CHAPTER 4

GEOMETRIC DESIGN

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4.0 GEOMETRIC DESIGN

This chapter presents geometric design guidelines for signalized intersections based on a review of technical literature and current design policy in the United States.

Geometric design of a signalized intersection involves the functional layout of travel lanes, curb ramps, crosswalks, bike lanes, and transit stops in both horizontal and vertical dimensions. Exhibit 4-1 illustrates the functional boundaries of a signalized intersection.

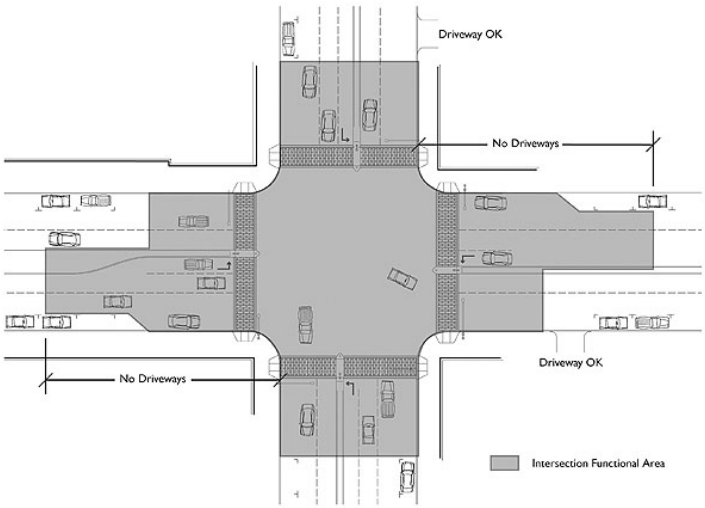


Exhibit 4-1. Intersection functional boundaries.

Source: "Intersection Design Guidelines," Institute of Transportation Engineers, http://www.ite.org/css/online/DWUT10.html

Geometric design profoundly influences roadway safety; it shapes road user expectations and defines how to proceed through an intersection where many conflicts exist. In addition to safety, geometric design influences the operational performance for all road users. Minimizing impediments, reducing the need for lane changes and merge maneuvers, and minimizing the required distance to traverse an intersection all improve intersection safety and operational efficiency.

All possible road users' (see Chapter 2) needs must be considered to achieve optimal safety and operational levels at an intersection. When road user groups' design objectives conflict, the practitioner must carefully examine the needs of each user, identify the tradeoffs associated with each element of geometric design, and make decisions with all road user groups in mind. For instance, practitioners may design corner radii to accommodate large vehicles. However, these larger radii would be detrimental to pedestrian safety due to the increase in walking distances and the increase in speed of turning vehicles. Exhibit 4-2 shows a typical example of this situation.

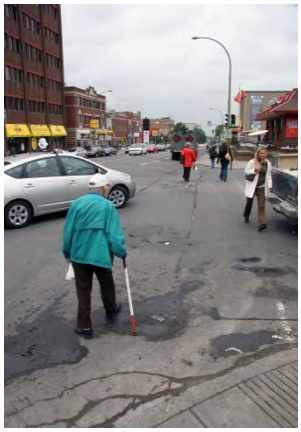


Exhibit 4-2. A large corner radius that impacts pedestrian safety.
Source: PBIC Image Library, Dan Burden

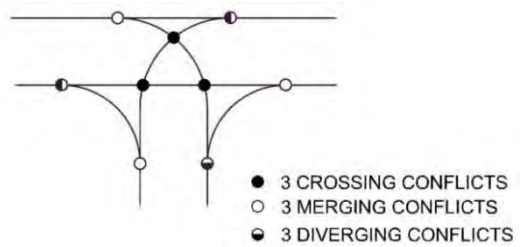
This chapter addresses the following topics:

- Number of intersection approaches.
- Principles of channelization.
- Horizontal and vertical alignment.
- Corner return radius access control.

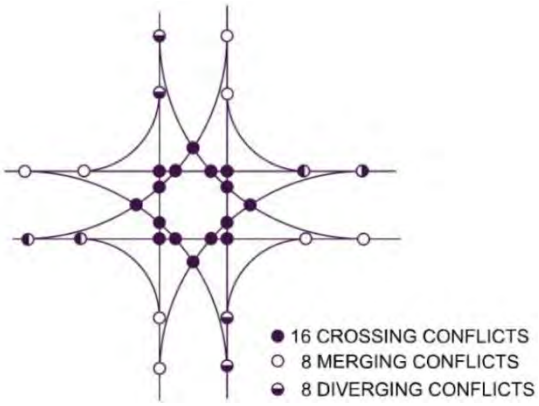
- Sight distances.
- Pedestrian treatments.
- Curb ramp design.
- Detectable warnings.
- Bicycle facilities.
- Transit facilities.

4.1 NUMBER OF INTERSECTION LEGS

The complexity of an intersection increases as the number of approach legs to the intersection increases. Exhibit 4-3, below, shows the number and type of conflicts that occur at intersections with three and four legs, respectively. Exhibit 4-4 shows a complex intersection with six approach legs. The number of potential conflicts for all users increases substantially at intersections with more than four legs. Note that many potential conflicts, including crossing and merging conflicts, can be managed (but not eliminated) at a signalized intersection by separating conflicts in time.



(a) Three-leg intersection.



(b) Four-leg intersection.

Exhibit 4-3. Potential conflicts at intersections with three and four legs.

Exhibit 4-4. Photograph of a six-leg intersection.
Source: Google 2012

4.2 CHANNELIZATION

A primary goal of intersection design is to limit and/or reduce the severity of potential road user conflicts. Basic principles of intersection channelization that can reduce conflicts are described below.[45]

1. **Discourage undesirable movements.** Designers can utilize corner radii, raised medians, or traffic islands to prevent undesirable or wrong-way movements. Examples include:

- Restricting left turns from driveways or minor streets based on safety or operational concerns.
- Designing channelization to discourage wrong way movements onto freeway ramps, one-way streets, or divided roadways.
- Designing approach alignment to facilitate intuitive movements.

