Traffic Engineering and Highway Safety Bulletin 18-03
June 2018

INTERSECTION GEOMETRIC DESIGN

In This Issue...

MILITARY SURFACE DEPLOYMENT AND DISTRIBUTION COMMAND, TRANSPORTATION ENGINEERING AGENCY (SDDCTEA)

1 Soldier Way
Scott Air Force Base, Illinois
62225-5006
http://www.sddc.army.mil/sites/TEA

Scan Here to Quickly Visit Us Online!

Overview

An intersection is defined as the general area where two or more roadways join or cross, including the roadway and roadside facilities for the traffic movements within this area. Each roadway approaching an intersection comprises a leg of the intersection. It is recommended that an intersection have no more than four of these intersecting legs.

The proper geometric design of an intersection is crucial to safe and efficient intersection operations for all road users. There are numerous elements to consider in the development of upgrades to an intersection. These elements fall under two major categories in intersection geometric design: Planning and Design. The primary focus of this bulletin is to discuss the more critical elements of intersection design.

Intersection Geometric Design consists of two major areas: Planning and Design. Each consists of critical elements which influence other design elements.

Intersection Planning

Planning an intersection involves analyzing an intersection for existing and future needs. The needs of an intersection could include capacity, geometric deficiencies, or roadside hazards.

The first step in intersection planning is to evaluate existing conditions. This is typically done by obtaining turning movement count data and collecting an inventory of existing lane use, traffic control, and roadside features. If the intersection is signalized, signal phasing and timings should also be obtained.

Once the existing conditions are established, perform a capacity analysis to determine the existing intersection operations. A capacity analysis should also be performed for future traffic conditions. Evaluate the appropriateness of the current traffic control, and analyze traffic signal warrants if necessary. Evaluate if additional lanes are needed to achieve an adequate level of service. If the intersection will be signalized, determine phasing needs, i.e. left-turn phasing, and optimize the signal timing cycle and splits.

Determine the appropriate intersection design vehicle. The design vehicle is the largest vehicle that is expected to use the intersection on a routine basis. An interstate tractor trailer (WB-67) may be appropriate for warehouse districts or arterials whereas school buses(S-BUS-36) and/or moving trucks (WB-50) may be more appropriate for residential areas.

Intersection Design

Once the needs of the intersection are established, the design process can begin. There are numerous design elements, many of which depend on each other. These elements include the following: using turning templates to evaluate design vehicles, stop line placement, corner radii design, channelization, turn lane design, pedestrian accommodations, signal pole placement, and sight distance.

This bulletin will focus on these areas of intersection planning and design.

Intersection Types

Intersection type is determined by the number of intersecting legs: three-legged, four-legged, or multi-legged. Any one of these 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.

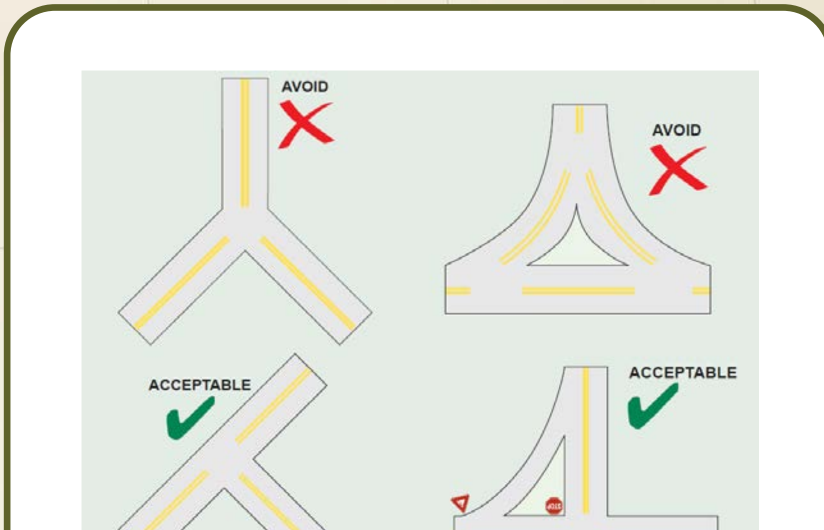
Three-Legged. Generally, this design is used to terminate one roadway. The intersection may be flared or designed with turning roadways where turning movements are hazardous or where traffic volumes warrant their use. A Y-type design is undesirable and generally results in safety and operational problems. Another undesirable configuration of a three-legged intersection is one with two bidirectional segments connecting the major roadway and side street. This type of intersection is generally not desired due to the additional conflict points it introduces. It is generally desired to reconstruct these intersections to one of the acceptable types shown in figure 1. If desired, a single-direction turning roadway could be used for right-turn traffic, as shown.

Four-Legged. A four-legged intersection 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 sight distance, pedestrian safety, and turning angles. Where skewed intersections must be used, the intersecting angle should be kept to 30 degrees or less as shown below. AASHTO's *A Policy on Geometric Design of Highways and Streets* (A.K.A. The Green Book) presents several realignment options.

Multi-Legged. This type of intersection generally represents a compromise of operational requirements. Generally, channelization and signalization should be used, or one leg of the intersection should be eliminated. A roundabout could also be used.

Figure 1 depicts several intersection types.

FIGURE 1: Intersection Types



Traffic Control Selection

FHWA's *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidelines for selecting appropriate traffic control devices. Military installations are required to conform to the MUTCD, in accordance with Joint Regulation of the Department of Defense Transportation Engineering Program (AR 55-80, OPNAVINST 11210.2, AFMAN 32-1017, MCO 11210.2D, and DLAR 4500.19). Also consult your state's requirements such as a state specific supplement to the MUTCD, as well as SDDCTEA's DoD supplement to the MUTCD. The guidelines presented in the MUTCD are primarily based on traffic volumes on the major street, minor street, pedestrian activity and crash history. There are six basic types of intersection traffic control:

- No control
- Yield control
- Stop control
- Multi-way stop control
- Traffic control signals
- Roundabouts

As directed by the MUTCD, the minimum appropriate level of traffic control that promotes safe and efficient traffic operations and minimizes delay while still being cost effective should be used.

The assessment of the necessary type of 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 highway department, a local traffic engineering consultant, or SDDCTEA.

Engineering judgment should be used to establish intersection control. The following factors should be considered:

- Vehicular, bicycle, and pedestrian traffic volumes on all approaches
- Number and angle of approaches
- Approach speeds
- Sight distance available on each approach
- Reported crash experience

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 based upon the state vehicle code.

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. The absence of traffic control should be used only in very low-volume applications where sufficient sight distance is available.

Yield Control. Vehicles controlled by a YIELD (R1-2) sign must yield to approaching traffic by slowing down or stopping, when necessary, to avoid interfering with conflicting traffic. The MUTCD identifies certain conditions that indicate when YIELD signs may be warranted. Large sight triangles are required with the use of YIELD signs. Adequate intersection sight distance is usually the controlling factor on whether a YIELD sign can be placed in lieu of a STOP sign on low volume roadways. Yield signs should be installed in accordance with Section 2B.09 of the MUTCD.

Stop Control. STOP (R1-1) signs should be used if engineering judgment indicates that a stop is required.

Per Section 2B.04 of the MUTCD, the following should be considered when considering stop control:

- Vehicular, bicycle, and pedestrian traffic volumes on all approaches
- Number and angle of approaches

- Approach speeds
- Sight distance available on each approach
- Reported crash experience.

