Traffic Engineering and Highway Safety Bulletin 25-03
February 2025

INTERSECTION DESIGN CONSIDERATIONS

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Overview

An intersection is the junction of two or more roadways. Intersections are used not only by vehicular traffic but also public transit, bikes and pedestrians and can vary widely in their size, shape, number of approaches, turn lanes, traffic control and pedestrian and bicycle accommodations.

A properly designed intersection meets traffic demand and capacity needs, accommodates turning vehicles and other geometric requirements, balances the needs of pedestrians and bicyclists, and utilizes the proper type of traffic control. The intersection must also be free of sight distance restrictions for the type of traffic control used, have sufficient lighting and operate safely for all users.

The upgrade of existing intersections and the design of new intersections is a complicated process and unique to the specific intersection. Upgrading an intersection is a function of several different aspects, from analysis to design. This bulletin focuses on several key aspects of intersection design.

Improvement Justification

Documenting deficiencies, which mostly are related to capacity and safety issues at an intersection, justify intersection design improvements. Several common deficiencies found at intersections include inappropriate traffic control, confusing or inadequate signing and markings, and poor access management among many others. While data provided by traffic studies can help determine capacity issues, a site visit/assessment is a valuable way to identify specific safety issues and gain a better understanding of the intersection.

The basis for an intersection capacity analysis begins with collecting the existing intersection traffic volumes during the weekday morning, midday, and afternoon peak periods. In some situations, Saturday traffic data may also be required to be collected, such as at a military installation that has weekend drills. Adjustments to the existing traffic data may be required, such as when troops are deployed, or when school is out of session. Existing volumes can be analyzed using traffic analysis software, such as Synchro or Highway Capacity Software (HCS) to determine the existing intersection operation. Intersection operation includes the level of service (LOS) for the overall intersection, as well as each intersection approach and each lane movement for that approach. LOS measures intersection performance based on the amount of average vehicular delay. LOS is reported in six classifications, LOS A through LOS F, where LOS A represents the highest, nearly free-flow traffic conditions and LOS F represents the worst, gridlock traffic conditions. Typically, for an existing intersection, LOS D or better is considered acceptable and intersection improvements are not required. Additionally, the intersection peak hour capacity analysis also reports the estimated traffic queue length for each approach which shows the typical traffic backup.

Evaluate the peak hour intersection operation for the future traffic conditions. Adjust the existing peak hour intersection traffic volumes for conditions that impact the future traffic volumes, including development, mission changes/deployment or relocation of services. Typically, the traffic volumes increase at the same rate as the population, and this can be the basis of the adjustment factor. For developments, utilize the Institute of Traffic Engineer's (ITE's) Trip Generation Manual to estimate the number of peak hour trips generated by a new development or land use. Distribute the additional/change in peak hour traffic appropriately to the roadway network and generate the future peak hour traffic volumes at each intersection. A "future" intersection capacity scenario is generated and the LOS and queue lengths for the existing and future conditions for each intersection, approach and lane group are compared. If the future intersection capacity operation indicates a LOS E or LOS F, intersection improvements or mitigation measures are typically required.

Mitigation can involve reassessing the traffic control; specifically analyzing traffic signal warrants at an unsignalized intersection or analyzing roundabout operations. It can also include adding turning lanes at intersections. Additional through lanes may also be needed as part of a larger corridor expansion if several intersections along a corridor experience poor levels of service.

In addition to an existing intersection capacity analysis, signalized intersections benefit greatly from an on-site assessment which can identify traffic signal operational problems such as malfunctioning detection, improper traffic signal phasing or controller settings. Updating the traffic signal controller to run an optimized traffic signal timing and phasing plan for each peak hour typically addresses many of the operational issues identified by the existing intersection capacity analysis and/or field visit/observation.

Another aspect of improvement justification is through safety. As part of the site visit, a traffic safety assessment (TSA) should be conducted at each intersection studied. A TSA should consider the following items:

- ☑ Traffic control
- ☑ Lane configuration
- ☑ Signing
- ☑ Striping
- ☑ Design vehicle accommodation and geometric adequacy
- ☑ Operational concerns
- ☑ Intersection Sight Distance
- ☑ Roadside hazards
- ☑ Improper traffic control devices
- ☑ Bicycle and pedestrian access
- ☑ Analysis of recent crash data

A thorough TSA identifies items within the intersection that are safety and/or operational deficiencies. Many safety-related deficiencies are often quick and simple low-cost fixes. However, some deficiencies require physical improvements such as realignment, addition of turn lanes, traffic signal installation or complete intersection reconstruction.