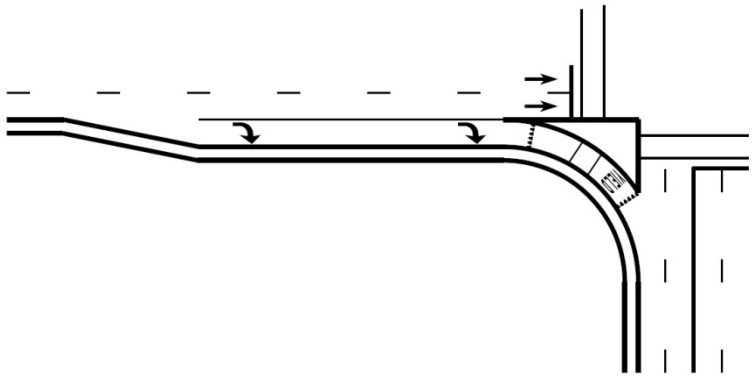
Exhibit 4-5 shows how a raised median can be used to restrict undesirable turn movements within the influence of signalized intersections.

Exhibit 4-5. This raised median restricts left-turn egress movements from a driveway located between two intersections.
Source: Google 2012

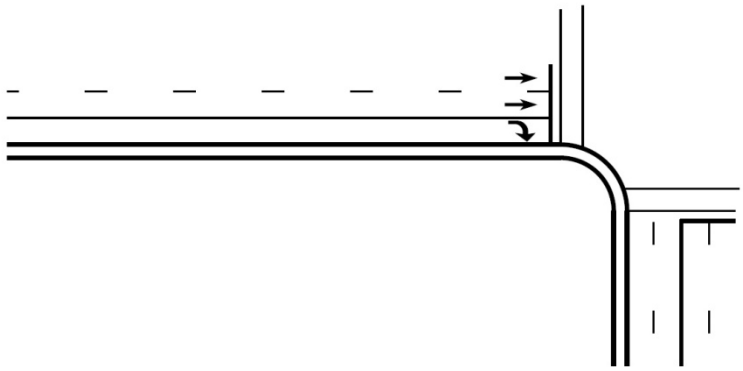
2. **Define desirable paths for vehicles.** The approach alignment to an intersection as well as the intersection itself should present the roadway user with a clear definition of the proper vehicle path. This is especially important at locations with complex geometry or traffic patterns such as highly skewed intersections, multi-leg intersections, offset-T intersections, and intersections with very high turn volumes. Clear definition of vehicle paths can minimize lane changing and avoid “trapping” vehicles in the incorrect lane. Avoiding these undesirable effects can improve both safety and traffic flow at an intersection. Exhibit 4-6 shows how pavement markings can be applied to delineate travel paths.

Exhibit 4-6. Single point urban intersection (SPUI) with pavement marking delineation for turning movements.
Source: Google 2012

3. **Encourage safe speeds through design.** Effective intersection design promotes desirable speeds to optimize intersection safety. The appropriate speed will vary based on the use, type, and location of the intersection. On high-speed roadways with no pedestrians, practitioners may want to promote higher speeds for turning vehicles to remove turning vehicles from the through traffic stream as quickly and safely as possible. This can be accomplished with longer, smooth tapers and larger corner radii. On low-speed roadways or in areas with pedestrians, practitioners may want to promote lower turning speeds. This can be accomplished with smaller turning radii, narrower lanes, and/or channelization features. These are illustrated in Exhibit 4-7.



(a) Higher speed design

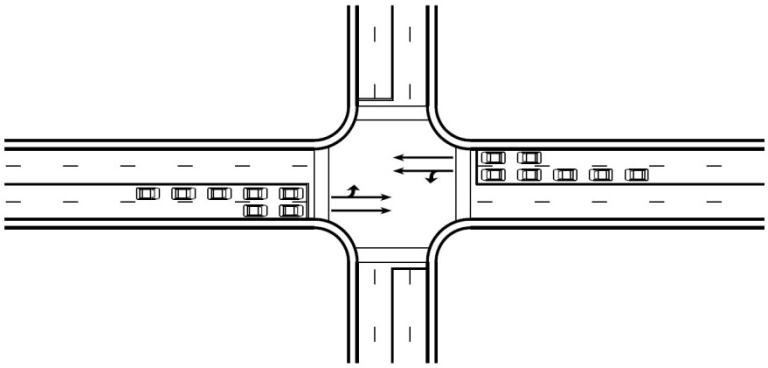


(b) Lower speed design

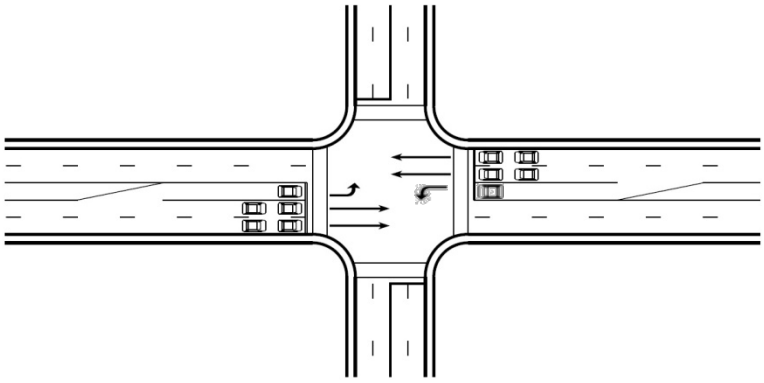
Exhibit 4-7. Various right-turn treatments may be used, depending on the speed environment.

Chapter 11 contains information pertaining to individual movements such as right- and left-turn lanes, including details concerning storage, multiple turn lanes, and warrants.