YIELD or STOP signs should be used at an intersection if one or more of the following conditions exist:

- An intersection of a less important road with a main road where application of the normal right-of-way rule would not be expected to provide reasonable compliance with the law
- A street entering a designated through highway or street
- An unsignalized intersection in a signalized area

In addition, the use of YIELD or STOP signs should be considered at the intersection of two minor streets or local roads where the intersection has more than three approaches and where one or more of the following conditions exist:

- The combined vehicular, bicycle, and pedestrian volume entering the intersection from all approaches averages more than 2,000 units per day
- The ability to see conflicting traffic on an approach is not sufficient to allow a road user to stop or yield in compliance with the normal right-of-way rule if such stopping or yielding is necessary
- Crash records indicate that five or more crashes that involve the failure to yield the right-of-way at the intersection under the normal right-of-way rule have been reported within a 3-year period, or that three or more such crashes have been reported within a 2-year periodh

At intersections where a full stop is not necessary at all times, consideration should first be given to using less restrictive measures such as YIELD signs (MUTCD Sections 2B.08 and 2B.09). The use of STOP signs on the minor-street approaches should be considered if engineering judgment indicates that a stop is always required because of one or more of the following conditions:

- The vehicular traffic volumes on the through street or highway exceed 6,000 vehicles per day
- A restricted view exists that requires road users to stop in order to adequately observe conflicting traffic on the through street or highway
- Crash records indicate that three or more crashes that are susceptible to correction by the installation of a STOP sign have been reported within a 12-month period, or that five or more such crashes have been reported within a 2-year period. Such crashes include right-angle collisions involving road users on the minor-street approach failing to yield the right-of-way to traffic on the through street or highway.

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. Exceptions to using two-way STOP control is when traffic volumes on both streets are balanced and visibility, pedestrian safety, or geometric conditions warrant stopping the other legs. If this condition exists, multi-way STOP control may be appropriate.

Multi-way stop control. Multi-way stop control is useful as a safety measure at locations where sight distance or crash history cannot be corrected through other means. However, it is a safety concern for pedestrians, bicyclists, and all road users that are expecting other road users to stop. Multi-way stop control can be used where the volume of traffic on the intersecting roads is approximately equal.

The decision to install multi-way stop control should be based on an engineering study using criteria presented in Section 2B.07 of the MUTCD. The following criteria should be considered in the engineering study for a multi-way STOP sign installation:

A. 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.

B. Five or more reported crashes in a 12-month period that are susceptible to correction by a multi-way stop installation. Such crashes include right-turn and left-turn collisions as well as right-angle collisions.

C. Minimum volumes:

1. 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

2. 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; but

3. If the 85th-percentile approach speed of the major-street traffic exceeds 40 mph, the minimum vehicular volume warrants are 70 percent of the values provided in Items 1 and 2.

D. Where no single criterion is satisfied, but where Criteria B, C.1, and C.2 are all satisfied to 80 percent of the minimum values. Criterion C.3 is excluded from this condition.

Other criteria that may be considered in an engineering study include:

- The need to control left-turn conflicts
- The need to control vehicle/pedestrian conflicts near locations that generate high pedestrian volumes
- Locations where a road user, after stopping, cannot see conflicting traffic and is not able to negotiate the intersection unless conflicting cross traffic is also required to stop
- An intersection of two residential neighborhood collector (through) streets of similar design and operating characteristics where multi-way stop control would improve traffic operational characteristics of the intersection.

Multi-way STOP signs must always be supplemented with an ALL WAY (R1-3p) plaque.

Traffic Control Signals. The selection and use of traffic control signals should be based on an engineering study of roadway, traffic, and other conditions. At least one of the nine signal warrants given in the MUTCD must be met before installing traffic signals; however, meeting the warrants do not require the installation of traffic signals. Many state Departments of Transportation (DoT) require at least two warrants be met before installing traffic signals. The traffic signal warrants are based on vehicular volume, pedestrian activities, and crash experience. Per MUTCD Section 4C.01, the nine warrants include:

- Warrant 1: Eight-Hour Vehicular Volume
- Warrant 2: Four-Hour Vehicular Volume
- Warrant 3: Peak Hour
- Warrant 4: Pedestrian Volume
- Warrant 5: School Crossing
- Warrant 6: Coordinated Signal System
- Warrant 7: Crash Experience
- Warrant 8: Roadway Network
- Warrant 9: Intersection Near A Grade Crossing.

Warrants must be professionally evaluated by a qualified traffic engineer.

Roundabouts. A roundabout is defined as a modified traffic circle conforming to specific geometric design criteria that promotes driver awareness, reduces travel speeds, and improves traffic flow. Roundabouts reduce traffic congestion by eliminating left turns and reducing conflict points. Since each approach to the roundabout is essentially an intersection with a one-way street, the driver is not delayed by traffic flow in two directions. Only right turns yielding to traffic in the circle are allowed. Roundabouts are advantageous because traffic can flow continuously when no conflicts are present versus having to stop. The disadvantage is that they require a higher initial cost for construction when compared to a traffic signal or stop control; however, when compared to a signalized intersection the cost of maintenance is lower. See FHWA's *Roundabouts: An Informational Guide* (http://www.fhwa.dot.gov/publications/research/safety/00068/) for more information.

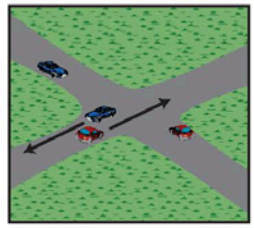
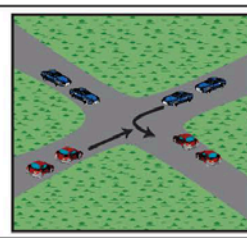
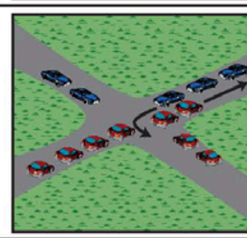
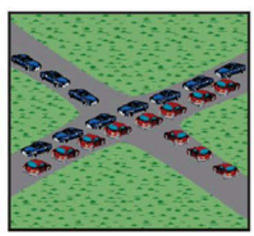
Capacity Analysis

One preliminary step in intersection planning is to perform a capacity analysis. Since the analysis requires the input of geometric information, the results are an indicator of the intersection's ability to carry traffic and is reported in a performance level. These performance levels are based on delay thresholods for the amount of delay a vehicle experiences. These levels are referred to as the Level of Service (LOS). Design capacity is the theoretical maximum volume of traffic that a proposed intersection would be able to serve for prevailing conditions.

LOS can be calculated for roadway segments or intersections. LOS calculations for a roadway segment are appropriate when a roadway lacks stop signs or traffic signals that stop the flow of traffic. This generally includes freeways and arterials. Where a roadway has traffic signals or stop signs, LOS for intersections generally governs.

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. These are described in figure 2.