Design Parameters

After identification of the intersection deficiencies and the appropriate mitigations/recommendations, the design parameters need to be identified. These design parameters include:

- ☑ Roadway Classification
- ☑ Design Vehicle
- ☑ Design Location (urban/rural)

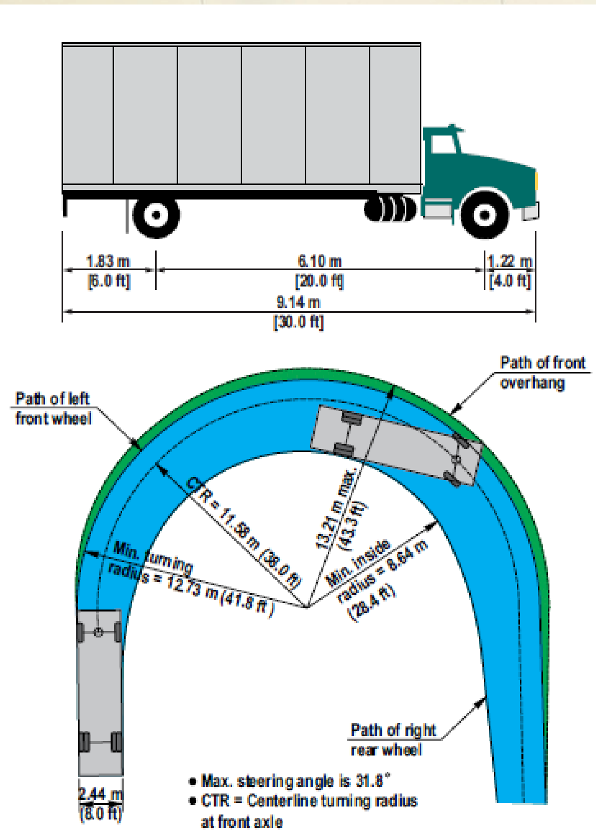
The roadway classification typically includes principal arterials, minor arterials, collectors, and local roads. Higher classification roadways, such as principal arterials and minor arterials have larger traffic volumes and higher speeds. An intersection can occur between any combination of these roadway classifications. Typically, when an intersection occurs between a higher roadway classification and a lower roadway classification, the higher roadway classification governs the intersection design.

The design location, urban versus rural, indicates the geometric and physical requirements of the intersection, such as bike lanes, pedestrian accommodations, turn lanes, etc. An urban intersection may have more requirements and be more constrained for space than a rural intersection.

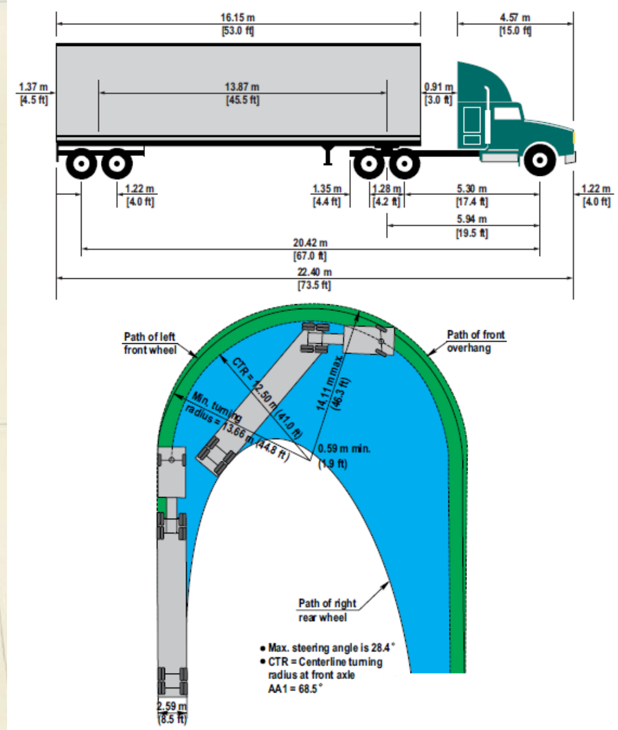
Selecting the appropriate design vehicle that will typically use the intersection is very important and should be established early in the intersection design process. The design vehicle dictates the size of the intersection footprint, specifically to accommodate the required turning radii. Right-turning traffic dictates the size of the corner radius and left-turning traffic dictates the position of the stop line for the intersection approach to the vehicle's left. Tractor trailers, such as a WB-67, have larger turning radii than other design vehicles, such as a bus or single unit truck. In areas where trucks are expected, use the WB-67 as the design vehicle. At other intersections, the single-unit truck (SU) or bus design vehicle may be used, with accommodations for larger vehicles, if necessary. The Turning Template Examples for SU-30 and WB-67 Design Vehicles show the differences in the turning paths between the two design vehicles. CAD-based software programs are available for evaluating design vehicle turning paths through intersections.