4. **Separate points of conflict where possible.** Separation of conflict points can ease the driving task while improving both the capacity and safety at an intersection. The use of exclusive turn lanes, channelized right turns, and raised medians as part of an access control strategy are all effective ways to separate vehicle conflicts. Exhibit 4-8 illustrates how the addition of a left-turn lane can reduce conflicts with through vehicles traveling in the same direction.



(a) Major street with shared left-through lane causes through vehicles to queue behind left-turning vehicles.



(b) Major street with dedicated left-turn lane removes left-turning vehicles from the paths of through vehicles.

Exhibit 4-8. Providing a dedicated left-turn lane reduces potential rear end collisions between left-turning and through vehicles, increasing the capacity of the approach for both left and through traffic.

5. **Facilitate the movement of high-priority traffic flows.** Accommodating high-priority movements at intersections addresses both drivers' expectations and intersection capacity. The highest movement volumes at an intersection, define the highest priority movements, although practitioners may also consider route designations and functional classification of intersecting roadways. In low density suburban and rural areas, it may be appropriate to give priority to motor vehicle movements; however, in some urban locations, pedestrians and bicyclists at times may be the highest priority users of the road system. Exhibit 4-9 shows an intersection where double and triple left-turn lanes are used to facilitate high-volume turning movements. Information concerning when these treatments are warranted can be found in Chapter 11.

Exhibit 4-9. The photo shows how double and triple left-turn lanes can be used to accommodate high-priority movements.
Source: Google 2012

6. **Facilitate the desired traffic control scheme.** The signalized intersection design should allow the agency to accommodate changing traffic patterns throughout the life of the intersection. Practitioners should ensure that intersection signs and markings are clearly understood and support correct driver decisions. Other equipment at the intersection should not block sight distance and should facilitate preventive maintenance by field personnel. Practitioners should design for simultaneous left-turning movements and potential u-turning movements. Operational impacts and the design of pedestrian facilities should be taken into account during the intersection's design.

7. **Accommodate decelerating, slow, or stopped vehicles outside higher speed through traffic lanes.** Speed differentials between vehicles in the traffic stream are a primary cause of traffic crashes. Speed differentials at intersections are inherent as vehicles decelerate to facilitate turning. The provision of exclusive left- and right-turn lanes can improve safety by removing slower moving turning vehicles from the higher speed through-traffic stream and reducing potential rear-end conflicts. In addition, through movements may experience lower delay and fewer queues.

Exhibit 4-10. Pedestrian refuge and bicyclist way finding.
Source: Steven Vance, 2010.

8. **Provide safe refuge and way finding for bicyclists and pedestrians.** Intersection design must consider non-motorist roadway users' needs. Intersection channelization can provide refuge and/or reduce the exposure distance for pedestrians and bicyclists within an intersection without limiting vehicle movement. Practitioners should also consider using raised medians, traffic islands, and other pedestrian-friendly treatments during the design process. Way finding may also be an issue, particularly at intersections with complicated configurations. Practitioners can address this through pavement marking and signing, as shown in Exhibit 4-10.

In locations where the horizontal or vertical alignment obscures raised or flush channelization or markings, practitioners may need to extend the limits of channelization or use other methods to call the attention of road users. For example, should the limits of raised channelization begin at the crest of a vertical curve, it should be extended to give motorists ample time to perceive and react to its presence. In an instance where a right-turn lane taper begins within the outside of a horizontal curve, the channelization or marking may be slightly exaggerated to indicate the presence of the tapered area.

4.3 HORIZONTAL AND VERTICAL ALIGNMENT

The approach to a signalized intersection should promote awareness of the intersection by providing the required stopping sight distance in advance of the intersection. This area is critical as the approaching driver or bicyclist begins to focus on the tasks associated with navigating the intersection.

Drivers' or bicylists' expectations on approaches to an intersection could be violated under the following conditions, and mitigation efforts should be considered:

- Approach grades to an intersection of greater than 3 percent.
- Intersections located along a horizontal curve of the intersecting road.
- Intersection tables (including sidewalks) with a cross slope exceeding 2 percent.

The angle of the intersection of two roadways can influence both the safety and operational characteristics of an intersection. Heavily angled intersections not only affect the nature of conflicts, but they produce larger, open pavement areas that can be difficult for drivers to navigate and pedestrians to cross. Such large intersections can also be more costly to build and maintain.

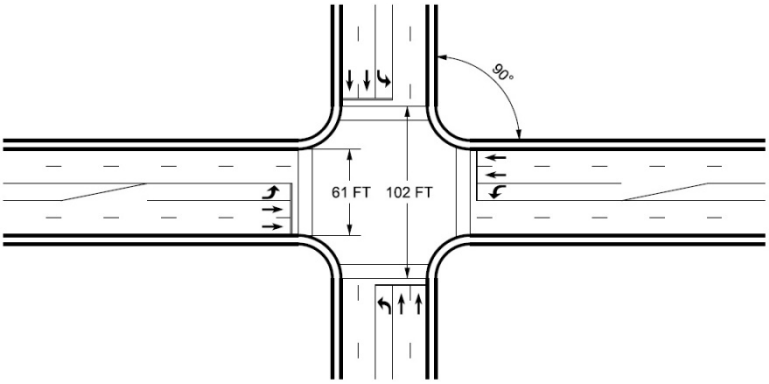
Undesirable operational and safety characteristics of skewed intersections include:

- Difficulty accommodating large vehicle turns. Additional pavement, channelization, and right-of-way may be required. The increased pavement area poses potential drainage problems and gives smaller vehicles more opportunity to "wander" from the proper path. Enhanced pavement marking or color-treated pavement can sometimes address this issue.
- Vehicles crossing the intersection are more exposed to conflicts. This requires longer change and clearance intervals and increased lost time, which reduces the capacity of the intersection.
- Longer pedestrian and bicyclist exposure to vehicular traffic. Longer pedestrian intervals may be required, which may have a negative impact on the intersection's capacity.
- Pedestrians with visual disabilities may have difficulty finding their way to the other side of the street when crossing.
- Driver confusion may be more likely at skewed crossings. Woodson, Tillman, and Tillman found that drivers are more positive in their sense of direction when roadways are at right angles to each other.[46] Conversely, drivers become more confused as they traverse curved or angled streets.