FIGURE 2: Level of Service Thresholds

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 the range of 10.1-20.0 spv ✓ More vehicles stop than LOS A		✓ Average delay in the range of 10.1-15.0 spv ✓ Short traffic delays to minor street traffic
C	✓ Average delay in the range of 20.1-35.0 spv ✓ Number of vehicles stopping is significant ✓ Cycle failures may begin to appear		✓ Average delay in the range of 15.1-25.0 spv ✓ Average traffic delays to minor street traffic
D	✓ Average delay in the range of 35.1-55.0 spv ✓ Congestion more noticeable ✓ Many vehicles stop ✓ Cycle failures noticeable		✓ Average delay in the range of 25.1-35.0 spv ✓ Long traffic delays to minor street traffic
E	✓ Average delay in the range of 55.1-80.0 spv ✓ Cycle failures frequent		✓ Average delay in the 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

A capacity analysis requires accurate traffic data and analysis. Traffic data collection, specifically turning movement counts, should be performed in accordance with SDDCTEA Pamphlet 55-8 Chapter 1. After the traffic volumes are collected, determine the future growth and establish future design volumes. Next perform the analysis using Synchro, Highway Capacity Software, or other approved analysis software packages. Typically, it is desirable to design for peak hour levels of service no lower than D in urban areas and no lower than C in rural areas for any movement in the future condition. If movements exist that operate at a level of service lower than LOS D, determine what improvements are needed to increase the level of service. This could include adding turning lanes, modifying the signal phasing and timing, or changing the intersection traffic control. Additional through lanes could also be a valid need, but additional through lanes would be more of a long-term corridor need since it would not be limited to the intersection.

Traffic signal timing optimization for an intersection or corridor can frequently provide a benefit to level of service. Timing optimization can have large benefit conpared to the cost of the improvement. In conjunction with this, changes to traffic signal phasing could include evaluating the following:

- Protected/permitted left-turn phasing – providing a protected left-turn arrow for left-turn vehicles, followed by allowing left-turn vehicles to proceed against gaps in opposing traffic. This phase is typically more efficient for left-turn vehicles, but could have safety concerns when left-turn volumes versus opposing through volumes are too great.
- Protected-only left-turn phasing – providing a protected left-turn arrow for left-turn vehicles, and prohibiting left-turn vehicles to proceed against gaps in opposing traffic. This can be less efficient for left-turns, but does not have the safety concerns assiciated with protected/permitted left-turn phasing.
- Right-turn overlap phase – providing a protected right-turn arrow for nonconflicting right-turn movements during a left-turn phase, such as a northbound right-turn arrow when a westbound left-turn arrow is on.
- Split side-street phasing – providing separate phases for each side-street approach. Depending on geometry, lane use, or significantly differing approach volumes, split side-street phasing phasing may be appropriate in certain situations.
- Pedestrian phasing – WALK and flashing DONT WALK times should be evaluated. If large pedestrian volumes are present, it may be appropriate to increase the WALK time to serve the pedestrian demand.

Design Vehicles

The design team must determine what design vehicle is appropriate for designing an intersection. 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. Intersection corner radii and stop line placement are critical geometric features that are influenced by the design vehicle.

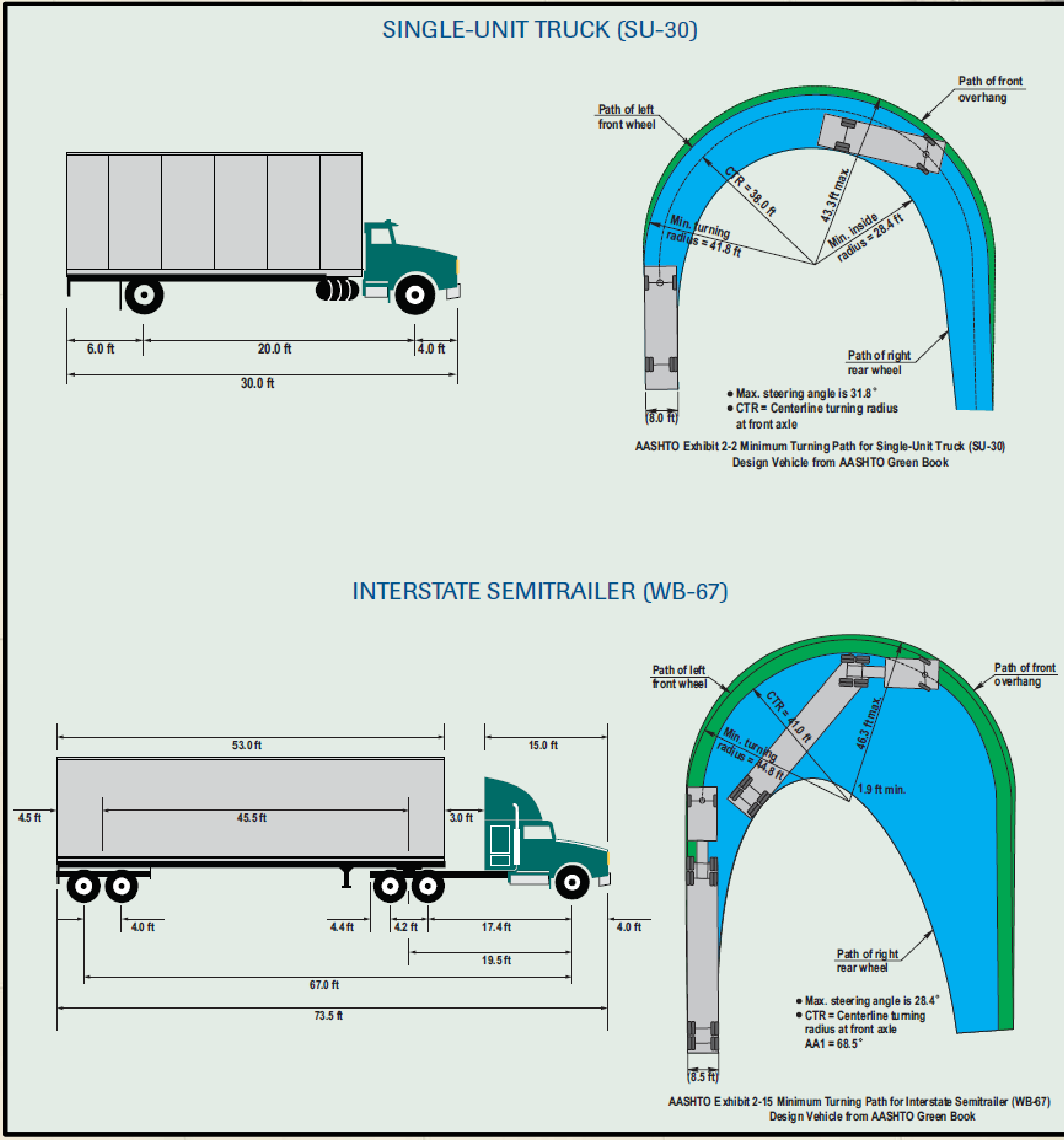
Typically, a WB-67 design vehicle should be used in areas that accommodate trucks. A single unit truck (SU) or a bus (school, transit, or other) may be the appropriate design vehicle at locations where trucks do not use the roadway with considerable frequency.

Vehicle turning templates are shown in the AASHTO Green Book. Many states also have turning templates that can be used for design. Turning templates are used to evaluate the turning path of a vehicle as it completes a turn. Larger design vehicles have larger turning radius requirements. Examples of turns include roadway sections through curves for lane widening, for designing radius returns at intersections, for designing intersection geometrics such as median noses, and for stop line placement at intersections.

When using design vehicle turning templates or software programs, it is generally considered unacceptable for vehicles to significantly overtrack into adjacent lanes. Encroachment should be avoided for the design vehicle of a lane. If a vehicle larger than the design vehicle encroaches into an adjacent lane, it is considered acceptable, especially when lower traffic volumes mean this will occur less frequently. At intersections or roadways with tight curves, the design vehicle should remain in its lane. Encroachment into the adjacent lane may result in a sideswipe crash. Generally, encroachment can be minimized by widening the lane. Recommended lane widths for sharper curves are summarized in the AASHTO Green Book, Table 3-26b. For example, with curve radii less than 200 feet, and larger design vehicles, the lane width may exceed 20 feet.