Turning Template Examples for SU-30 and WB-67 Design Vehicles

Image Source: SDDCTEA Pamphlet 55-15



AASHTO Exhibit 2-2 Minimum Turning Path for Single-Unit Truck (SU-9[SU-30])
Design Vehicle from AASHTO Green Book

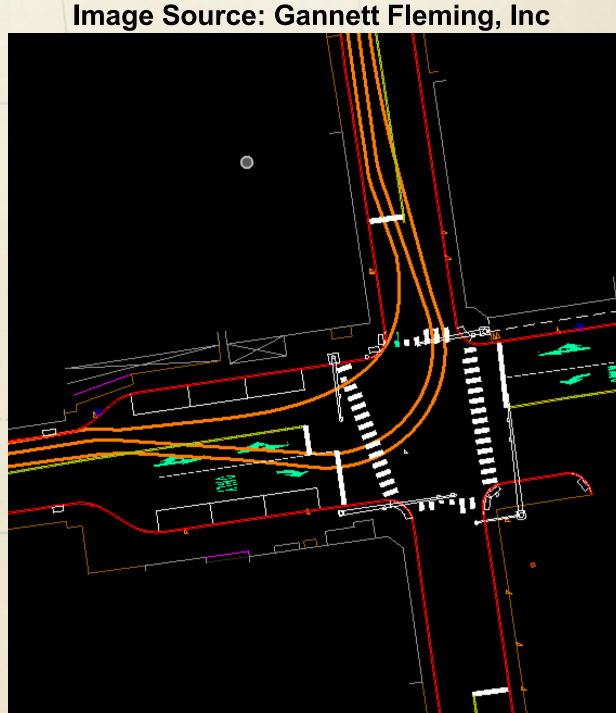


AASHTO Exhibit 2-15 Minimum Turning Path for Interstate Semitrailer (WB-20[WB-67])
Design Vehicle from AASHTO Green Book

A Truck Turning Analysis, shown below, can show the need to redesign the intersection to accommodate a large truck turning because the truck encroaches to the northbound lanes on the north approach and eastbound traffic lanes on the west approach. The orange lines represent the path of a tractor trailer navigating a southbound right-turn.

Truck Turning Analysis through Tight Intersection

Image Source: Gannett Fleming, Inc



Traffic Control

The type of traffic control needed is another key aspect of intersection design. Traffic volumes and location context dictate the appropriate form of control. Traffic control options include: No Intersection Control, Yield Control, Minor Road Stop Control, All-Way Stop Control, or Traffic Signal.

A review of existing conditions through the intersection is critical to proper traffic control assessment. Some of the existing conditions can be obtained by a review of an aerial image and photographs of the intersection, but field investigation is often much more effective. During the review, note the following:

- ☑ Number of intersection approaches
- ☑ Presence of separate turn lanes
- ☑ Angle of intersection approaches
- ☑ Speed limits of each approach
- ☑ Available sight distance on each approach
- ☑ Reported crash experience within and near the intersection
- ☑ Presence of a grade crossing near the intersection
- ☑ Determine the minor roadway.

There are several steps to determine the traffic control, as detailed below.

- ☑ Collect existing vehicle, bicycle and pedestrian traffic volumes on all approaches.
- ☑ Determine the future traffic volumes for vehicles, bicycles and pedestrians.
- ☑ Evaluate All-Way Stop Control Warrants. The MUTCD has all-way stop control warrants that should be evaluated as part of the intersection traffic control selection process. There are five (5) warrants for consideration and one (1) or more of these warrants should be satisfied to justify the installation of All-Way Stop Control.
- ☑ Evaluate traffic signal warrants. The Manual on Uniform Traffic Control Devices (MUTCD) includes nine traffic signal warrants for the basis of the analysis for the installation of a traffic signal at an intersection. Vehicular, pedestrian and bicycle traffic volumes are compared to the minimum values listed in the various warrants. At least one of these nine warrants needs to be satisfied, along with engineering judgement and an evaluation of the physical characteristics of the location, for the consideration of the installation of a traffic signal. The warrants are also utilized to justify the removal of an existing traffic signal when traffic patterns have changed at the signalized intersection.
- ☑ Capacity Analysis. After the initial selection of the appropriate traffic control, the peak hour intersection capacity is evaluated using software programs like Synchro or HCS. Intersection information, such as peak hour design volume traffic for each movement, turn lanes, roadway centerline profile grades, lane widths, design speeds, and storage lane lengths, are entered to evaluate the intersection. Review the LOS results for the intersection, each intersection approach, and each approach lane group, to ensure that the LOS is acceptable (usually LOS D or better). The intersection capacity analysis can help identify the need for additional improvements, such as turn lanes, to meet the acceptable LOS requirements for the intersection.
- ☑ As part of determining traffic control, evaluate whether there is adequate sight distance for the type of intersection traffic control selected. Different types of traffic control have different intersection sight distance (ISD) requirements, depending on whether the major road must stop.

