illuminance is a measure of the intensity of light on a surface. A foot-candle is the U.S. customary unit of measure equal to one lumen per square foot and originally quantified as the amount of light from a typical candle burning at a distance of one foot from the surface. Exhibit 20.1 shows a range of some illumination levels.

Although illuminance is typically measured on a horizontal surface, the term "vertical illuminance" is used in the ID check areas, pedestrian areas, and perimeter lighting. This vertical illuminance is the density of light on upright objects, which is very important in identifying people.

Exhibit 20.1: Typical Illuminance Values

LIGHTING SOURCE	LEVEL OF ILLUMINANCE (FOOT-CANDLES)
Full moon	0.02
Gas station canopy	10-20
Office	20-50
Overcast day	100
NFL football stadium	300
Direct bright sunlight	10,000

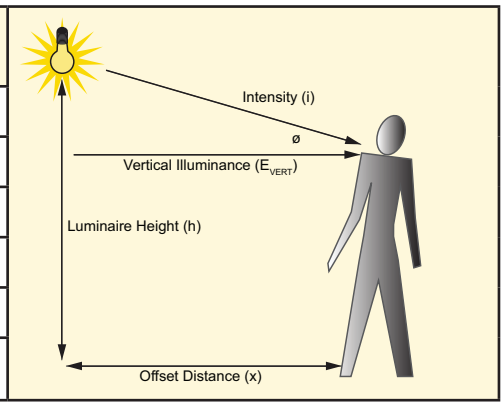


Exhibit 20.2 shows minimum illuminance levels at select locations within DoD installations.

20.1.2. Types of Lamps

There are currently several types of lamps:

- ✓ High-pressure sodium (HPS) lamps are currently the most common lamp but they do not have the best efficiency, longevity, or color.
- ✓ Pulse-start metal halide (MH) lamps are the current lamp of choice for most external lighting due to their excellent color and high efficiency. However, because of a long restrike and warm-up periods as discussed on the next page, when used for security purposes they always require backup lights. (Note: Standard MH lamps are not as efficient or durable as the pulse-start types.)
- ✓ Quartz-halogen lamps are inefficient, but provide excellent color and a quick start, making them ideal for backup lighting.
- ✓ Incandescent lamps have excellent color, but poor energy efficiency.
- ✓ Fluorescent lamps have excellent color and can be of a rapid start variety.

Newer lighting technologies are rapidly evolving that should further reduce energy and maintenance costs. For example, light emitting diode (LED) street lighting is commercially available but there are reliability issues. However, when these issues are resolved, LED street lights could perhaps become the recommended lamp.

High efficiency lighting has many applications at entry control facilities and for general lighting on DoD installations.

Exhibit 20.2: Minimum Illuminance

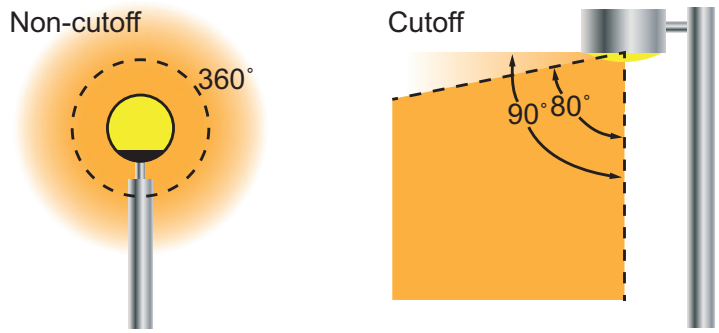
LOCATION	MINIMUM ILLUMINANCE (FOOT-CANDLES)	NOTES
ECFs Near the ID Check Area ✓ Approach and response zones ✓ Search area parking and roadways	✓ 3 [4 for Air Force at primary gates]*	✓ Illuminance on the pavement and sidewalks ✓ Average-to-minimum uniformity levels shall not exceed 4:1
ECFs at the ID Check Area ✓ Access control zones ✓ Search areas	✓ 5 in general areas* ✓ 10 or twice the immediate surrounding areas at the ID checking area [Air Force is 20 under the canopy and 30 at the point of contact]*	✓ Average-to-minimum uniformity levels shall not exceed 3:1 ✓ In immediate area where ID and inspection occur, vertical illuminance is 25% of horizontal illuminance at driver level
Parking Lots	✓ 1 – 2**	✓ The maximum-to-minimum uniformity ratio should be not greater than 15
Pedestrian Areas	✓ 0.5**	✓ By using shorter poles with illuminance from multiple directions, adequate vertical illuminance should be provided to light individuals and their faces
Perimeter Lighting	✓ 0.2 - 0.4 vertical illuminance**	✓ See Table 6-1 in UFC 3-530-01