Examples of AASHTO design vehicles, along with their accompanying turning template, are shown in figure 3.

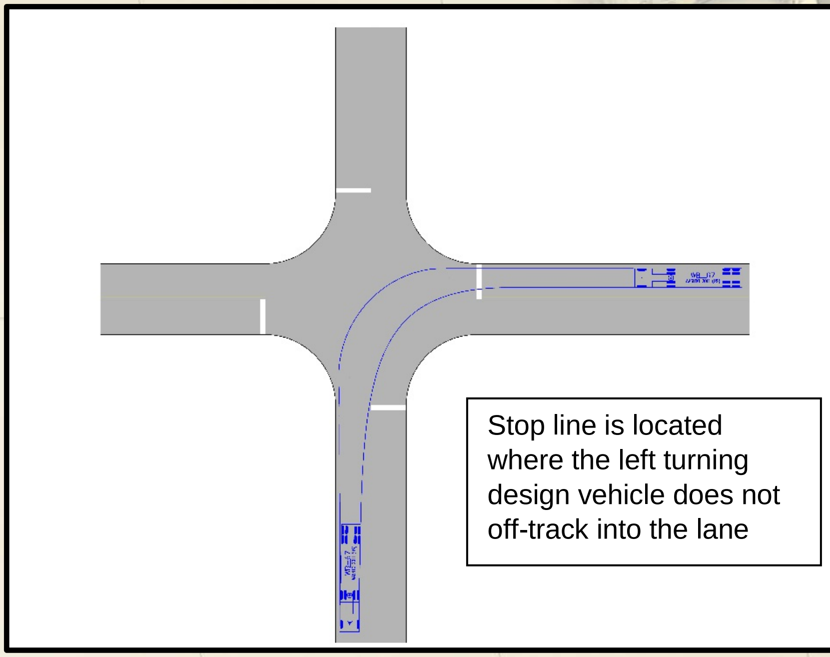
FIGURE 3: Design Vehicle Turning Template Examples



Stop Line Placement

Design vehicles are used to set the location of stop lines. Specifically, the design vehicle turning template for a left-turning vehicle should be checked versus the stop line for the approach that the vehicle is turning onto. In general, locate the stop line as close to the intersecting roadway as possible, provided there are no conflicts with turning vehicles. Narrow roadways and larger design vehicles require the stop line to be located further from the intersection. This can influence not only the stop line location, but also the location of signing and traffic signal detection. Per the MUTCD, stop lines at intersections should be a maximum of 30 feet and a minimum of 4 feet from the nearest edge of the intersecting traveled way. Additional geometric elements, such as a median, may need to be incorporated into the design in order to meet these requirements. Figure 4 illustrates the location of a stop line with respect to a design vehicle.

FIGURE 4: Stop Line Versus Design Vehicle Example



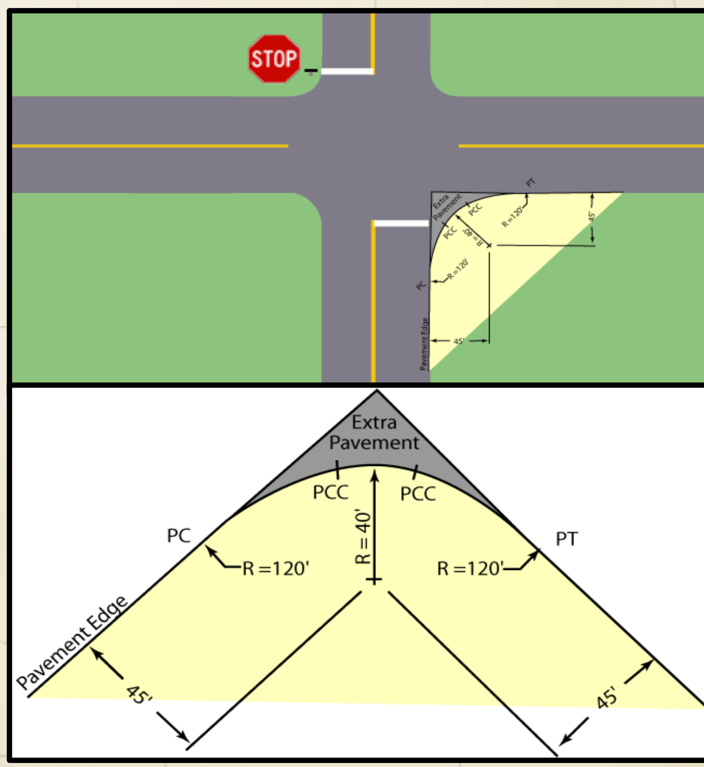
Corner Radius

Factors to consider when determining the corner radii of intersections include: availability of right-of-way, angle of intersection, pedestrian use, vehicle speeds, and the width and number of lanes. Right-turn traffic dictates the size of the outside corner radius. Consider whether there is significant volume of right-turn trucks and buses. Radii of 15 to 25 feet are typically used at minor cross streets without significant truck and bus traffic.

Where buses and large trucks turn frequently, corner radii of 40 feet or more will be necessary. The use of very large radii (more than 40 feet) often create problems for the placement of traffic signals and other traffic control devices.

The ease of vehicle movement, especially for trucks and buses, is normally the objective of using rounded corners at intersections. Radius returns are necessary to keep traffic in their respective lanes. Because vehicle turns do not follow a perfect circular path, the most efficient design for a corner is a three-centered compound curve. A three-centered compound curve more closely follows the inner wheel track of trucks and buses as compared to a simple, circular curve and can be used to avoid the cost of unnecessary pavement. It begins and ends with a fairly large radius curve and has a much sharper curve at the middle of the turn. Figure 5 shows a three-centered compound curve with 120’-40’-120’ radii, offset 45’.

FIGURE 5: Corner Radius Example



Channelization

The concept of channelization is the design of traffic lanes and islands/medians in a way that provides well-defined paths for vehicles to follow through an intersection. Effective channelization reduces points of conflicting traffic movements and helps to separate traffic flow. Proper channelization increases capacity and improves safety. Improper channelization has the opposite effect and may be worse than none at all. Avoid over channelization as it can create confusion and worsen intersection operations.

There are several different types of channelization:

Raised channelization: This type of channelization is accomplished through the use of curbed islands and medians. Raised channelization prevents wrong way movements, provides a refuge area for pedestrian movements, and provides a location for posting signs and signals.

Flush channelization: This type of channelization is accomplished by painting the travel path, without curbed islands. While this can be used to delineate the travel paths, it does not offer the pedestrian refuge and equipment location advantages of raised channelization since there is no curb to redirect vehicles back into their travel path.

Channelizing islands: These are islands typically used at intersections, most frequently to channelize right-turn traffic away from the adjacent through movement. A Yield condition is often used where the right-turn merges with the side street.

Channelizing Island (above)

Divisional Island (below)

Raised corner islands (for right turning traffic) should not be less than 75 square feet for rural intersections and 50 square feet for urban intersections. If islands must be small, provide adequate delineation such as pavement markings to warn motorists or substitute a painted island for the raised island.

Divisional islands: These are islands typically used to divide adjacent lanes of traffic. The most frequent case is a median island that divides both directions of traffic.

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.

Divisional islands can be narrow (4-foot typical minimum) but can get wider based on tapering for left-turn lanes. Where medians and divisional islands are used, the through lanes should line up through the intersection.