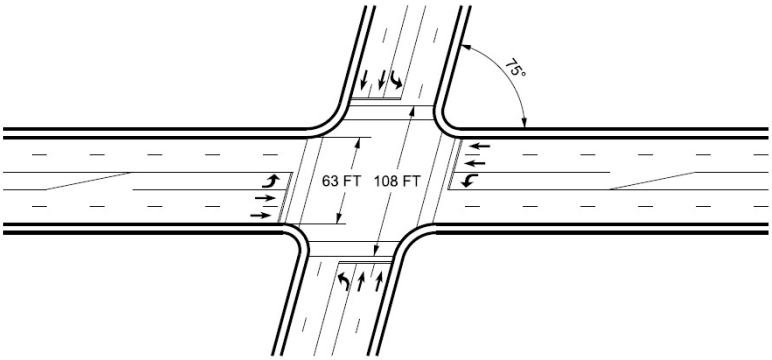
Angled intersections tend to have more frequent right-angle type crashes associated with poor sight distance. AASHTO policy and many State design standards permit angled intersections between 60 to 90 degrees.[3] NCHRP Report 500, Volume 12 (Signalized Intersections) recommends 75 degrees or greater to avoid the issues related older drivers, turning right on red, and judging gaps for left-turn maneuvers.

Gattis and Low conducted research to identify constraints on the angle of a left-skewed intersection as it is affected by a vehicle body limiting a driver's line-of-sight to the right.[47] Their findings suggest that if roadway engineers are to consider the limitations created by vehicle design, a minimum intersection angle of 70 to 75 degrees will offer an improved line-of-sight. FHWA's *Highway Design Handbook for Older Drivers and Pedestrians* recommends intersection angles of 90 degrees for new intersections where right-of-way is not a constraint, and angles of not less than 75 degrees for new facilities or redesigns of existing facilities where right-of-way is restricted.[15]

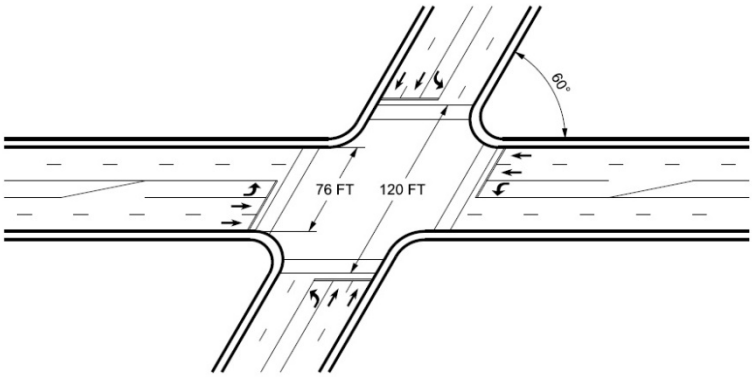
Practitioners should strive to design approaches to intersect at or near right angles. Exhibit 4-11 shows how an angled intersection approach can increase the distance to clear the intersection for pedestrians and vehicles.



(a) Intersection angle at 90 degrees (i.e., no skew)



(b) Intersection angle at 75 degrees (i.e., 15-degree skew)



(c) Intersection angle at 60 degrees (i.e., 30-degree skew).

Exhibit 4-11. Intersection angle increases both the intersection width and pedestrian crossing distance.

It should be noted that the intersection angle and intersection skew, by definition, are complimentary angles. The HSM shows that intersection skew is measured from orthogonal, as shown in Exhibit 4-12.

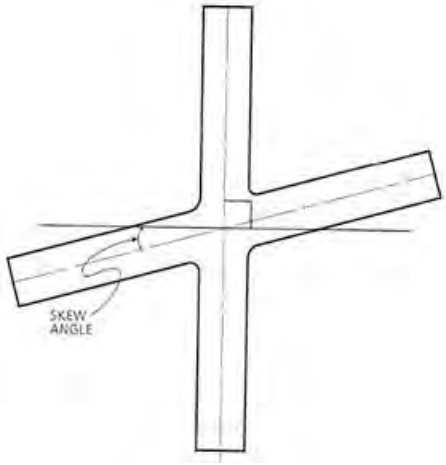


Exhibit 4-12. Intersection skew.

4.4 CORNER RADIUS

Appropriately designed intersection corners accommodate all users. Practitioners should select corner radii and curb ramp design based upon pedestrian crossing and design vehicle needs at the intersection. In general, pedestrian crossings should be as near to perpendicular to the flow of traffic as practical with no intermediate angle points. This keeps pedestrian crossing time and exposure to a minimum, which may allow for more efficient operation of the signal. It also aids visually impaired pedestrians in their way finding task by eliminating changes in direction that may not be detectable.

Practitioners should design corner radii to accommodate the turning path of a design vehicle to avoid encroaching on pedestrian facilities and opposing lanes of travel. Section 4.6.1 addresses curb ramp design in greater detail.