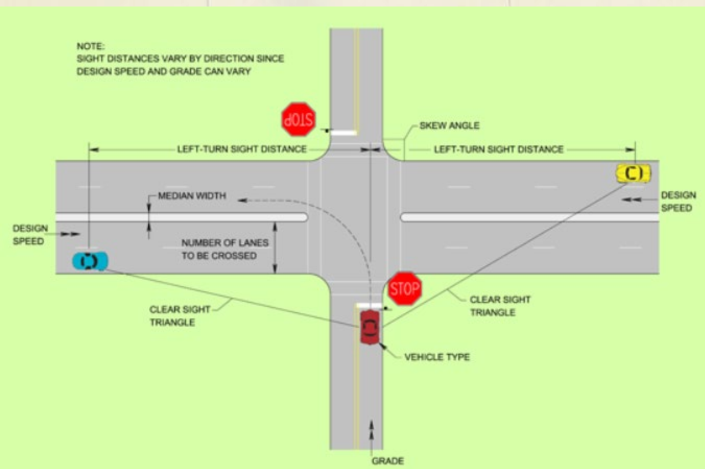
Sight Distance

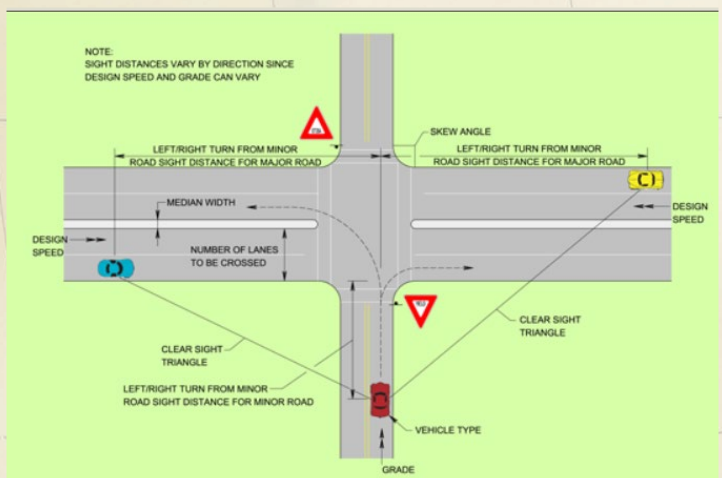
Intersection sight distance (ISD) is the length of the intersecting roadway that an approaching driver needs to be able to see clearly to identify an oncoming vehicle and react appropriately. It is also important that drivers on the intersecting roadway be able to clearly see the approaching vehicle as well so they can assess the situation and respond appropriately. Obstructions that can limit or block ISD can include trees, bushes, signs, fences, parked vehicles, utility poles or buildings. Adequate sight distance must be provided at all intersections.

The required sight distance is a function of the type of traffic control for the intersection, the design speed of each approach, the grade of each approach, the intersection width, and the angle of the intersecting roads. A driver approaching an intersecting roadway needs to see far enough down the roadway, in both directions, to judge the travel speed and the available gaps in the traffic before turning right, turning left or crossing the travel lanes on the intersecting roadway. The required minimum ISD must be calculated for the specific intersection conditions and for each movement from each intersecting roadway. The ISD calculations result in distances along each intersecting roadway, that when plotted on a drawing or aerial image or even staked out in the field at the intersection, creates an "intersection sight distance triangle". The area inside this triangle needs to be free of obstructions. The figure below illustrates the ISD triangles for a yield control intersection as compared to a stop control intersection, with the primary difference being the distance needed on the side-street approach.

Sight Triangle Requirements for Stop and Yield Intersection Approaches

Image Source: SDDCTEA BMTE





See TEA's *Better Military Traffic Engineering (BMTE)* located here for calculators to determine the required ISD for the following scenarios:

- ☑ No Control
- ☑ Stop Control
    - Left turn from the minor road
    - Right turn from the minor road
    - Crossing maneuver from the minor road
- ☑ Yield Control
    - Left or right turn from the minor road
    - Crossing maneuver from the minor road
- ☑ Traffic signal control
- ☑ All-Way Stop Control
- ☑ Left Turn from the Major Road

These calculators follow the AASHTO Green Book guidelines for calculating required ISD. If the required ISD cannot be provided, there are several options that could help meet the required ISD, including:

- ☑ Removal or relocation of an object blocking sight distance.
- ☑ Trimming trees and vegetation blocking sight distance.
- ☑ If horizontal or vertical curvature blocks sight distance, consider regrading. Sometimes slight sight distance restrictions from hillsides can be regraded to improve sight distance. Sharp vertical curvature can be more challenging.
    - If curvature cannot be regraded and there are no other options to eliminate a sight distance restriction, it may be possible to reduce the ISD required, such as reducing the speed limit or changing to a form of traffic control requiring less sight distance. If either of these ideas are considered, the location should be professionally evaluated to determine their appropriateness.