Raised divisional islands should be offset from the edge of travel lane by the width of a shoulder if possible but no less than 2 feet from the travel lane. In no case should an island obstruct or reduce adjacent lanes, as this may cause the motorist to sway to avoid them.

Where islands are smaller, painted islands can be used to delineate the travel path. Similar pavement markings are used versus those with a raised island, however hatching can be used to discourage travel over the island.

It is very important to properly sign raised divisional islands. Commonly used signs include: Divided Highway (W6-1) or Keep Right (R4-7). These signs are generally used at the noses of islands; the W6-1 at a non-intersection location where a median starts, and the R4-7 at intersections or to show the presence of a median nose. It is important that the sign width is no larger than the median width.


W6-1


R4-7

Auxiliary Lanes

Left-turn lanes are typically required when (at a signalized intersection) left-turn traffic approaches 50 vehicles per peak hour, or where needed for signal phasing and operation. Right-turn lanes should also be considered to accommodate right-turn volumes. Consult state criteria for appropriate criteria for auxiliary lane use. Auxiliary lane components include approach taper, deceleration length, bay taper, and storage length.

Approach Taper. Use an approach taper to transition the through-travel lanes, and to obtain the necessary width to accommodate the left-turn lane. The length of the approach taper is based on speed and width of the auxiliary lane to be added. This is calculated with the formula $L=W*S^2/60$ for speeds of 40 mph or less, and $L=W*S$ for speeds greater than 40 mph; where L is the approach taper length in feet, W is the width of the lane in feet, and S is the speed limit in miles per hour.

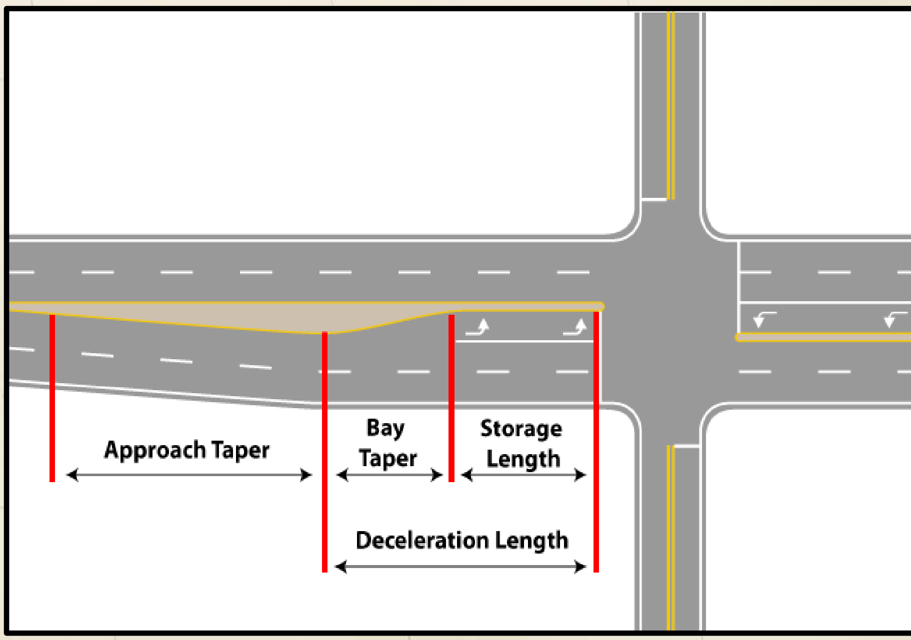
Deceleration Length. On high-speed roadways, it may be desirable to design turn lanes based on deceleration requirements rather than storage needs. This allows vehicles to gradually reduce their speed separately from the through lane, thereby reducing the potential for rear-end collisions. Minimum deceleration lengths (including the taper length) for lanes with an accompanying stop condition are 235, 320, and 435 feet for design speeds of 30, 40, and 50 mph, respectively.

Storage Length. 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 turning 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. Synchro (the capacity analysis software previously mentioned) and Highway Capacity Software calculates queue lengths, which are derived from the queue length formulas presented in the Highway Capacity Manual for manual queue calculation. Whenever possible, the storage lengths should be at least as large as these calculated queues. Storage lengths may need to be increased based on deceleration requirements for high-speed highways.

Bay Taper Length. 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. Typically, the bay taper length is 100 feet for speeds up to 30 mph and 180 feet for speeds of 35 mph and greater for a standard 12-foot wide left-turn lane. Verify distances with state criteria.

These taper components are shown in Figure 6.

FIGURE 6: Auxiliary Lane Components



Intersection Sight Distance

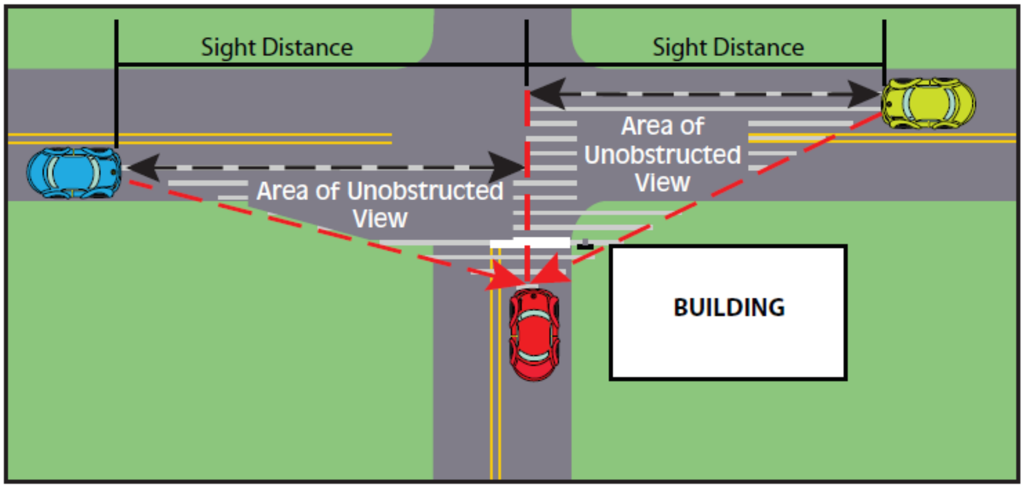
Intersection sight distance is the sight distance required by drivers to see one another (i.e., the driver at the entrance on the minor road pulling out onto the major road and the driver traveling along the major road). The sight distance requirements vary based on the type of intersection traffic control. Section 9.5 in the AASHTO Green Book provides equations, calculations, traffic control scenarios, and additional information for intersection sight distance.

No Control. A clear sight triangle is required for all legs. These distances are typically longer on the minor approaches when compared to stop and yield control on the minor approaches, but shorter than the lengths required on the major approaches for stop and yield control on the major approaches. The speed and grade of each roadway are factors in determining the required sight distance. SDDCTEA's Better Military Traffic Engineering (BMTE) calculator can be used to compute these sight distances. See:

https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/BMTE/calcIntersections/Pages/calcintersectionsightdistance.aspx

Stop Control. The clear sight triangle required for two-way stop control is comprised of one leg being the distance from the center of the intersection to a point 14.5 feet from the edge of travelway on the minor roadway, and the second leg being a calculated distance along the major roadway**. In reference to the stopped vehicle in Figure 6, for left turn and crossing maneuvers from the minor roadway, this calculated 'sight' distance applies to both directions (i.e., major roadway traffic approaching from the left and traffic approaching from the right); however, for right turn maneuvers from the minor roadway, the calculated 'sight' distance applies only to the left side (i.e., major roadway traffic approaching from the left).** The calculated distance varies based on vehicle type, speed, grade, skew angle, number of lanes to be crossed, median width, and movement type. Right turns require less sight distance than left turns. Traffic crossing the intersection requires less distance than left turns, and rarely governs over left turns. Therefore, right turn and left turn sight distance must be provided for both side street approaches of a typical bidirectional four-leg intersection. Figure 7 shows sight distance requirements for a passenger car on a flat grade turning onto a two-lane roadway. SDDCTEA's BMTE calculator can be used to determine the required sight distances for other variables (such as grade, vehicle type, etc.) in this type of control.

