INTERSECTION DESIGN GUIDELINES

Introduction

Multimodal intersections operate with pedestrians, bicycles, cars, buses and trucks, and in some cases, trains. The diverse uses of intersections involve a high level of activity and shared space. Intersections have the unique characteristic of accommodating the almost-constant occurrence of conflicts between all modes, and most collisions on thoroughfares take place at intersections. This characteristic is the basis for most intersection design standards, particularly for safety.

Designing multimodal intersections with the appropriate accommodations for all users is performed on a case-by-case basis. The design extends beyond the immediate intersection and encompasses the approaches, medians, StreetSide and driveways, and adjacent land uses**(Figure 10.1).** The designer should begin with an understanding of the community objectives and priorities related to design trade-offs such as vehicular capacity and level of service, large-vehicle turning requirements, conflicts, pedestrian and bicycle convenience, accessibility and the efficiency of public transit service. Intersections are perhaps the most sensitive operational component of thoroughfare systems **(Figure 10.2).**

In urban areas, intersections have a significant place-making function as well as a transportation function. Significant land uses and architecturally significant buildings are located at intersections and might provide pedestrian access directly from the corners. Intersections may also serve as gateways and are frequently the first thing visitors see when they enter a neighborhood **(Figure 10.3).** It is often requested that the practitioner include aesthetic treatments in intersection design.

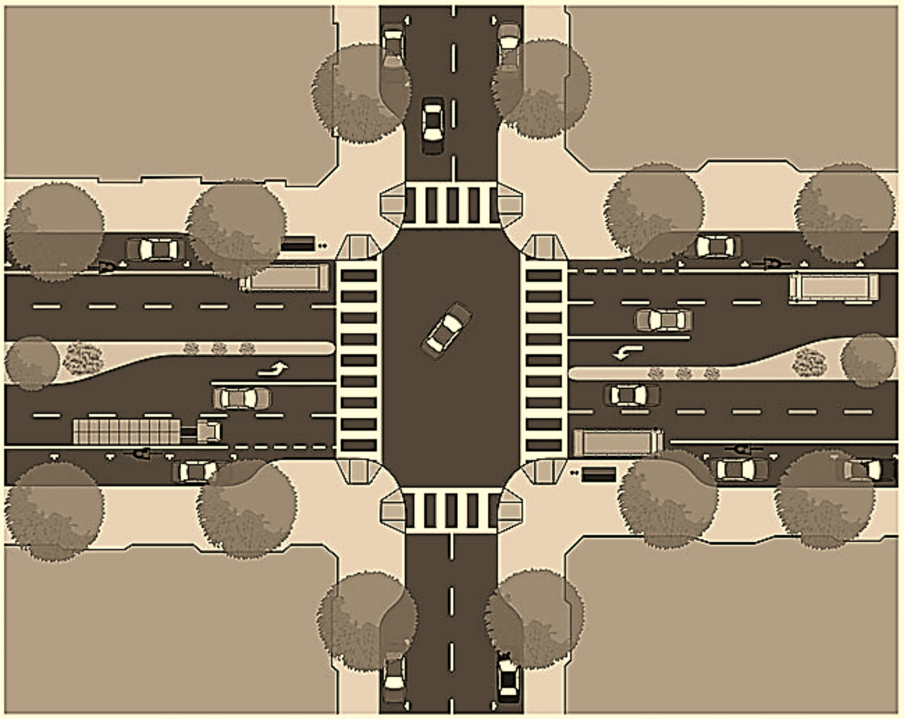


Figure 10.1 The design of intersections encompasses the intersection itself and the approaches to the intersection. It can even affect adjacent land uses. Source: Digital Media Productions.

Figure 10.2 Intersections have the unique characteristic of accommodating the almost-constant occurrence of conflicts between all modes. Source: Texas Transportation Institute.

Objectives

This chapter:

1. Describes several fundamental aspects of intersection design, including managing multimodal conflicts, sight distance and layout; and

2. Provides general principles, considerations and design guidelines for key intersection components including curb return radii, channelized right turns, modern roundabouts, crosswalks, curb extensions, bicycle lanes and bus stops.

General Principles and Considerations

Intersections are required to meet a variety of user expectations, particularly for users of motor vehicles. Drivers expect to safely pass through intersections with minimal delay and few conflicts. Drivers of large vehicles expect to be able to negotiate turns easily. In urban areas, however, expectations based on rural and suburban experiences are unreasonable. Intersection users in urban areas will experience delays and conflicts between vehicles, pedestrians and bicyclists. Driver expectations need to shift toward taking turns with other modes and a sense of uncertainty, which creates a slower, vigilant and safer environment.