Larger intersection curb radii have disadvantages for pedestrians. Larger radii increase pedestrian crossing distance and the speeds of turning vehicles, creating increased exposure risks. This can be particularly challenging for pedestrians with impaired vision. Large radii also reduce the corner storage space for pedestrians, move pedestrians out of the driver's line of sight, and make it more difficult for pedestrians to see vehicles. On the other hand, smaller radii limit the speeds of turning vehicles and may reduce the operational efficiency of an arterial intersection. A curb that protrudes into the turning radius of the design vehicle can cause vehicles to drive over and damage the curb, as well as increase the potential of hitting a pedestrian standing at the curb.[48]

Factors that influence the selection of appropriate corner radii include the following:

- **Design vehicle**. Selection of a design vehicle should be based on the largest vehicle type that will regularly use an intersection. This can be represented as a standard passenger car, motor home, single-unit truck, bus or semi-trailer. The AASHTO *Green Book* describes representative design vehicles parameters. Practitioners should select an appropriate design vehicle based on the existing and anticipated type of use and the tradeoffs involved with design and spatial impact, and with input from stakeholders and the public. They should select the largest class of vehicle that uses the facility on a regular as the design vehicle. It should represent a cost-effective choice for the project and be appropriate for its context. Use of the facility by the design vehicle should be both a measurable (i.e., over 0.5 percent) and reasonably predictable percentage of the average daily traffic.[49] Often, agency policy will mandate a design vehicle, regardless of vehicle mix. In certain instances, more than one design vehicle may be appropriate, depending on traffic patterns. There may be instances where it is necessary to consider flush radii instead of raised curbs. By incorporating flush radii, vehicles with large turning radii can be accommodated without modifications to curbed sections. However, not all situations are ideal for flush radii; practitioners should consider the volume and type of non-motorized transportation and locations of intersection infrastructure.
- **Angle of intersection**. Large intersection skew angles necessitate non-matching corner radii, as well as very large or very small radii to accommodate the skew.
- **Pedestrians and bicyclists**. In areas of high pedestrian and bike use, smaller radii are desirable to reduce turning speeds and decrease the distance for pedestrians and bikes to cross the street.
- **Constraints**. Multi-centered curves or simple curves with tangent offsets may better match the turn path of the design vehicle and reduce required right-of-way. Additional pavement may be added to either curbed or flush radii to serve as a truck apron.
- **Encroachment**. A designer must consider whether a turning vehicle's wheel path or swept path should encroach into adjacent lanes (same direction), flush islands that separate traffic, or even into opposing lanes. This concept is important in both right- and left-turn maneuvers. The curb return radii imposed on raised median islands may affect the ability to maintain speed and safely make left turns for motorists leaving or arriving at the approach. Traffic signal infrastructure located within the radius of a right turn maneuver may be damaged due to encroaching vehicles.
- **Intersection size**. Corner radius influences the overall width of the intersection. While larger radii allow for use by vehicles with larger turning radii, it may increase the crossing distance for pedestrians and lengthen overall intersection delay.

4.5 SIGHT DISTANCE

Drivers' ability to see the road ahead and other intersection users is critical to safe and efficient use of all roadway facilities, especially signalized intersections. Stopping sight distance, decision sight distance, and intersection sight distance are particularly important at signalized

intersections. It is imperative that drivers be given sufficient distance to perceive, recognize, and react to the presence of traffic control elements such as traffic signal indications, pavement markings, and signing, in addition to the possibility of queued vehicles and the need to maneuver into auxiliary lanes prior to the intersection.

4.5.1 Stopping Sight Distance

Stopping sight distance is the roadway distance required for a driver to perceive and react to an object in the roadway and to brake to a complete stop before reaching that object. Designers should provide sufficient stopping sight distance to road users throughout the intersection and on each entering and exiting approach. Exhibit 4-13 gives recommended stopping sight distances for design, as computed from the equations provided in the AASHTO policy.[3]

Exhibit 4-13. Design values for stopping sight distance.

Speed (km/h)	Computed Distance* (m)	Design Distance (m)	Speed (mph)	Computed Distance* (ft)	Design Distance (ft)
20	18.5	20	15	76.7	80
30	31.2	35	20	111.9	115
40	46.2	50	25	151.9	155
50	63.5	65	30	196.7	200
60	83.0	85	35	246.2	250
70	104.9	105	40	300.6	305
80	129.0	130	45	359.8	360
90	155.5	160	50	423.8	425
100	184.2	185	55	492.4	495
110	215.3	220	60	566.0	570
120	248.6	250	65	644.4	645

* Assumes 2.5 s perception-braking time, 11.2 ft/s^2 (3.4 m/s^2) driver deceleration
Source: American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets.* Washington, DC: AASHTO, 2011.

Practitioners should calculate stopping sight distance using an assumed height of driver's eye of 3.5 ft and an assumed height of object of 2.0 ft.[3]

4.5.2 Decision Sight Distance

Decision sight distance is "the distance needed for a driver to detect an unexpected or otherwise difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently."[3, p. 115] Decision sight distance at intersections applies to situations where vehicles must maneuver into a particular lane in advance of the intersection (e.g., alternative intersection designs using indirect left turns).

Decision sight distance varies depending on whether the driver is to come to a complete stop or make some kind of speed, path, or direction change. Decision sight distance also varies depending on the environment—urban, suburban, or rural. Exhibit 4-14 gives recommended values for decision sight distance, as computed from equations in the AASHTO policy.[3]

Exhibit 4-14. Design values for decision sight distance for selected avoidance maneuvers.

U.S. Customary (ft)					
Speed (mph)	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365

Avoidance Maneuver A: Stop on rural road, time (t) = 3.0 s.
Avoidance Maneuver B: Stop on urban road, t = 9.1 s.
Avoidance Maneuver C: Speed/path/direction change on rural road, t = 10.2 s to 11.2 s.
Avoidance Maneuver D: Speed/path/direction change on suburban road, t = 12.1 s to 12.9 s.
Avoidance Maneuver E: Speed/path/direction change on urban road, t = 14.0 s to 14.5 s.
Source: American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets.* Washington, DC: AASHTO, 2011.