FIGURE 7: Stop Control Intersection Sight Distances for Two-Lane Roadways (feet)



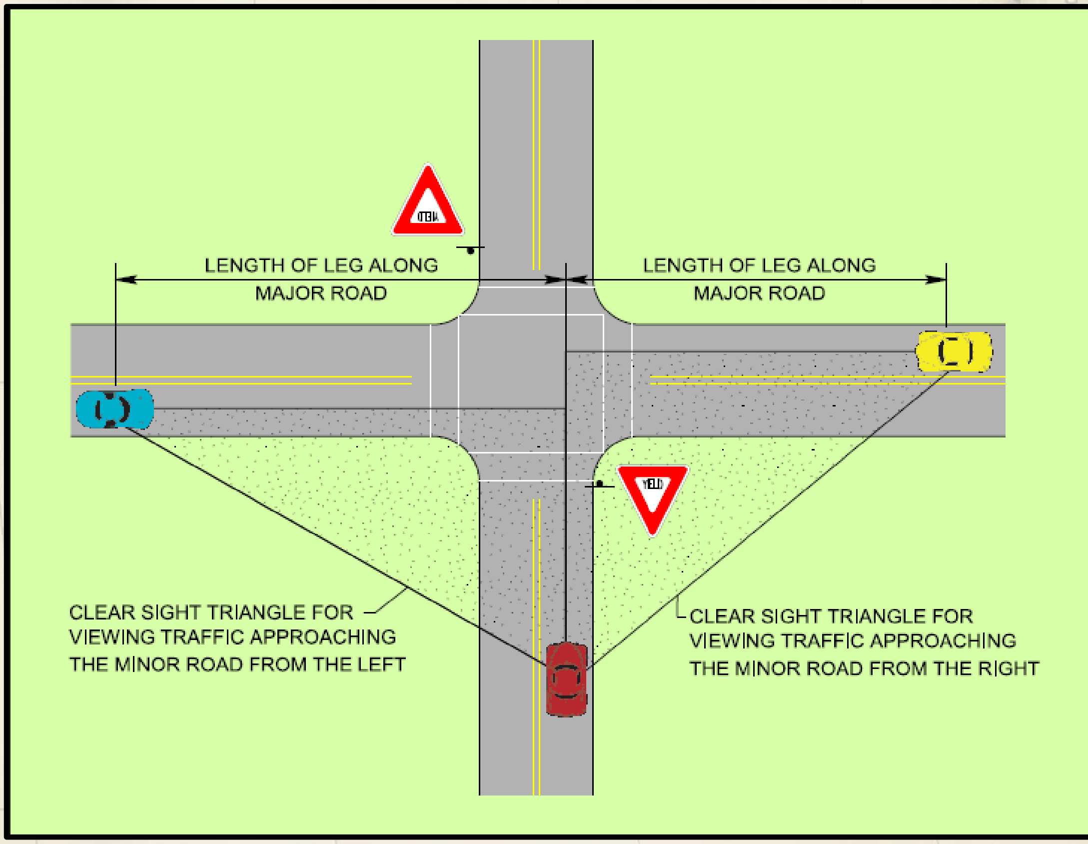
Note: The vertex (decision point) of the sight triangle on the minor road should be 19.5 ft. from the edge of the major road traveled way.

Length of Leg Along Major Roadway		
Major Road Design Speed (MPH)	Left-Turn from Minor Road (Level Grade) (Feet)	Right-Turn and Crossings from Minor Road (Level Grade) (Feet)
25	280	240
30	335	290
35	390	335
40	445	385
45	500	430
50	555	480
55	610	530
60	665	575

Source: AASHTO Green Book, Tables 9-6 and 9-8

Yield Control. Similar to No Control, yield control requires a longer sight distance leg along the minor roadway. Similar to stop control, the distance along the major roadway varies by vehicle type, design speed, skew angle, number of lanes to cross, median width, and movement type. Unlike stop control, the crossing movement can govern and must be checked. The same sight distance is required for left and right turns. Figure 8 shows yield control sight distance for passenger vehicles crossing or turning onto a two-lane roadway, with level grades and no skew. SDDCTEA's BMTE calculator can be used to determine the required sight distances for other variables in this type of control.

FIGURE 8: Yield Control Intersection Sight Distances (feet)



LEFT OR RIGHT TURN FROM MINOR ROAD		
Major Road Design Speed (MPH)	Length of Leg Along Major Road (FT)	Length of Leg Along Minor Road for Right Turns (FT)*
25	295	82
30	355	82
35	415	82
40	475	82
45	530	82
50	590	82
55	650	82
60	710	82

* The distance is based on the assumption that drivers making left and right turns without stopping will slow to a turning speed of 10 mph; AASHTO page 9-46. The length of leg for left turns is equal to 82 ft plus the lane width of the major road.
Source: AASHTO, Green Book, Table 9-12

CROSSING FROM MINOR ROAD			
Major Road Design Speed (MPH)	Length of Leg Along Major Roadway (FT)		
	Minor Road Design Speed (MPH)		
	20-50	55	60
25	240	250	255
30	290	300	305
35	335	345	360
40	385	395	410
45	430	445	460
50	480	495	510
55	530	545	560
60	575	595	610

Minor Road Design Speed (MPH)	Length of Sight Triangle Leg along Minor Road (FT)
25	130
30	160
35	195
40	235
45	275
50	320
55	370
60	420

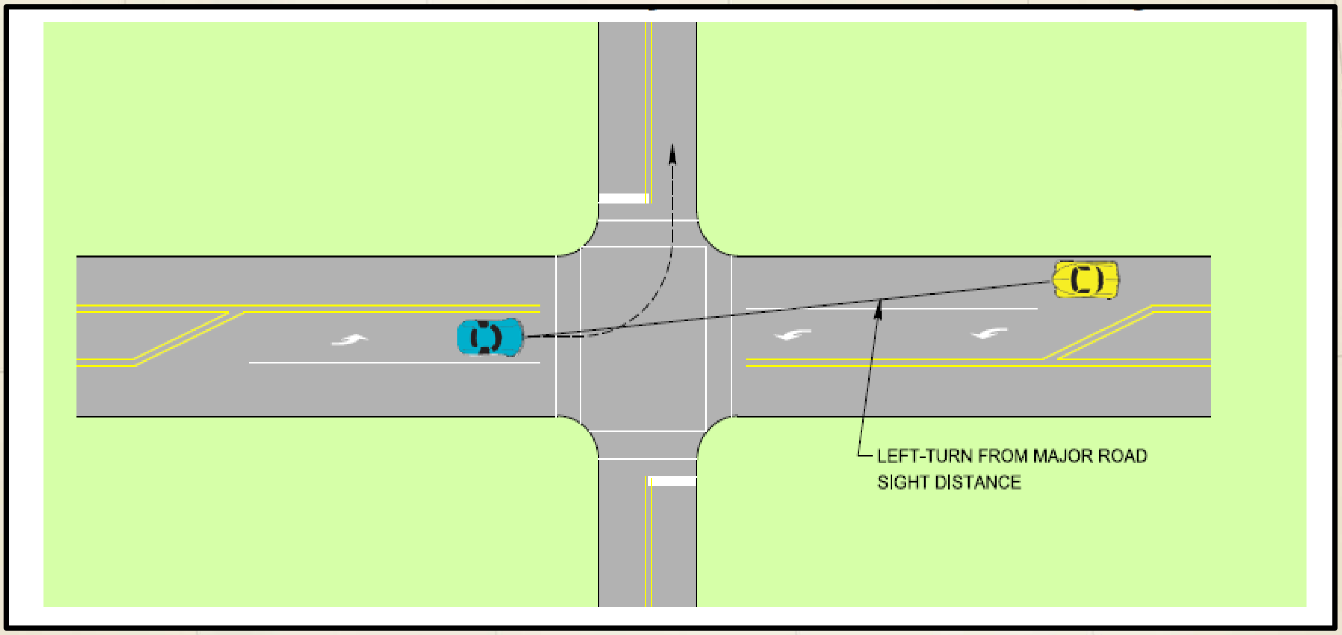
Source: AASHTO, Green Book, Tables 9-9 and 9-10