Successful multimodal intersection design is based on several fundamental geometric design and operational principles. These principles include:

- Minimize conflicts between modes (such as signal phasing that separates vehicle movements and pedestrian crossings, bicycle lanes extended to the crosswalk, pedestrian refuge islands, low-speed channelized right turns and so forth.) Provide crosswalks on all approaches.

- Accommodate all modes with the appropriate levels of service for pedestrians, bicyclists, transit and motorists given the recommended speed, volume and expected mix of traffic.

Figure 10.3 Intersections are community gateways. Landscaping in the center island of an intersection. Source: Kimley-Horn and Associates, Inc.

Figure 10.4 Intersections must be accessible to pedestrians with disabilities. This curb extension is equipped with curb ramps and high-contrast detectable warnings. Source: Kimley-Horn and Associates, Inc.

- Avoid elimination of any travel modes due to intersection design. Intersection widening for additional turn lanes to relieve traffic congestion should be balanced against impacts to pedestrians, bicyclists and transit.
- Provide good driver and nondriver visibility through proper sight distance triangles and geometric features that increase visibility, such as curb extensions.
- Minimize pedestrian exposure to moving traffic. Keep crossing distances as short as practical and use operational techniques (protected left-turn signal phasing and prohibited right turn on red) to separate pedestrians and traffic as much as possible.
- Design for slow speeds at critical pedestrian-vehicle conflict points, such as corners, by using smaller curb return radii or low-speed channelized right-turn lanes.
- Avoid extreme intersection angles and break up complex intersections with pedestrian refuge islands. Keep intersections easily and fully comprehensible for all users. Strive for simplicity in intersection design—avoid designing intersections with more than four approaches (or consider a modern roundabout) and keep cross streets as perpendicular as possible.
- Ensure intersections are fully accessible to the disabled and hearing and sight impaired. Provide flush access to crossings, visual and audio information about WALK/DON'T WALK phases and detectable warnings underfoot to distinguish pedestrian from vehicular areas **(Figure 10.4).**

Considerations regarding intersection design include the following:

- The preferred location for pedestrian crossings is at intersections. However, if the block length exceeds 400 feet, consider adding a midblock crossing. The target spacing for pedestrian crossings in more intensive urban areas (C-4 to C-6) is every 200 to 300 feet.
- Increases in intersection vehicular capacity by adding lanes increase pedestrian wait times and crossing distances, and discourage pedestrian activity and bicycle use. Therefore, consider interconnecting streets in the network, using parallel routes and other strategies before increasing the number of travel lanes beyond the number of lanes recommended in **Table 6.4** in Chapter 6.
- Where possible, facilitate shared cross-access legal agreements between adjacent properties to close and consolidate nonresidential driveways near an intersection. Integrate access management policies and techniques into long-range transportation plans, area plans and design standards.
- If needed to reduce speeds along a thoroughfare, use speed tables or narrower lanes starting on the approach to intersections, or other speed-management techniques (see Chapter 9 section on Speed Management).