4.5.3 Intersection Sight Distance and Line of Sight

The distance drivers without right-of-way at signalized intersections require to perceive and react to the presence of traffic signal indications, conflicting vehicles, and pedestrians is the intersection sight distance. Horizontal and vertical sight distance must also be maintained such that roadway users have an adequate line-of-sight to traffic control elements as they approach the intersection. Any overhead structure could cause a sight obstruction to nearby traffic signal heads. Practitioners should take care to design the structure and/or modify traffic control devices such that overhead structures do not obstruct approaching road users' view of traffic signals (and other elements like signing). Exhibit 4-15 shows an example where an overhead walkway obstructs the line-of-sight approaching a signalized intersection.

Exhibit 4-15. A pedestrian grade separation treatment restricts sight distance of the traffic signal as motorists approach the intersection.
Source: Synectics Transportation Consultants, Inc.

Practitioners should refer to the AASHTO *Green Book* for a complete discussion of intersection sight distance requirements.[3] Intersection sight distance at signalized intersections is generally simpler than at stop-controlled intersections. The following criteria should be met:

- The first vehicle stopped on an approach should be visible to the first driver stopped on each of the other approaches.
- Vehicles making permissive movements (e.g., permissive left turns, right turns on red, etc.) should have sufficient sight distance to select gaps in oncoming traffic.
- Permissive left turns should satisfy the case for left turns from the major road.
- Right turns on red should satisfy the case for a stop-controlled right turn from the minor road.

However, the sight distance needed for stop-controlled intersections should always be maintained for signalized intersections in the event that traffic signals are installed to flash for emergency situations or during instances of power failure where the traffic signal indications are dark.

Intersection sight distance is traditionally measured through the determination of a sight triangle. This triangle is bound by a length of roadway defining a limit away from the intersection on each of the two conflicting approaches and by a line connecting those two limits. Intersection sight distance should be measured using an assumed height of driver's eye of 3.5 ft and an assumed object height of 3.5 ft.[3] The area within the triangle is referred to as the sight triangle, and any object at a height above the elevation of the adjacent roadways that would obstruct the driver's view should be removed or lowered, if practical. Such objects may include buildings, parked vehicles, highway structures, roadside hardware, hedges, trees, bushes, un-mowed grass, tall crops, walls, fences, and terrain itself. Exhibit 4-16 illustrates intersection sight distance triangles that should be designed and maintained for all signalized intersections.

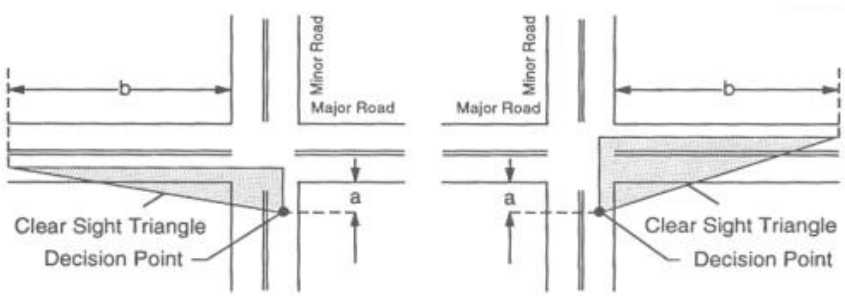


Exhibit 4-16. Intersection sight distance.

Source: Modified from the American Association of State Highway and Transportation Officials (AASHTO) publication *Policy on Geometric Design of Highway and Streets*, 5th Edition, 2004.

4.6 PEDESTRIAN TREATMENTS

It is the policy of the USDOT to "incorporate safe and convenient walking and bicycling facilities into transportation projects," which is accomplished by working with State and local agencies that receive Federal-aid funding to plan, design and implement these features.[197] Furthermore, in 2008, the FHWA Office of Safety included walkways on its list of Proven Safety Countermeasures, recognizing their significant safety benefits.[198] Therefore, practitioners should provide for pedestrian facilities at all intersections in urban and suburban areas, and at any intersection with known or expected pedestrian activity. This is especially important for signalized intersections, since additional equipment is needed to accommodate pedestrians.

In general, practitioners should design the pedestrian facilities of an intersection with the most challenged users in mind, those pedestrians with mobility or visual impairments. The resulting design will serve all pedestrians well. The *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way* provides technical requirements and advisory information pertaining to the design, construction, and alteration of facilities such that they are made accessible to and usable by individuals with disabilities. The guidelines take into consideration three laws that require newly constructed and altered facilities to be accessible to individuals with disabilities: the Americans with Disabilities Act, Section 504 of the Rehabilitation Act, and the Architectural Barriers Act.[54] Therefore, providing pedestrian facilities that are accessible is not merely a matter of best practice, it is also the law.

Pedestrians may face a number of disincentives to walking, including centers and services located far apart, physical barriers and interruptions along pedestrian routes, perceptions that routes are unsafe due to motor vehicle conflicts or crime, and esthetically unpleasing routes.[50]

Certain key elements of pedestrian facilities that practitioners should incorporate into their design are listed and described below:[Adapted from 51]

- **Pedestrian route.** Ensure the routes and crossings are free of barriers, obstacles, and hazards. Ensure curb ramps, transit stops (where applicable), equipment such as pushbuttons, etc., are well located and meet accessibility standards.
- **Exposure to traffic.** Clearly indicate where crossings should occur and the actions pedestrians are expected to take at crossing locations. Limit exposure to conflicting traffic by minimizing the crossing distance as much as practical, ensure the crosswalk is a direct continuation of the pedestrian's travel path and provide refuges where advantageous.
- **Roadside features.** Provide a separation buffer between the nearest vehicular travel lane and the pedestrian route. Keep corners free of obstructions to provide enough room for pedestrians waiting to cross. Design corner radii to ensure that vehicles do not encroach into pedestrian areas.
- **Visibility and conspicuity.** Strive to design facilities so that pedestrians and traffic are mutually visible by maintaining adequate lines of sight between drivers and pedestrians, especially at crosswalks. When intersection lighting is provided, arrange the lighting to achieve positive contrast of pedestrians.
- **Level of service.** Provide appropriate and regular intervals for crossings and minimize wait time for pedestrians.