** minimum illuminance at location 6 inches above the ground level*

*** average illuminance*

Exhibit 20.3: Cutoff Classifications

CLASSIFICATION	MAXIMUM INTENSITY (% LAMP LUMENS)	
	ABOVE HORIZONTAL	80° ABOVE VERTICAL
Full Cutoff	0	10
Cutoff	2.5	10
Semi-Cutoff	5	20
Non-Cutoff	n/a	n/a



20.1.3. Light Trespass

Light trespass is defined as any direct visibility of the source light beyond its target area. To help promote dark skies and minimize light trespass, whenever possible, use full cutoff luminaires as addressed in Exhibit 20.3.

It is generally possible to classify the type of cutoff by visual observation. For example, if the lens is not visible when viewed from the side it is a full cutoff lamp, whereas a low hanging globe-like lens is a semi-cutoff lamp.

The primary issue with the full cutoff lamps is the fact that more poles and lamps may be required to provide proper illuminance. The angle of the cutoff may vary by application. For roadway lighting, a cutoff angle of 80 degrees as shown in Exhibit 20.3 may be appropriate. For other applications, such as building entrances or exits, lower cutoff angles to limit the light trespass may be more appropriate.

A canopy over an ECF will also reduce light trespass. In addition, special shields can be used to further reduce light trespass.

Exhibit 20.4 shows a significant light trespass problem.

Exhibit 20.4: A Light Trespass Problem

Photo courtesy Chuck Bueter

20.1.4. Color Rendering

The color rendering index (CRI), ranges from 1 to 100 and indicates how accurately colors are rendered by a light source. The greater the number, the better the light source is at rendering colors. "White" light produces higher CRI than "yellow" lighting. A light source with a CRI greater than 65 should always be used.

When closed circuit television (CCTV) is used as part of the traffic and security operations, it is important to provide the correct lighting to support the CCTV system. It is also important to ensure that the camera is capable of automatically adjusting the white balance.

20.1.5. Restrike and Warm-up Times

Another important design consideration is the restart or restrike time for the lamps. Restart occurs when a lamp experiences a loss of power, which could be caused by a power outage or someone accidentally turning off a light switch. Once power is restored, the time it takes for the lamp to cool down and then begin to come back on is the lamp's "restrike time."

After the restrike time, many lamps still take several minutes for the lights to warm up and reach their full intensity. This warm-up time is generally measured from restrike to the time the light output is 60 percent of its maximum output. Exhibit 20.5 identifies three different lamps and their restrike and warm-up times. For example, a power outage of only a few seconds may require 6 minutes for the preferred MH lamp to cool down, restart, and warm up sufficiently to produce 60 percent of its normal illuminance.

It is important to note that MH lamps should be the pulse start lamps and not the standard MH lamps. The standard MH lamp is not as efficient and does not last as long, but the biggest problem is that they have even larger restrike and warm-up times.

Exhibit 20.5: Types of Lamps

LAMP TYPE	LUMEN OUTPUT (INITIAL)	RESTRIKE TIME (MINUTES)	WARM-UP TIME TO 60% LIGHT OUTPUT (MINUTES)	LIGHT COLOR/CRI	NOTES
MH (Pulse Start)	44,000 (400W)	4	2	White/65 or greater	Preferred lamp due to high efficiency
HPS (w/color improved lamp)	37,400 (400W)	1	3	White/65 or greater	Acceptable, but has lower lumen and life expectancy than MH lamps
Quartz-Halogen	5,000 (250W)	n/a	n/a	White/97-100	Recommended backup lighting. Typical designs provide 15% of normal illuminance

20.2. ENTRY CONTROL FACILITIES

From a security standpoint, the importance of good lighting is the most critical on DoD installations at the entry control facilities (ECFs) where lighting is required for guards to perform their security functions. For safety reasons, it is also important that motorists and guards can see each other. Therefore, ECFs should be designed with lighting features that support the operational requirements during dawn, dusk, and nighttime periods. Even if an ECF is intended to be used only during daylight hours, lighting should be included to accommodate the short winter days and in the event that in the future there is a change in usage.