Pedestrians at Intersections

Pedestrians must be considered and accommodated at intersections. The type of intersection control influences what specific accommodations are used and where they are located. The presence of sidewalks on approaches leading to the intersection is an indicator of the need for crosswalks, as a means of continuing the pedestrian network. Pedestrian demand should be accommodated; if pedestrian usage is frequent around the intersection even without sidewalks, crosswalks and pedestrian accommodations should be provided within the intersection.

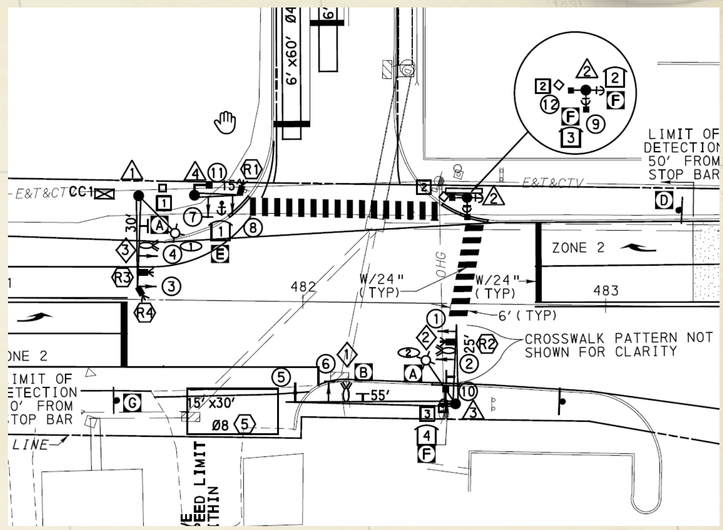
The use of a crosswalk should be considered as follows:

- ☑ At signalized intersections, typically crosswalks should be located across all approaches. Traffic signal components, including pedestrian signal heads and pedestrian push buttons, should be used to facilitate pedestrian crossings.
- ☑ At All-Way Stop Control intersections, a crosswalk should be located across all approaches. No pedestrian warning signs are necessary since traffic stops in all directions.
- ☑ At Minor Street Stop or Yield Control intersections, a crosswalk should be located across the minor street such that the stopping or yielding point is located at least 4 feet before the crosswalk. Whether a crosswalk spans the major street is a function of traffic volumes and pedestrian volumes. See the *Crosswalk Warrants and Guidelines* document. When warranted, the crosswalk should be located across one approach of the major street, to concentrate all crossings to that location, versus using two crosswalks across both major street approaches. As shown in the *Crosswalk Warrants and Guidelines* document, the crosswalks should have warning treatments intended to maximize warning to drivers and increase safety for pedestrians.

Once the decision to install a crosswalk is made, the precise location of the crosswalk on the approach should be considered. It is preferred to have the crosswalk as close to the center of the intersection as possible, because this puts the stopping point for traffic closer to the center of the intersection and it makes pedestrians in the crosswalk more visible to drivers turning onto the approach on which they are crossing. However, because of the intersection corner radius increasing the crossing length, it is preferable to locate the crosswalk away from the center of the intersection. Therefore, the balance must be made between the two objectives. Designing for a larger vehicle by using a larger corner radius creates a gentler rate of curvature which can allow a crosswalk to be located partially within the radius. Designing for a smaller vehicle typically results in the use of a smaller corner radius, which in turn allows for a crosswalk closer to the center of the intersection. If necessary, crosswalks can be skewed somewhat if the opposite corners are not symmetrical. See example of a skewed crosswalk in the figure on the next page

Example of Skewed Crosswalk

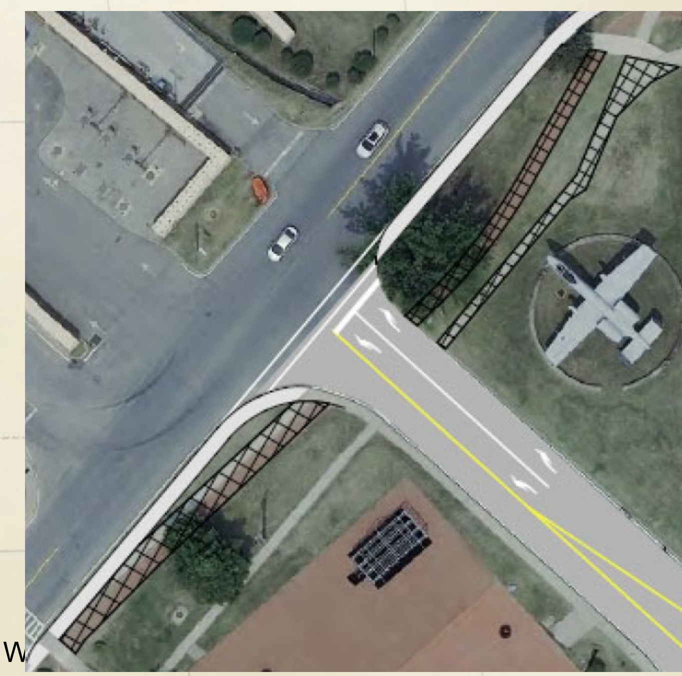
Image Source: Gannett Fleming, Inc.