4.6.1 Curb Ramp Design

Curb ramps provide access for people who use wheelchairs and scooters. Curb ramps also help people with strollers, luggage, bicycles, and other wheeled objects negotiate the intersection. The basic components of a curb ramp, including ramp, landing, detectable warning, flare, and approach, are diagrammed in Exhibit 4-17. The *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way* reflects the technical requirements for curb ramps as stated in the ADA and ABA Accessibility Guidelines (ADAAG). The ADAAG requires that curb ramps be provided wherever an pedestrian route crosses a curb, which includes crosswalks at new and retrofitted signalized intersections.[36] While curb ramps increase access for mobility-impaired pedestrians, they can decrease access for visually impaired pedestrians by removing the vertical curb face that provides an important tactile cue. This tactile cue is instead provided by a detectable warning surface (DWS) placed at the bottom of the ramp, which provides information on the boundary between the sidewalk and roadway. More information about DWS can be found later in this chapter.

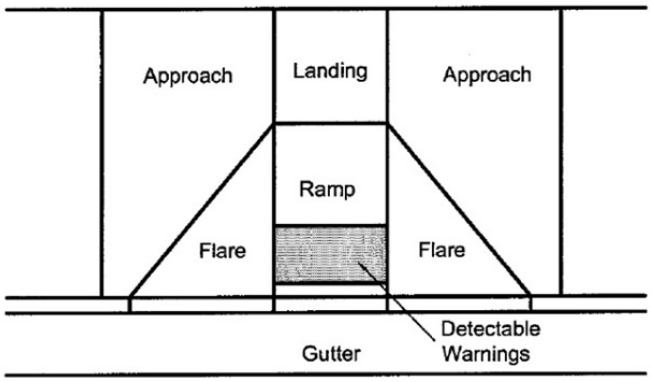
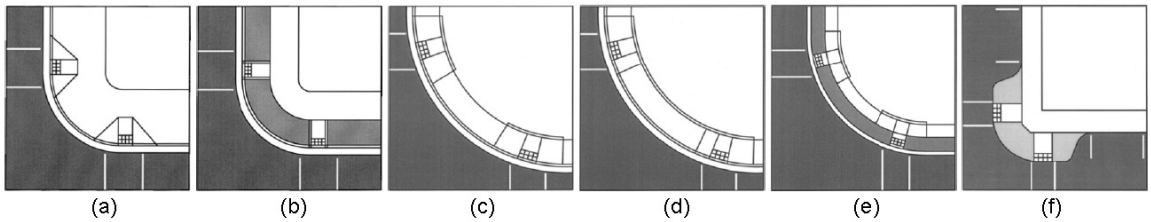


Exhibit 4-17. Curb ramp components

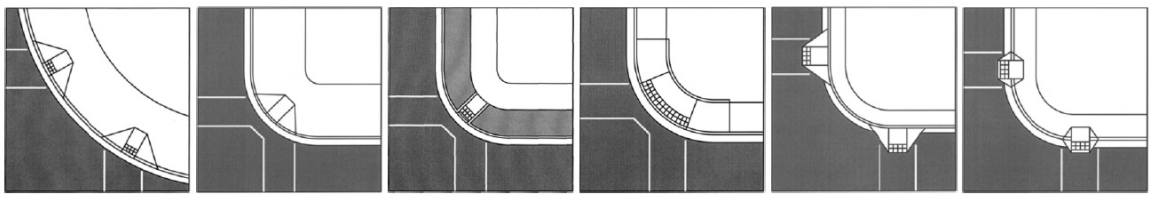
The AADAG provides designers with *Survey Form 4: Curb Ramps* to help in development of accessible curb ramps that meet the requirements of the AADAG, available at http://www.access-board.gov/adaag/checklist/CurbRamps.html. Designers may also use FHWA's *Designing Sidewalks and Trails for Access, Part 2: Best Practices Design Guide,* as a source of recommended fundamental practices for curb ramp design, along with the rationale behind each practice.[37] A designer can apply these principles in designing intersections in a wide variety of circumstances.

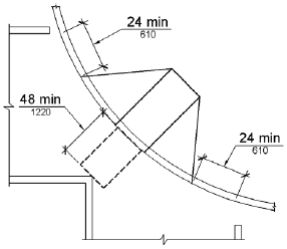
Exhibits 4-18, 4-19, and 4-20 provide examples of three categories of typical curb ramp treatments used at signalized intersections: those that should be implemented wherever possible ("preferred designs"), those that meet minimum accessibility requirements but are not as effective as the preferred treatments ("acceptable designs"), and those that are inaccessible and therefore should not be used in new or retrofit designs ("inaccessible designs"). Additional guidance and design details can be found in the source document.[37]



a. Perpendicular curb ramps with flares and a level landing.
b. Perpendicular curb ramps with returned curbs and a level landing.
c. Two parallel curb ramps on a wide turning radius.
d. Two parallel curb ramps with a lowered curb.
e. Two combination curb ramps on a corner with a wide turning radius.
f. A curb extension with two perpendicular curb ramps with returned curbs and level landings.

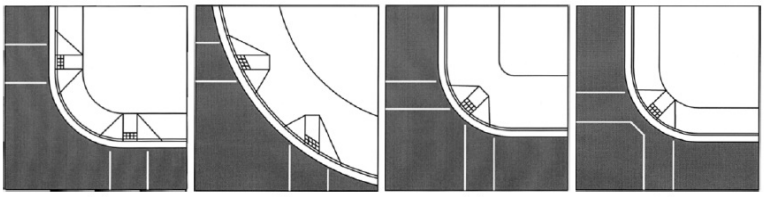
Exhibit 4-18. Examples of preferred designs.





a. Perpendicular curb ramps, oriented perpendicular to the curb, on a corner with a wide turning radius.
b. Diagonal curb ramp with flares and a level landing, in addition to at least 48 inch of clear space.
c. Diagonal curb ramp with returned curbs, a level landing, and sufficient clear space in the crosswalk.
d. Single parallel curb ramp with at least 48 inch clear space.
e. Two built-up curb ramps.
f. Partially built-up curb ramps.