ECF lighting should be complete and continuous, and in accordance with UFC 4-022-01. Specific areas of the ECF have their own lighting requirements, as captured in Exhibit 20.2.

The level of illuminance required depends on the task being performed and the needed visibility to perform those tasks. Special consideration must be given to the ID check and inspection areas where the identification of vehicle occupants and contents occurs. As noted in Exhibit 20.2, the vertical illuminance is a minimum of 25 percent of the required horizontal illuminance.

This lighting should be directed across the vehicle's travel path, where it will illuminate the roadway in front of the gatehouse, the driver, and the guard. Lighting may also be mounted at or below pavement level to facilitate under vehicle inspection, but lighting should not be directed toward either the guards' or the drivers' eyes.

The ability to identify and distinguish colors accurately and confidently is very important, particularly in ECF areas. For example, at an ECF, the color of the driver's eyes and hair is very important for ID purposes. Further, the color of the car may be important in a description to a guard in an oversight position, especially since a green car under yellow lights will have a blue tint.

Within the ECF, it is essential that either backup lamps are provided or that an uninterrupted power supply (UPS) is available. The recommended type of backup lamps is the quartz-halogen lamp as referenced in Exhibit 20.5. Portable lamps operating off of a backup power supply may also be used within ECF areas in the event of a power interruption.

Entry Control Facility Lighting

20.3. APPROACH ROADWAYS

Transitional lighting is necessary on approaches to and departures from the ECF to minimize blinding effects as drivers travel into and out of a brightly illuminated ECF. Therefore, transitional lighting should be used as drivers enter the ECF in the approach zone and leave the ECF in the response zone.

Standard conventional lighting is mounted at a height of 30 to 60 feet. When standard conventional lighting is used, transitional lighting should be provided to allow time for the driver's eyes to adjust to the change in lighting levels on arrival or departure. Departure lighting is more critical since the human eye has more trouble adjusting from light to dark than from dark to light. Therefore, designers should provide gradual change in lighting levels using three or more lighting poles.

The UFC recommends that illuminance levels should not be reduced more than 50 percent within 15 seconds. For example, if the speed limit is 25 mph (i.e., 36.67 feet per second), the luminance should be a minimum of 5 foot-candles (i.e., 50 percent of the minimum 10 foot-candles required at the ID checking area) when vehicles are at a maximum distance of 550 feet (i.e., 15 seconds x 36.67 feet per second) after the ECF.

High mast lighting in the range of 60 to 120 feet high is practical because it provides broader and more natural light distribution. It also requires fewer poles than standard conventional lighting and may reduce the need for transitional lighting. However, high mast lighting may cast light on neighboring properties, herein referred to as "light trespass."

The final determination of the lighting type selected should consider the life-cycle cost of each system. Although one high mast light can often replace six conventional lights, the construction cost of high mast lights are often five times more than the cost of standard light poles.

Light poles can be placed along the roadway or in the median. In some cases, light poles in the median may limit the number of poles needed. However, on wider roadways such as at ECFs with numerous lanes, the needed illuminance may not be achievable with median light poles; therefore, light poles may need to be placed on both sides of the road. When light poles are in uncurbed areas the pole should be located outside of the clear zone. In curbed areas, at least a 2-foot clearance from the curb face to the pole is required.

The *Roadway Lighting Design Guide* is an excellent resource for designing roadway lighting.

Definitions

High-pressure sodium (HPS) lamp – A high intensity discharge (HID) lamp in which light is produced by radiation from sodium vapor.

Horizontal illuminance – The density of light that falls on a horizontal surface and measured at a location 6 inches above the ground.

Light trespass – Unwanted light that either illuminates adjacent properties or creates excess brightness in someone's field of vision. Unwanted light can generally be reduced or eliminated by using cutoff or shielded luminaires.

Metal halide (MH) lamp – A high-intensity discharge (HID) lamp in which the major portion of the light is produced by radiation of metal halides and their products of dissociation, possibly in combination with metallic vapors such as mercury.

Vertical illuminance – This is the application of light on upright objects such as people, instead of horizontal surfaces like roadways and parking lots. For security purposes, the need to illuminate people, especially their face, for identification purposes is more important than illuminating horizontal surfaces. Vertical illuminance is generally measured at a height of 5 feet above the grade.