Crosswalks should always be located between the stop line and the intersecting roadway. A problem frequently observed on installations is when a sidewalk is offset from the roadway, a crosswalk is located at the same distance from the intersection. This results in the crosswalk located in advance of the stopping location. The mitigation for this is to move the sidewalk closer to the intersection.

Example of Sidewalk in front of Stop Bar

Image Source: Osan AB Imagery



W le for adding a curb ramp. The crosswalk connecting to the sidewalk system must be PROWAG-compliant, which requires certain slope and geometric requirements. In constrained locations, the ability to fit a ramp at a crosswalk can be a consideration in where the crosswalk is located.

Typical Signal Placement

At signalized intersections, the location of signal equipment such as traffic signal poles, signal heads, pedestrian signals and push buttons, traffic signal controller cabinets, etc., must be considered. Signal poles must be located such that signal heads are located to provide the proper placement for visibility by approaching vehicles. Signal heads must be located such that they are mounted above the approach lanes within the driver's cone of vision. Typically, at a 4-leg intersection, the signal poles should be located at the far-right corner for each approach. This maximizes the distance between the signal heads and the stop bar and provides the required signal head visibility. At a three-leg intersection, the practice is similar, except it may be possible to use pedestal poles to locate the signal heads for the side street approach since there is no opposite leg. Heavily constrained or significantly skewed intersections may result in different pole configurations, including the use of twin mast arms, angled mast arms, span wires in lieu of mast arms, or signal heads for multiple approaches mounted on one mast arm.

The need to mount pedestrian signals and pushbuttons also impacts, and can be a major consideration in, pole locations. PROWAG requires that pedestrian pushbuttons be located no more than 10 feet from a curb ramp, and a reach of no more than 10 inches from the edge of a sidewalk. It also requires that if two pushbuttons are used in an intersection quadrant, as is typical for a corner with a crosswalk spanning each of the two different intersecting legs, that each pushbutton be located on a separate pole, separated by at least 10 feet. When this occurs, there are a few options for the placement of the two poles in each quadrant:

- ☑ Use the main signal pole for one of the pushbuttons and a short stub pole for the second pedestrian pushbutton. The pedestrian signals would be mounted on the main signal pole.
- ☑ If the main signal pole is not located near a curb ramp, install a pedestal pole, 12 feet in height, for one of the pushbuttons and for the pedestrian signals. Install a short stub pole for the second pedestrian pushbutton.
- ☑ If neither the main signal pole nor the pole used for the pedestal poles (if different) are located at the curb ramps, then two short stub poles for the pedestrian pushbuttons can be used. The main poles would be located where needed for vehicular and pedestrian signal placement.

The location of the traffic signal controller cabinet is a major component that must be given proper consideration. It is preferable that a controller cabinet be mounted on a concrete pad since it can be bigger to fit more equipment. In constrained settings, they can be pole mounted. When the controller is mounted on a pad it should be easily accessible by a technician. It should be located out of the way of pedestrians, and located near a parking space, so the technician can park easily near it. It should be located such that the technician has a good view of the intersection. It is also extremely important that it be out of the clear zone to minimize the chances of being struck by a vehicle and not block sight distance for vehicles and pedestrians.