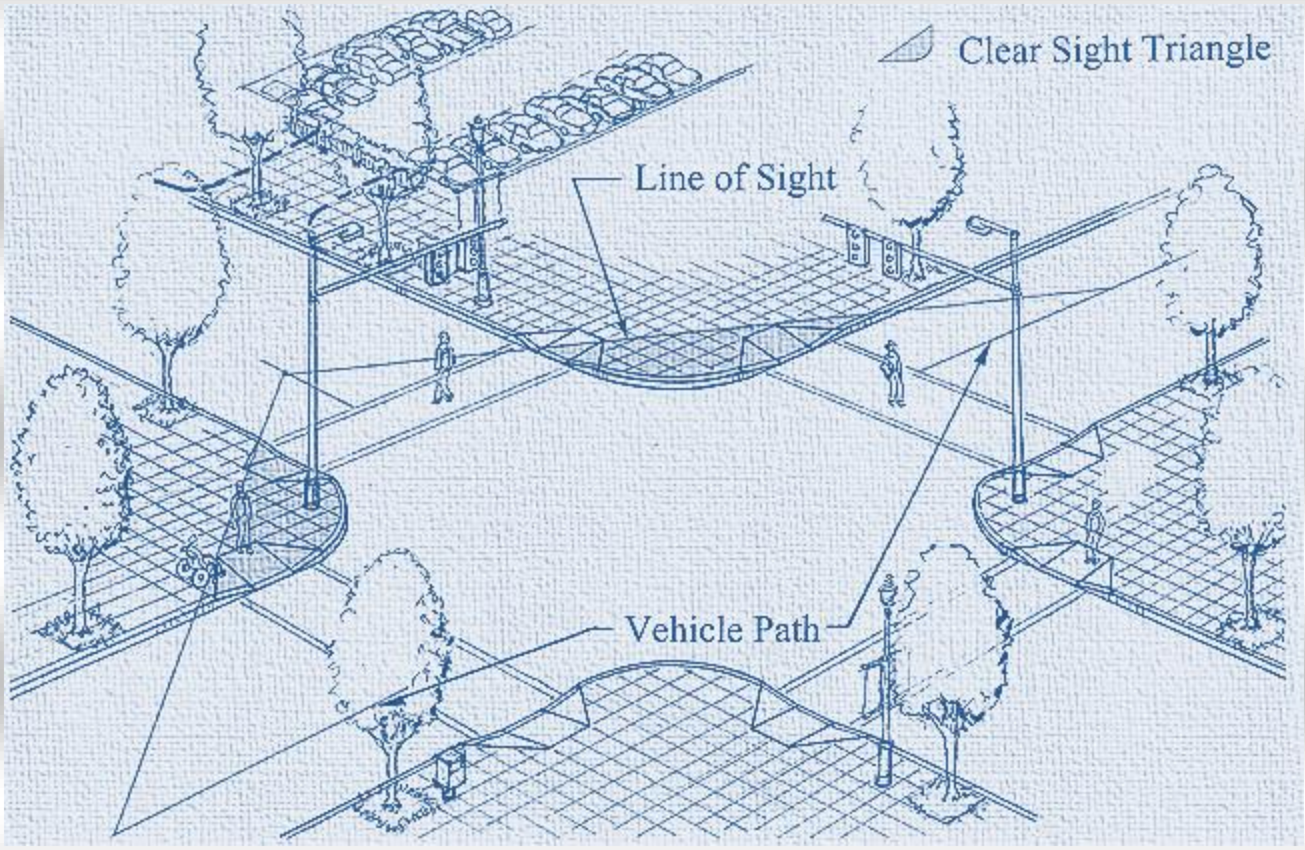


Figure 10.5 Sight distance triangle at intersections. The required sight distance varies with the type of intersection control. Refer to AASHTO Green Book for more details. Source: Kimley-Horn and Associates, Inc.

- Traffic control alternatives should be evaluated for each intersection, including stop control, traffic signals and modern roundabouts.
- Design for U-turn movements to facilitate access to property whenever adding a raised median. Use local, state, or the American Association of State Highway and Transportation Officials (AASHTO) guidelines to determine the U-turn radii needs. While local standards vary, it is desirable to use a passenger car as the design vehicle for U-turns on walkable urban thoroughfares.
- The median or the median nose adjacent to a turn lane should extend to the crosswalk. Medians can end prior to the crosswalk for a continuous pedestrian crossing or can extend through the crosswalk if a channel at street grade or a ramp is provided through the median. Median noses extended through the crosswalk provide a refuge area for pedestrians. Carefully review turning radii of large vehicles that may strike the extended median nose.

Intersection Sight Distance

Specified areas along intersection approaches, called clear sight triangles (shown in **Figure 10.5),** should be free of obstructions that block a driver's view of potentially conflicting vehicles or pedestrians entering the traveled way. The determination of sight triangles at intersections varies by the target speed of the thoroughfares, type of traffic control at the intersection and type of vehicle movement.

In urban areas, intersection corners are frequently entrances to buildings and are desirable locations for urban design features, landscaping and other streetside features. In designing walkable urban thoroughfares, the practitioner works in an interdisciplinary environment and has a responsibility to balance the desire for these streetside features with the provision of adequate sight distance, ensuring safety for all users. In urban areas, examples of objects that limit sight distance include vehicles in adjacent lanes, parked vehicles, bridge piers and abutments, large signs, poorly pruned trees, tall shrubs and hedges, walls, fences and buildings.

Considerations regarding intersection sight distance include the following:

- Based on AASHTO guidelines, urban traffic controls (e.g., traffic signals, stop signs) alleviate the need for large sight triangles where such controls are employed. Where necessary sight triangles cannot be achieved, target speed, intersection traffic control types, sight line obstructions and/or other design elements should be changed.
- If the sight triangle for the appropriate target speed and intersection control is obstructed, every effort should be made to eliminate or move the obstruction or mitigate the obstruction (for example, install curb extensions to improve visibility of crossing pedestrians, prune street trees to branch height greater than 8 feet, or use lower appurtenances).