20.4. INTERSECTION AND CROSSWALK LIGHTING

Intersection lighting increases motorist and pedestrian visibility and reduces crash potential. Although no specific warrants have been established, the *MUTCD* suggests roadway lighting if a disproportionate number of crashes occur at night. Lighting should be installed at those locations where a qualified lighting engineer has determined that lighting will contribute to the efficiency, safety, and/or comfort of motorists and pedestrians. Similar lighting can also be used at midblock pedestrian crosswalks and would be especially beneficial at busier crosswalks.

Most state DOTs, as well as IESNA, have developed criteria to assist in determining lighting requirements. When designing lighting, the following factors should be considered; luminaire type, light source type, wattage, mounting height, and pole location. A qualified lighting engineer should evaluate intersection lighting.

In an effort to improve visibility of pedestrians, the preferred location of light standards for intersection and midblock crosswalks is as illustrated in Exhibit 20.6.

It is also permissible to use in-roadway warning lights in a line parallel to the edges of the crosswalk, either at or within 10 feet of the near edge of the crosswalk as illustrated in Exhibit 20.7. Additional design details are included in Chapter 4N of the *MUTCD*. However, DoD installations should be aware that these systems are expensive, and for installations with winter maintenance activities snowplowable light assemblies will be required. The lights are generally activated by a pedestrian push button and the lights flash for a sufficient period of time to allow pedestrians to either reach the far side of the roadway or another push button, for example, in a median.

Exhibit 20.6: Recommended Location for Luminaires at Intersections and Midblock Crosswalks

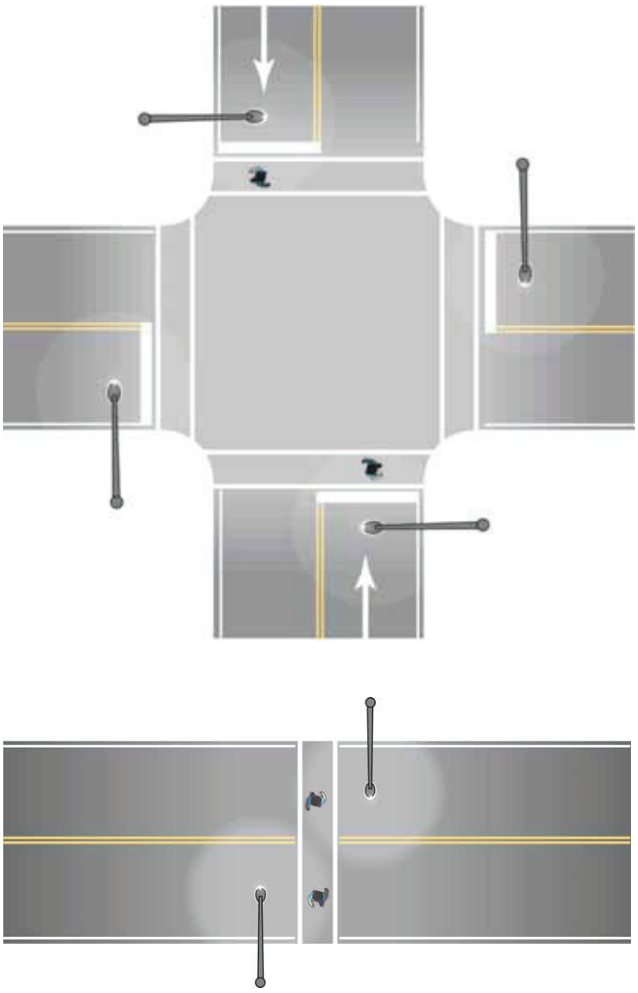
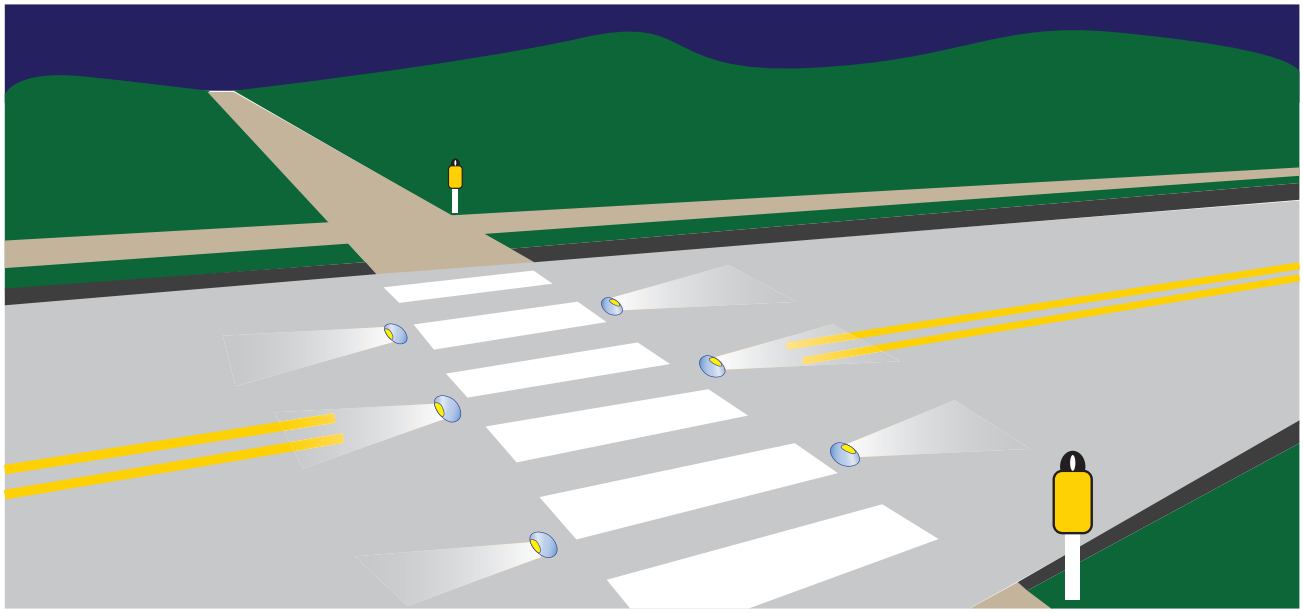