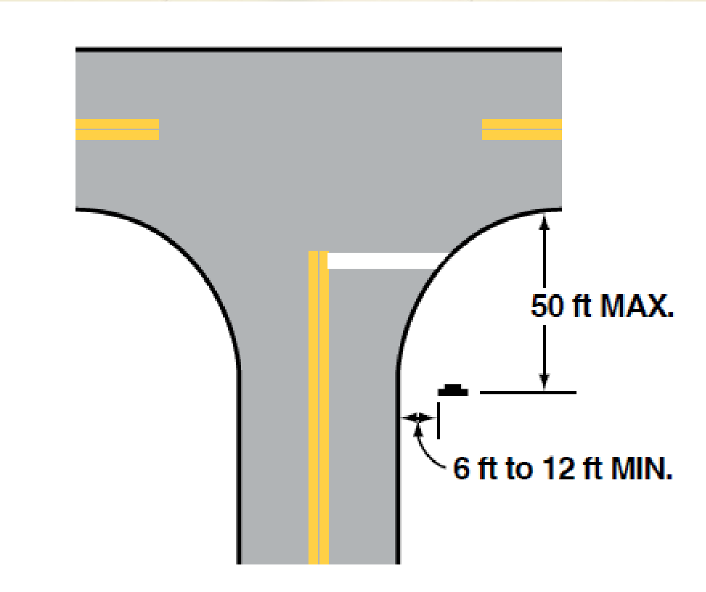
Signal Controller in Urban Setting

Signing Locations

STOP or YIELD signs should be located appropriately per the MUTCD. These signs must be mounted on the right-hand side of the approach under that control. STOP or YIELD signs should not be placed farther than 50 feet from the edge of the pavement of the intersected roadway. If the intersection corner radius is so large that it pushes the sign away from the edge of the road that it controls, thereby reducing its visibility, consider adding an additional sign on the left-hand side of the roadway to increase sign visibility. Additionally, installing advance intersection warnings, such as Stop Ahead (W3-1) signs or an overhead flashing red beacon at the intersection can provide proper notice of the upcoming control.

Stop Sign Location with Respect to Cross Street

Image Source MUTCD



The stop line location is related to the crosswalk and accommodating truck turning movements. If a truck is the design vehicle, it should be able to turn through an intersection without conflicting with stopped vehicles on other approaches. Specifically, the stop line should be far enough back to avoid a truck turning path. The location where the stop line must be placed to avoid a turning vehicle's path is also the location of the Stop sign.

Several additional signs found at or near an intersection are:

- ☑ Keep Right (R4-7) signs are often used when a median is present to notify drivers to avoid the median.
- ☑ ONE WAY (R6-1) and DO NOT ENTER (R5-1) signs are used if a one-way restriction is in place.
- ☑ No Right Turn (R3-1) or No Left Turn (R3-2) signs are used if a turn restriction is in place.
- ☑ Street Name signs are located within the intersection and should be located to maximize visibility of the signs from both streets. They are often placed above a STOP sign. With a few specific exceptions, no other signs should be used on the same post as a STOP sign.

At signalized intersections, several signs are often mounted on the mast arm next to the signal heads, including signing for left-turn signals, NO TURN ON RED (R10-11, R10-11b) signing, if needed, or Street Name signs. Additionally, regulatory, warning or guide signs may be required to be installed on the intersection approaches/departures to provide proper information to the motorists.

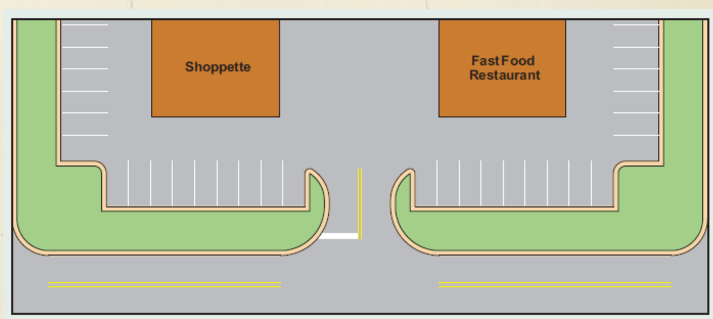
Access Management

Access management needs to be considered in the design of an intersection. While access management, or the practice of limiting the number of driveways and access points along a roadway, should be considered in the design of roadway corridors, the applicability to intersections still must be considered.

The location of driveways/access points to adjacent properties/buildings near intersections is another key element of intersection design. As part of the intersection capacity analysis results, the queue length for each movement for each intersection approach should be reviewed. Intersections have traffic that stops, waits and may even back up. This queue of waiting traffic can limit drivers' access to/from driveways or access points. Driveways located within the storage bay or taper of a left-turn lane or right-turn lane are undesirable due to the potential of traffic queuing in the turn lane and blocking driveway access. For traffic exiting the driveway, this queue of waiting vehicles creates a safety concern with limited sight distance. Driveways should be located outside the intersection influence area. One potential solution is to combine driveways for adjacent land uses as shown in the illustration below.

Example of Joint Property Access

Image Source: SDDCTEA Pamphlet 55-17



Proper spacing for roadway access points must be considered when designing an intersection. The recommended spacing varies based on speeds and roadway type. The following table shows the recommended access spacing.

Recommended Access Spacing

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.	

If spacing of an access is too close to an intersection and cannot be relocated, consider turning restrictions, specifically restricting the left-turn into and/or out of the access and creating a right in/out (RIRO) access point. The benefit of restricting left-turns generally is safer and operationally more efficient. When the volume of mainline roadway traffic is so high that it is extremely difficult to turn left out of the driveway, motorists may accept unsafe gaps in traffic attempting to turn left which increases the likelihood of crashes. Additionally, motorists waiting to turn left can also cause unacceptable delays to right-turning vehicles.