Managing Modal Conflict at Intersections

Strategies to eliminate or avoid conflict can result in designs that favor one mode over others. For example, eliminating crosswalks at an urban intersection with a high volume of turning vehicles as a strategy to eliminate conflicts will discourage walking. The practitioner must weigh the ever-present trade-offs between vehicle level of service, large-vehicle accommodation and pedestrian and bicycle connectivity and convenience. For the most part, in urban areas, the tradeoffs are clear; every user shares the intersection and equally shares in the benefits and drawbacks of mul-timodal design.

In locations where the community places a high priority on vehicular level of service, intersection designs should incorporate mitigating measures such as pedestrian countdown signals, pedestrian refuge islands and the replacement of free-flow right turns with low-speed channelized right turns (see applicable section in this chapter).

When improving safety at intersections, it is important that the measures that are used to improve vehicle traffic flow or reduce vehicle crashes not compromise pedestrian and bicycle safety. Safety aspects need to be identified in an engineering review. The following strategic decisions need to be considered when improving intersection safety design and operation:

- Minimize vehicle-pedestrian conflicts without reducing accessibility or mobility for any user;
- When it is not possible to minimize all conflicts, reduce the exposure of pedestrians and bicyclists to motor vehicle traffic while maintaining a comfortable walking environment; and
- Design intersections so that when collisions do occur, they are less severe.

Traffic engineering strategies can be highly effective in improving intersection safety. These strategies consist of a wide range of devices and operational modifications. Some examples include the following:

- **Addition of left turn lanes at intersections.** Turn lanes are used to separate turning traffic from through traffic. Studies have shown that providing turn lanes for left-turning vehicles can reduce accidents. In walkable urban areas, turn lanes should be limited to a single left-turn lane. The operational benefits of adding turn lanes should be weighed against the increase in pedestrian crossing time.

- **Signals.** Increase the size of signal lenses from 8 to 12 inches to increase their visibility; provide separate signal faces over each lane; install high-intensity signal indications; and change signal timing, including the length of yellow-change and red-clearance intervals. Consider protected left-turn phasing as a strategy to reduce vehicle-pedestrian conflicts.
- **Innovative intersection design.** In appropriate applications, consider innovative intersection designs such as modern roundabouts. Roundabouts reduce speed, eliminate certain types of crashes and lessen the severity of other types of crashes. Examples of an alternate intersection design include "indirect left-turn" intersections, where left turns are accommodated at midblock U-turns to convert left turns to right turns, or "bowtie" intersections where left turns from the major street are directed to nearby roundabouts on the minor street where they make a U-turn followed by a right turn at the major intersection. Each alternative design has advantages and disadvantages and handles pedestrians and bicyclists differently. The CSS process needs to weigh the trade-offs to select the best alternative.
- **Improve drivers' visibility of pedestrians.** Restrict parking near intersections, properly trim vegetation, move stop lines back from crosswalks by 4 feet, use longitudinal crosswalk striping and use curb extensions.

Design Elements for Intersections in Walkable Areas

Most urban signalized intersections provide basic pedestrian facilities, including crosswalks, pedestrian signal heads, curb ramps and appropriate pedestrian clearance times. Many urban and especially suburban unsignalized intersections are unmarked for pedestrians. Older intersections in walkable urban areas need to be updated to conform to Americans with Disabilities Act (ADA) Public Rights-of-Way Accessibility Guidelines (PROWAG) requirements, better serve bicyclists, improve transit operations, or to simply enhance the pedestrian environment. This section provides a summary of intersection design features the practitioner may want to consider when designing walkable urban intersections.

Uncontrolled Intersections

Common engineering practice is to exclude marked crosswalks from intersections without traffic control approaching the crossing. This is due to a number of factors including avoiding a false sense of security provided by crosswalks when traffic is uncontrolled, encouraging pedestrian caution when legally crossing at intersections without crosswalks, as well as raising liability and maintenance concerns. Indeed, several research studies have shown that pedestrian-vehicle crash rates are higher at unsignalized intersections with marked crosswalks versus those without.