Exhibit 20.7: In-Roadway Warning Lights



20.5. PARKING LOT LIGHTING

In addition to security, lighting in parking lots also plays a critical role in maximizing visibility between motorists and pedestrians since pedestrians typically walk next to vehicle parking aisles. In large PX and commissary parking lots, lighting is also helpful as shoppers transfer goods from shopping carts to their vehicles.

Mounting height and spacing of luminaires should be sufficient to distribute the desired lighting intensity to the entire parking area. Pole heights range from 20 to 50 feet high or more. A normal lighting level is from 1 to 2 foot-candles, and the maximum-to-minimum uniformity ratio should be not greater than 15.

Locate light fixtures away from traffic aisles and parking stalls wherever possible. Light poles are ideally located in islands and protected by raised curbs. When light poles are within parking rows, locate the poles at the junctions of adjacent stalls, and install them on top of a 3-foot high concrete base to avoid accidental knockdowns. While this practice is acceptable in parking lots, high concrete bases should not be used on open roadways due to the need to provide breakaway designs in areas with higher travel speeds. Poles and fixtures should be in scale and accommodating to the setting and surrounding area, while providing adequate illuminance of the parking lot. As illustrated in Exhibit 20.8, luminaires should direct the light downward to promote dark skies.

Exhibit 20.8: Parking Lot Lighting using Full Cutoff Lamps

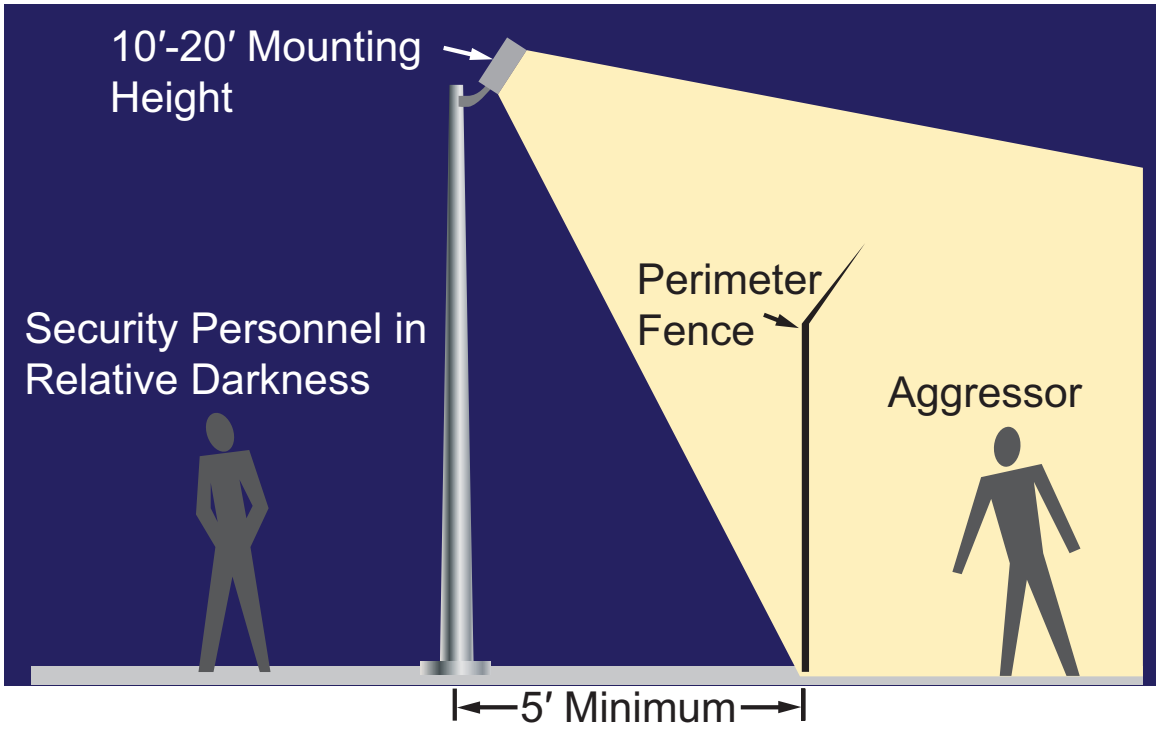
20.6. PERIMETER SECURITY LIGHTING

Securing the perimeter around a military installation is important, but expensive. When used, perimeter lighting normally can be on standby except when there is a perceived threat. Activation can be done either manually by security personnel or automatically by an intrusion detection system. A standby system creates the impression of activity and may offer a deterrent value while also achieving energy conservation. Use lamps that do not have a restrike and warm-up period.

It would be very expensive to light the entire perimeter of a large base as they are often many miles around. Due to the cost, this practice could be reserved to areas that are adjacent to off-base roadways or nearby on-base attractions.