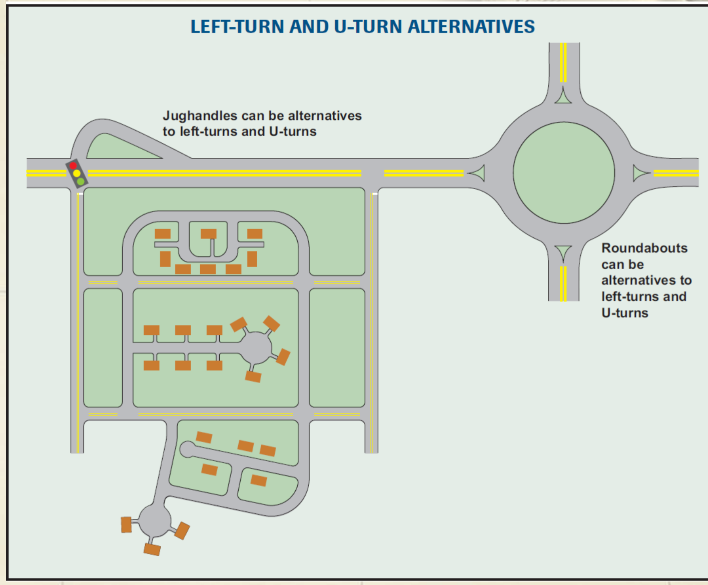
When this type of restriction occurs, especially for a large traffic generator, it may be necessary to accommodate traffic that otherwise needs to make these left turns. One potential solution could be to provide a secondary access point from the site to a side street. A second potential solution is providing vehicles with the ability to make a U-turn 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 if permitted by state law.
- ☑ 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.

The following figure illustrates these alternatives.

Left-Turn and U-Turn Alternatives

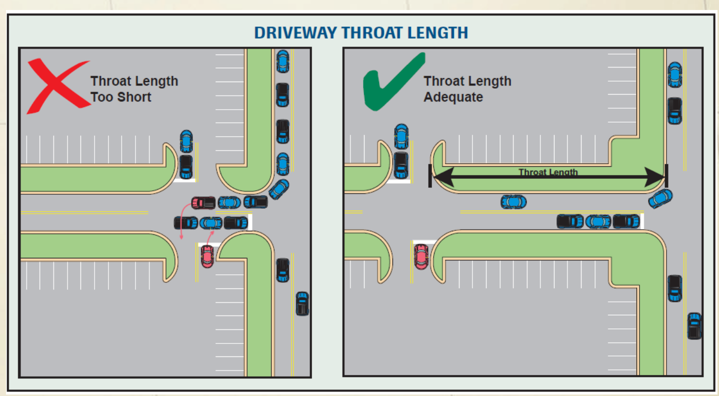
Image Source: SDDCTEA Pamphlet 55-17



It is also important to ensure that the driveway throat length, or the length between an intersection and an internal intersection in the site is adequately spaced. Providing adequate driveway throat length accommodates traffic at the internal intersection and reduces the potential for the internal intersection to back-up and spill out into the main roadway. The figure below illustrates this concept of adequately sized driveway throat length.

Driveway Throat Length

Image Source SDDCTEA Pamphlet 55-17



Type of Establishment	Recommended Throat Length	Approximate No. of Cars
Small Strip Mall, Shoppette, Fast Food Restaurant	75-95 Feet	5
Small Shopping Center, Exchange, Commissary	200 Feet	11

Lighting

Providing proper lighting is an important aspect of intersection design. Crash rates are higher at night and while there are driver-related factors, roadway factors also play a role. Lighting provides a larger range of visibility as compared to a vehicle's headlights. This helps the driver, as well as pedestrians walking at night. Lighting can be installed at specific locations, like at an intersection or crosswalk, or along a roadway corridor. If installed along a roadway corridor, luminaires would be installed on utility poles at certain intervals. This often occurs in urban areas where pedestrian activity is more frequent. If installed at a specific location such as an intersection, luminaires should be located to adequately light the intersection and crosswalks, if present. Typically, if the intersection is signalized, luminaires would be attached to the traffic signal poles. Depending on the size of the intersection, there may be a luminaire on one, two, or four poles through the intersection.

Summary

There are several aspects to intersection design, all of which must be considered for safe and efficient operation. Proper capacity and appropriate traffic control must support the traffic demand, and appropriate accommodations must be provided for pedestrians and cyclists to cross safely. The intersection must have proper sight distance and spacing between other intersections and driveways must be adequate such that one does not impact the operations at another. It must also have sufficient lighting to help drivers and pedestrians see at night. When considering all these aspects, the design of an intersection will allow it to operate efficiently and be safer for all road users.

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Reference List

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- ☑ American Association of State Highway and Transportation Officials *Policy on Geometric Design of Highways and Streets*, "Green Book", 2018

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