The authors of NCHRP Report 562, *Improving Pedestrian Safety at Unsignalized Intersections,* found that the "safest and most effective pedestrian crossings use several traffic control devices or design elements to meet the information and control needs of both motorists and pedestrians." The NCHRP study and other research has found that marked crosswalks alone are insufficient and, when used, should be used in conjunction with other measures depending on the circumstances. In combination with marked crossings, measures to enhance uncontrolled intersections include:

- High visibility crosswalk markings such as longitudinal bars;
- A median refuge island (minimum of 6 feet) to make the street crossing in stages and more convenient;
- Street and crosswalk illumination;
- Advanced yield lines to improve the visibility of crossing pedestrians and reduce "multiple threat" type crashes;
- Installation of curb extensions to shorten crossing distance and improve driver and pedestrian visibility;
- Installation of pedestrian-activated flashing beacons to warn motorists of crossing pedestrians;
- Motorist signs to indicate that pedestrians have the legal right of way, "YIELD TO PEDESTRIANS," "STOP HERE FOR PEDESTRIANS," or internally illuminated pedestrian crossing signs; and
- Pedestrian signs or median designs ("Z" crossings) that encourage or facilitate looking for potential conflicts.

Signalized Intersections

Signalized intersections, while providing some level of pedestrian protection by controlling traffic, have many available design features that increase pedestrian visibility, information and convenience. These features are listed in **Table 10.1.**

Design Guidance Intersection Geometry

This section provides general principles, considerations and guidelines on the geometric layout of urban at-grade multimodal intersections and the key components that comprise geometric and operational design. These guidelines include a section on the application and design of modern roundabouts as an alternative to the conventional intersection.

Table 10.1 Pedestrian and Bicycle Features at Signalized Intersections

Shorter and more visible crosswalks	Crosswalks on all approaches; Longitudinal markings (possible use of colored and/or textured paving); Reduced overall street widths by reducing the number of travel and turn lanes, or narrowing travel lanes; Curb extensions with pedestrian push buttons on extensions; and Median refuges on wide streets (greater than 60 feet) with median push buttons.
Priority for pedestrians, bicyclists, and accessibility	Shorter cycle lengths, meeting minimum pedestrian clearances (also improves transit travel times); Longer pedestrian clearance times (based on 3.5 feet/sec. to set flashing (clearance) time and 3.0 feet/sec for total crossing time); Reduced conflicts between pedestrians and turning vehicles achieved with: Pedestrian lead phases;

	Scramble phases in very high pedestrian volume locations; Restricted right turns on red when pedestrians are present during specified hours; and Allowing right turns during cross-street left turn phases reduces the number of right turn conflicts during pedestrian crossing phase.
Low speed channelized right turn lanes	Adequate sized islands for pedestrian refuge; Raised pedestrian crossing/speed table within channelized right turn lane; and Signal control of channelized right turn in high pedestrian volume locations.
Improved pedestrian information	Pedestrian countdown timers; and "Look Before Crossing" markings or signs.
Bicycle features	Bicycle lanes striped up to crosswalk (using "skip lines" if vehicular right turns are allowed); Bicycle detectors on high volume routes, or bicyclist-accessible push buttons; Adequate clearance interval for bicyclists; Colored paving in bicycle/vehicle lanes in high-conflict areas; and "Bike Boxes" (painted rectangle along right hand curb or behind crosswalk) to indicate potential high-conflict area between bicycles continuing through an intersection and right turning vehicles, and to allow bicyclists to proceed through intersection or turn in advance of vehicles.
High-priority transit thoroughfare elements	Adaptive Transit Signal Priority (TSP) when transit detected: Extended green phase on bus route (rapid transit signal priority); Truncated green phase for cross street; Re-order phasing to provide transit priority (transit priority not to be given in two successive cycles to avoid severe traffic impacts); Other bus priority signal phasing (sequencing) Queue jump lanes and associated signal phasing; and Curb extension bus stops, bus bulbs.
Accessibility and space for pedestrians	Properly placed pedestrian actuation buttons, with audible locator tones; Detectable warnings; Two curb ramps per corner depending on radius of curb return and presence of curb extensions; Clear pedestrian paths (and shoulder clearances) ensuring utilities and appurtenances are located outside pedestrian paths; Vertical and overhang clearance of street furnishings for the visually impaired; Properly placed signal poles and cabinets: Behind sidewalks (in landscaping or in building niches);

	In planting strips (furnishings zone); and In sidewalk or curb extensions, at least three feet from curb ramps.
Traffic operations for safe speeds and pedestrian convenience	Target speeds between 25-35 mph; Signal progression at target speeds; and Fewer very long/very short cycle lengths.
Higher priority on aesthetics	Textured and colored material within the streetside; Colored material within crosswalks, but avoid coarse textures which provide rough surfaces for the disabled; Attractive decorative signal hardware, or specialized hardware; and Attention to landscaping and integration with green street stormwater management techniques.