As illustrated in Exhibit 20.9, one suggestion is to place lights slightly inside a security perimeter and to direct the light outward. This method is useful when the glare of the lights across the surrounding territory will neither annoy nor interfere with operations outside of the security fence. The fact that the light illuminates the potential intruder makes it more difficult for them to see what is inside the fence. Therefore, this practice protects the security personnel by keeping them in relative darkness while enabling them to see a considerable distance beyond the fence.

Exhibit 20.9: Suggested Perimeter Security Lighting



20.7. MISCELLANEOUS CONSIDERATIONS

Good lighting does not eliminate the need to use retroreflective traffic signs. Lighting devices should be provided in temporary traffic control areas based on engineering judgment. When nighttime work is being performed, floodlights should be used to illuminate the work area, equipment, crossings, and other areas. Except in emergency situations, flagger stations shall be illuminated at night, and provide vertical illuminance without producing disabling glare for approaching road users, flaggers, or workers.

Although solar powered lights are not currently good for illuminance, they can be used to energize large "flashing arrow" and "dynamic message" panels used on construction projects and for special events. These solar-powered devices have large solar panels and sufficient batteries to work for many cloudy days. They also have the added benefit of operating without the noise of a generator.

Solar power is also a cost effective power source to operate flashing lights such as pedestrian-activated lights attached to Pedestrian signs, or flashing lights attached to signs in remote areas that do not have readily-accessible commercial electricity.

20.8. FUTURE TECHNOLOGIES

Solar-powered lighting currently is not a viable lighting solution except as landscape lights to delineate walkways. These inexpensive lights do not adequately illuminate walking surfaces, but they are effective in defining the edges of pathways and sidewalks. Reliability of these inexpensive lights is an on-going problem.

With on-going improvements in solar collectors, batteries and energy-efficient lights, solar power will undoubtedly become a more viable option in the future.

As noted on Page 20-2, LEDs may ultimately replace other types of lighting. Some of the potential advantages of LEDs include:

- ✓ Reduce energy consumption
- ✓ Reduce maintenance costs
- ✓ Provide more uniform illuminance
- ✓ Eliminate the need for backup lamps
- ✓ Reduce the number of insects attracted to the lights

In all cases, it is important to use a qualified engineer to ensure that your lighting needs are satisfied. SDDCTEA is available to assist your installation.

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