Traffic Signal Control. At signalized intersections, the first vehicles stopped on one approach should be visible to the driver of the first vehicle stopped on each of the other approaches. If right turns are permitted on red, perform a right-turn sight distance calculation as if that approach was stop controlled. If the intersection operates in flash mode regularly, perform a left- and right-turn sight distance calculation as if that approach was stop controlled.

All-Way Stop Control. The first stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches. There are no sight distance calculations associated with this form of traffic control.

Left Turns from Major Road. This sight distance is needed for motorists to see oncoming traffic on the major road in order to determine if they have enough time to complete their crossing maneuver. The distance is from the left-turning point to traffic in the opposite direction. Figure 9 shows the distance requirements for a passenger car crossing one lane of traffic. SDDCTEA's BMTE calculator can be used to determine the required sight distances for other variables in this type of control.

FIGURE 9: Left-turn from Major Road on Two-Lane Roadways



Left Turns from the Major Road Sight Distance (feet)	
Speed (mph)	Sight Distance
25	205
30	245
35	285
40	325
45	365
50	405
55	445
60	490

Source: AASHTO Green Book, Table 9-14

Crosswalk Placement

Crosswalks should always be located between the stop line and the edge of intersecting roadway. The precise location should be weighed based on site conditions. Crosswalks should be located close enough to the edge of the intersecting roadway such that pedestrians in the crosswalks are visible to traffic traveling parallel to the crossing. They should also be located far enough from the intersecting roadway such that the intersection's corner radii does not create unnecessarily long crossing distances. Additionally, ABA-compliant curb ramps must be provided on both roadway edges intersecting the crosswalk. Sufficient area must be available to construct a proper curb ramp. If the intersection is signalized, pedestrian pushbuttons must be located in accessible locations, specifically no greater than 10 feet from the curb ramp landing area, and no greater than 10 inches away from the edge of the edge of the ramp or sidewalk.

The stop line should be located no less than four feet from the crosswalk. The crosswalk does not need to be located outside of design vehicle turning paths, therefore the stop line can be located farther than four feet from the crosswalk if needed to avoid design vehicle turning paths. In the absence of a stop line, as in the case of a crosswalk spanning the major road approach of a two-way stop control intersection, the same placement guidelines apply. In this case, follow the signing requirements identified in SDDCTEA Pamphlet 55-17 Chapter 13.

Signal Pole Placement

Roadside features, such as sign posts or lighting standards, should be breakaway supports to yield when impacted by an errant vehicle. According to AASHTO's *Roadside Design Guide*, traffic signal poles may be a special situation where a breakaway support may not be practical. A fallen traffic signal pole may become an obstruction, and with a fallen signal pole, the consequences of the lack of signalization needs to be considered.

Traffic signal poles, as well as the traffic signal controller, located on high-speed roadways should be located as far away from the roadway as possible. Shielding these can be considered as well. When locating traffic signal poles, check for state-specific guidance on pole placement. In the absence of state-specific guidance, the following guidelines for different scenarios can be used:

- **Curbed roadway and speeds of 35 mph or less:** Provide a minimum of two-foot clearance between the face of full-height barrier curb and the face of the support.
- **Curbed roadway and speeds of greater than 35 mph:** Provide a minimum of ten-foot clearance between the face of full-height barrier curb and the face of the support.
- **No curbing and shoulder 0-8 feet wide:** Provide a minimum 10-foot clearance from the travel lane.
- **No curbing and shoulder greater than 8 feet wide:** Provide a minimum two-foot clearance from the edge of shoulder.