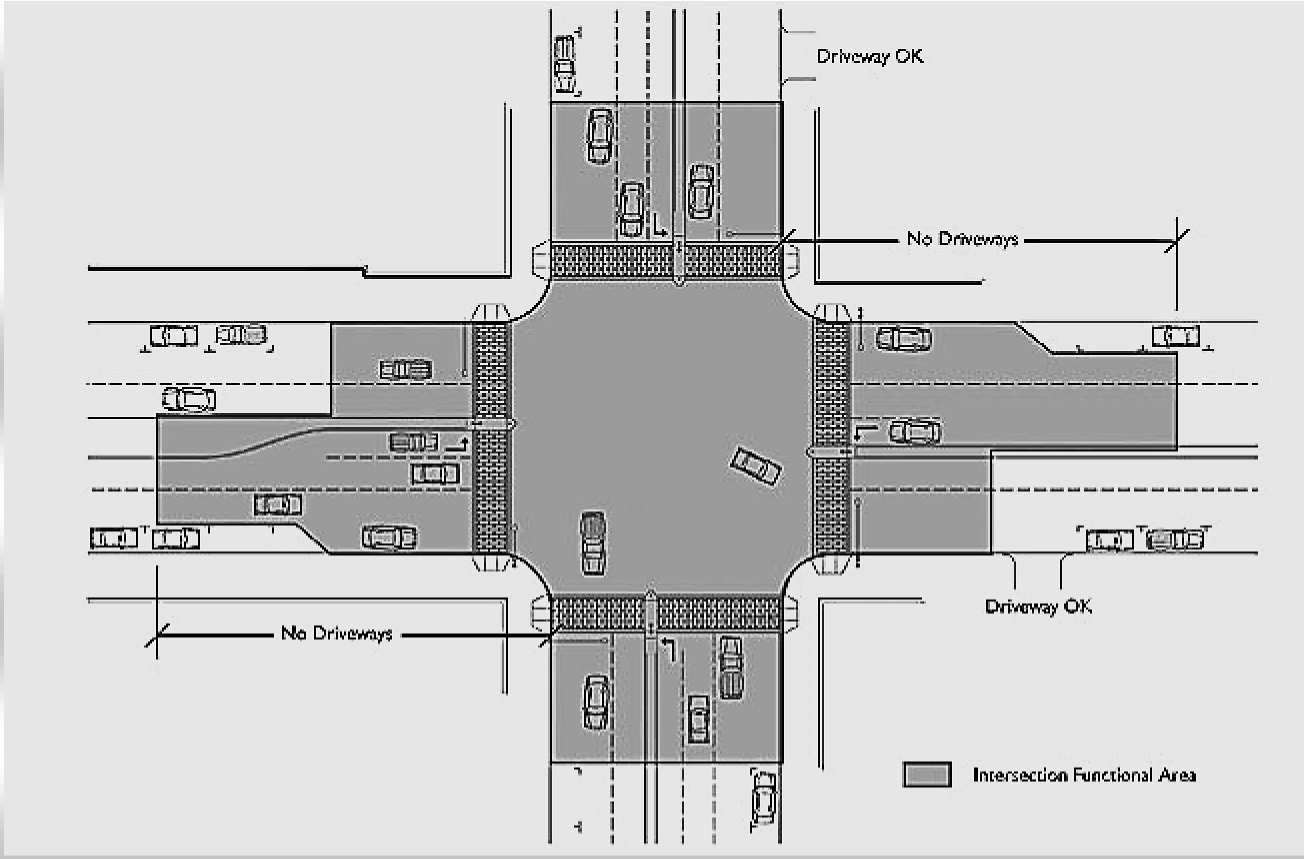


Figure 10.6 many decisions are made within the functional area of an intersection. Source: Community, Design + Architecture.

General Intersection Layout

Intersection layout is primarily composed of the alignment of the legs; width of traffic lanes, bicycle lanes, crosswalks, and sidewalks on each approach number of lanes, median and StreetSide elements; and the method of treating and channelization of turning movements. Like the design of the thoroughfare's cross-section, the design of an intersection's layout requires a balance between the needs of pedestrians, bicyclists, vehicles, freight and transit in the available right of way. Beyond intersection layout, the practitioner needs to work with a multidisciplinary team to address accessibility, traffic control and placement of equipment, traffic operations, lighting (safety and pedestrian scaled), landscaping and urban design.