Exhibit 4-19. Examples of acceptable curb ramp designs.



a. Perpendicular curb ramps without a landing.
b. On a corner with a wide turning radius, curb ramps are aligned parallel with the crosswalk.
c. Diagonal curb ramp with no clear space or no level area at the bottom of the curb ramp.
d. Diagonal curb ramps without a level landing.

Exhibit 4-20. Examples of designs prohibited.

Source: Reproduced from Report No. FHWA-EP-01-127, table 7-2

4.6.2 Detectable Warning Surfaces

ADAAG and PROWAG require that a detectable warning surface (DWS) be provided at the bottom of curb ramps and within the refuge of any medians and islands (defined in the ADAAG as "hazardous vehicle areas") to provide tactile cues to individuals with visual impairments so they can determine where the pedestrian route crosses traffic.[33] Detectible warning surfaces consist of a pattern of truncated domes built in or applied to walking surfaces. The domes provide a distinctive surface detectable by cane or underfoot. This surface alerts visually impaired pedestrians of the presence of the vehicular travel way. They also provide physical cues to assist pedestrians in detecting the boundary from sidewalk to street where curb ramps and blended transitions are devoid of other tactile cues typically provided by a curb face.

At the face of a curb ramp and within the refuge area of any median island, a detectable warning surface should be applied, as shown in Exhibit 4-21. The U.S. Access Board and FHWA encourage the use of the design pattern and application found in the 2011 PROWAG.

Exhibit 4-21. This crosswalk design incorporates the use of detectable warning surfaces into the curb ramps to facilitate navigation by a visually impaired pedestrian.
Source: Lee Rodegerdts, 2003

4.7 BICYCLE FACILITIES

Some intersections have on-street bicycle lanes or off-street bicycle paths entering the intersection. When this occurs, intersection design should accommodate the needs of bicyclists in safely navigating such a large and often complicated intersection. Some geometric features that should be considered include:

- Bike lanes and bike lane transitions between through lanes and right-turn lanes. Widths are typically 4 ft when curb and gutter are not present and 5 feet when the lane is adjacent to parking, from the face of the curb or guardrail.[26]
- Left turn bike lanes.
- Median refuges with a width to accommodate a bicycle: 6 ft = poor; 8 ft = satisfactory; 10 ft = good.[26, p. 52]

The interaction between motor vehicles and bicyclists at interchanges with merge and diverge areas is especially complex. Some signalized intersections also have merge and diverge areas due to free right turns or diverted movements. AASHTO recommends that "[i]f a bike lane or route must traverse an interchange area, these intersection or conflict points should be designed to limit the conflict areas or to eliminate unnecessary, uncontrolled ramp connections to urban roadways."[26]

Figure 9C-4. Example of Bicycle Lane Treatment at a Right Turn Only Lane

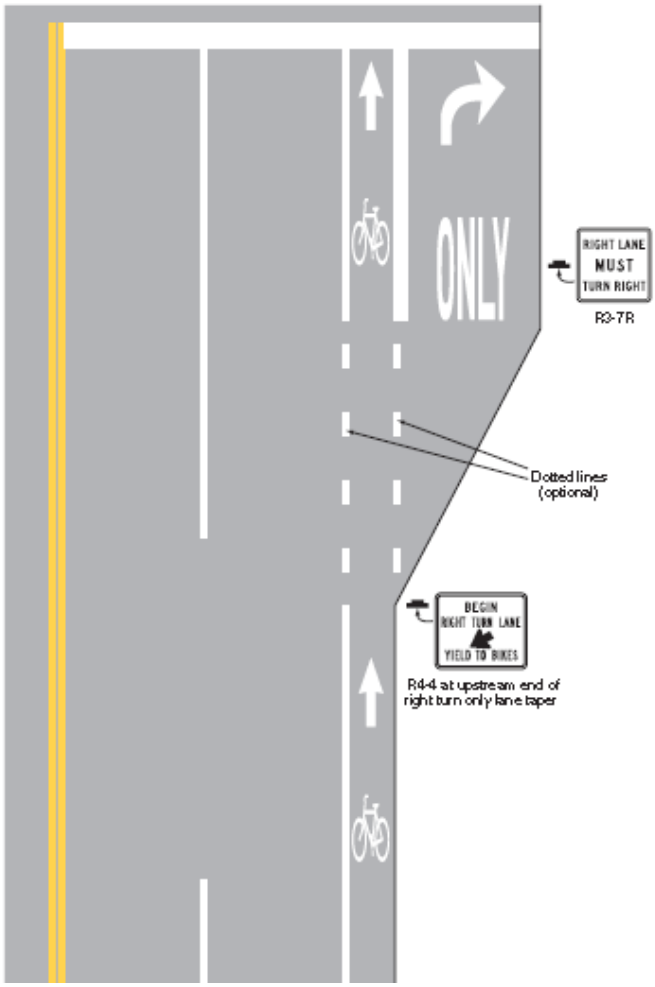


Exhibit 4-22. MUTCD diagram of right-turn lane bicycle accommodation
Source: 2009 MUTCD, Figure 9C-4.

4.8 TRANSIT FACILITIES

Transit facilities near intersections are commonplace in urbanized areas and occur in some rural areas. The placement of the bus stop can impact the safety and operational performance of the intersection. A discussion of transit facilities is included in Section 9.3 of Chapter 9, Intersection-Wide Treatments.

Exhibit 4-23. Transit facility in Santa Barbara, CA
Source: PBIC Image Library, Dan Burden, 2006