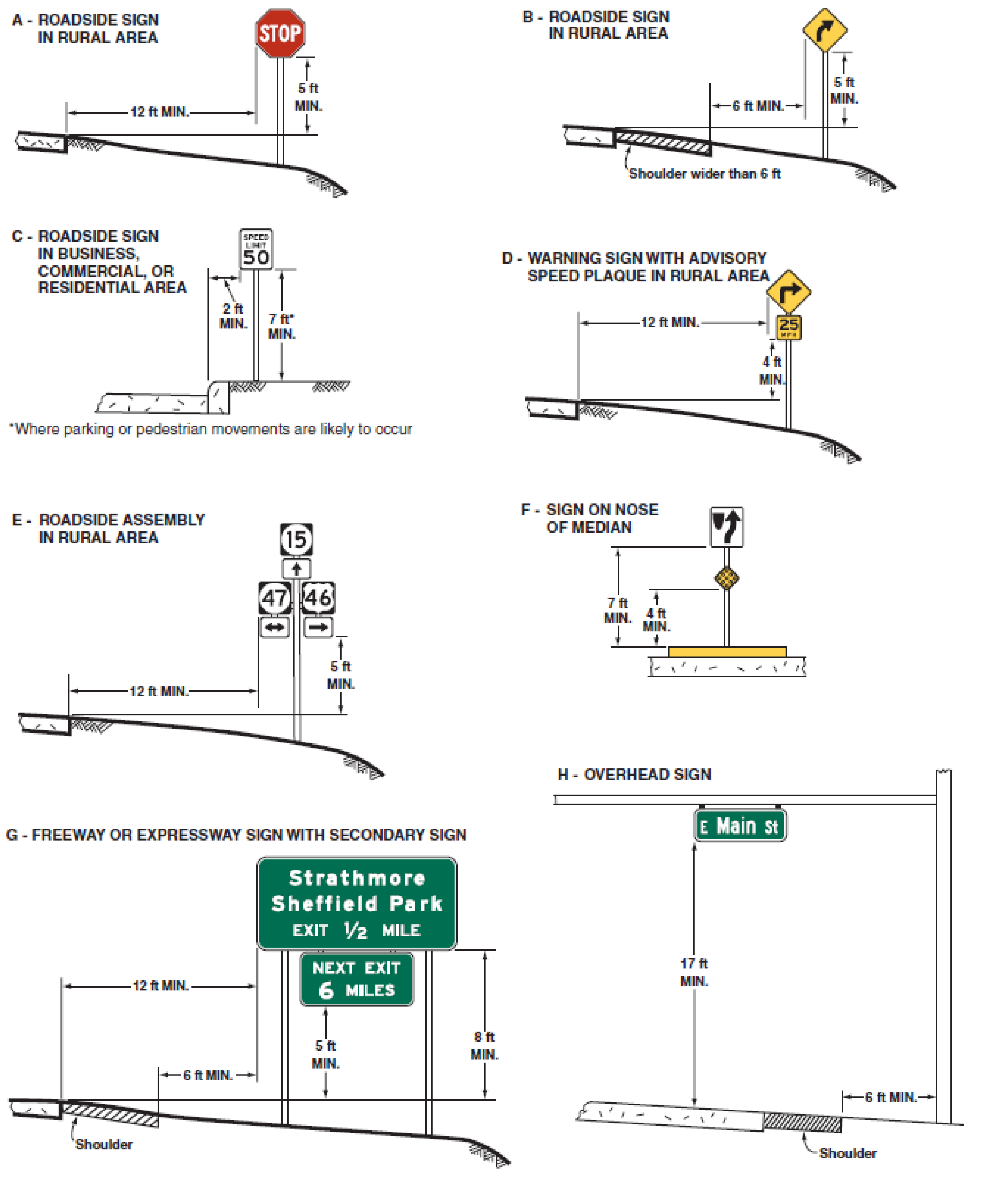
Signing and Pavement Markings

Signing and pavement marking design should be consistent with the MUTCD and SDDCTEA Pamphlet 55-17, as well as state practices. Many states have adopted a supplement to the MUTCD or have specific requirements that exceed the MUTCD. Signing and markings on military bases must be consistent with state requirements.

Pavement Markings. Longitudinal markings for intersections are consistent with those used for roadway sections. These consist of double yellow lines used for centerlines and broken and dashed white lines used for lane designation. Most commonly used transverse markings at intersections include stop lines and crosswalks.

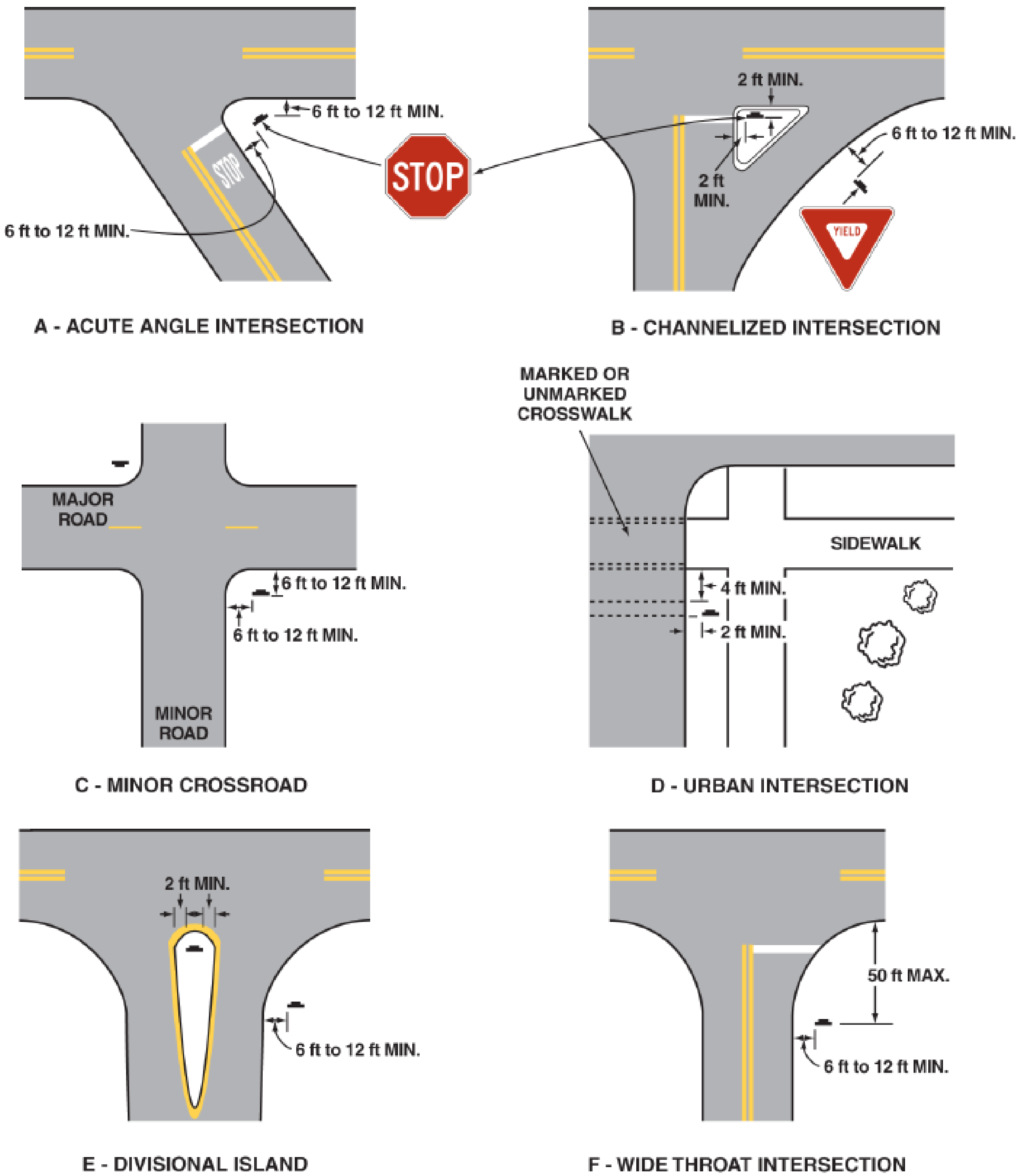
Signs. Many sign messages shown in the MUTCD are applicable to intersections. Signs should be installed on breakaway posts when located within the clear zone. Sign placement should be consistent with the MUTCD, depending on the condition and layout of the intersection, as illustrated in Figure 10.

FIGURE 10: Heights and Lateral Location of Signs (1/2)



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.

FIGURE 10: Heights and Lateral Location of Signs (2/2)



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.

Mr. Bruce A. Busler, SES
Director, Transportation Engineering Agency

Contact Us

MILITARY SURFACE DEPLOYMENT AND DISTRIBUTION COMMAND

TRANSPORTATION ENGINEERING AGENCY (SDDCTEA)

1 Soldier Way
Scott Air Force Base, Illinois
62225-5006

DSN: 618-220-5218

FAX: 618-220-5125

EMAIL: army.sddc.safb.traffic@mail.mil

WEBSITE:
https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/default.aspx for pamphlets, bulletins and studies

Reference List

- ☑ TEA Home: https://www.sddc.army.mil/sites/TEA
- ☑ SDDCTEA Pamphlet 55-8: *Traffic Engineering Studies Reference,* 2016
https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/pamphlets.aspx
- ☑ SDDCTEA Pamphlet 55-17: *Better Military Traffic Engineering,* 2016
https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/pamphlets.aspx
- ☑ SDDCTEA: Better Military Traffic Engineering (BMTE) Web-based Software
https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/BMTE/Pages/default.aspx
- ☑ U.S. Department of Transportation, Federal Highway Administration. *Manual on Uniform Traffic Control Devices*, 2009 http://mutcd.fhwa.dot.gov/.
- ☑ AASHTO *Roadside Design Guide*, 2011
- ☑ AASHTO *A Policy on Geometric Design of Highways and Streets*, 2011.
- ☑ U.S. Department of Transportation, Federal Highway Administration. *Roundabouts: An Informational Guide*, Pub. No. FHWA-RD-00-068, March 2000 http://www.fhwa.dot.gov/publications/research/safety/00068/.