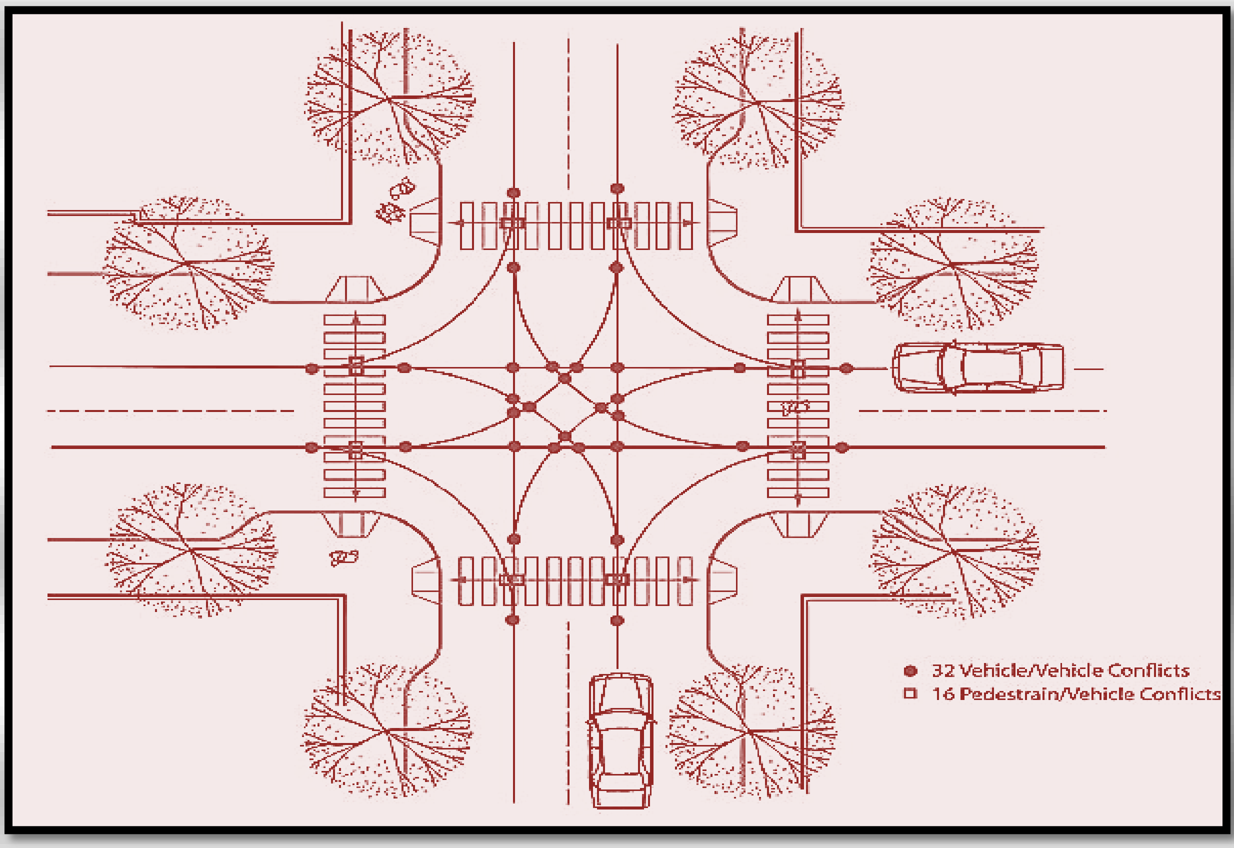
Intersection Fundamentals

Intersections are composed of a physical area—the area encompassing the central area of two intersecting streets as shown in **Figure 10.6.** The functional area is where drivers make decisions and maneuver into turning movements. The three parts of the functional area include (1) the perception-reaction distance, (2) maneuver distance and (3) storage distance. AASHTO's *A Policy on Geometric Design of Highways and Streets* (2004a) addresses the issues and provides guidance for the detailed geometric design of the functional area.

The basic types of intersections in urban contexts include the T-intersection (a three-leg intersection), cross-intersection (four-leg intersection), multileg intersection (containing five or more legs) and the modern roundabout, which is discussed later in this chapter.

Intersection Conflicts

Intersections, by their very nature, create conflicts between vehicles, pedestrians and bicyclists. **Figure 10.7** illustrates the number of conflicts between different modes at three- and four-leg intersections. According to AASHTO's *Guide for the Planning, Design and Operation of Pedestrian Facilities* (2004b), the following are principles of good intersection design for pedestrians:



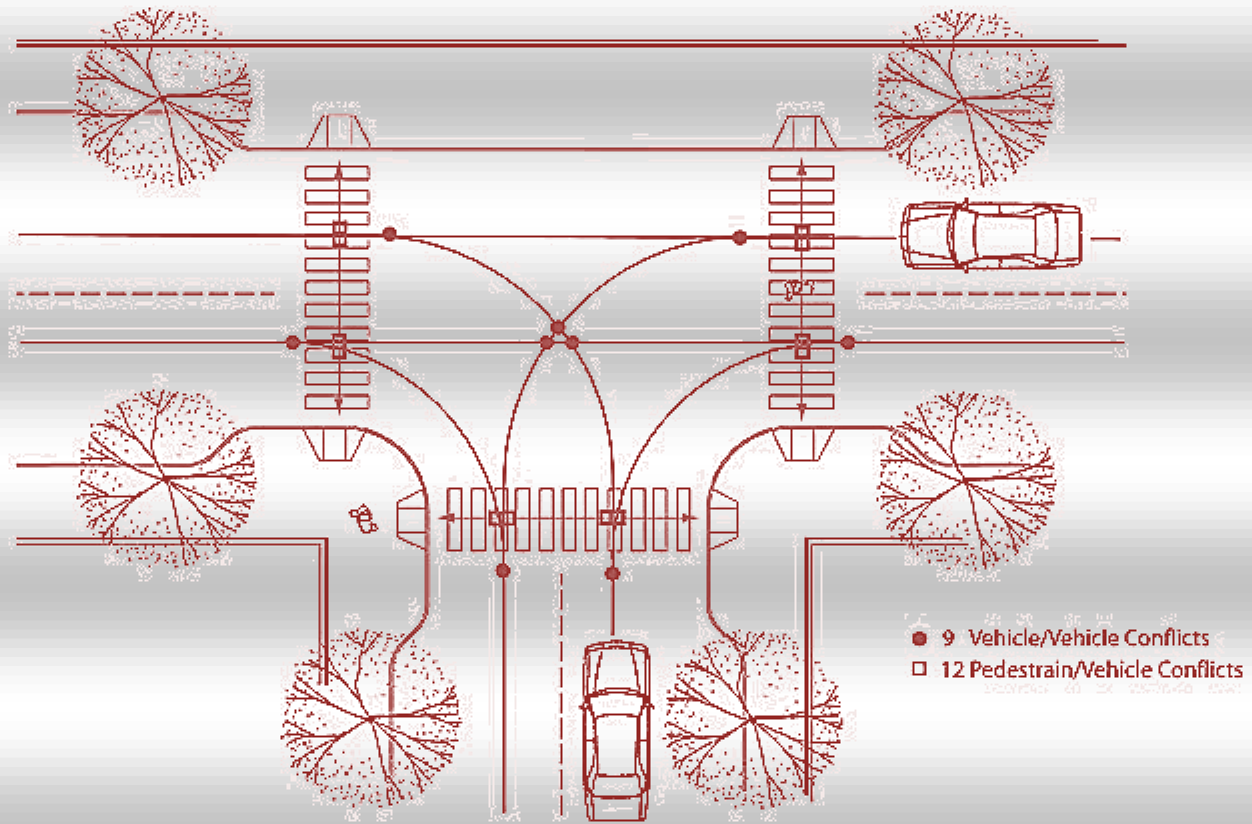


Figure 10.7 Vehicle and pedestrian conflicts at three- and four-leg intersections. Source: Community, Design + Architecture, adapted from an illustration by Michael Wallwork.

- **Clarity—**making it clear to drivers that pedestrians use the intersections and indicating to pedestrians where the best place is to cross;
- **Predictability—**drivers know where to expect pedestrians;
- **Visibility—**good sight distance and lighting so that pedestrians can clearly view oncoming traffic and be seen by approaching motorists;
- **Short wait—**providing reasonable wait times to cross the street at both unsignalized (via gaps created in traffic or two-stage crossings) and signalized intersections (via signal cycle length);
- **Adequate crossing time at signalized intersections**—the appropriate signal timing for all types of users to cross the street;
- **Limited exposure—**reducing conflict points where possible, reducing crossing distance and providing refuge islands when necessary; and
- **Usable crossing—**eliminating barriers and ensuring accessibility for all users.

General Principles and Considerations

General principles and considerations for the design of intersection layouts include the following:

- Intersections should be designed as compact as practical in urban contexts. Intersections should minimize crossing distance, crossing time and exposure to traffic and should encourage pedestrian travel.
- A design speed appropriate for the context. Motorists traveling at slower speeds have more time to perceive and react to conflicts at intersections.
- Intersection approaches should permit motorists, pedestrians and bicyclists to observe and react to each other. Intersection approaches should, therefore, be as straight and flat as possible, and adequate sight distances should be maintained.
- Avoid providing very short radius horizontal curves approaching the major street to mitigate acute approach alignments, as motorists might encroach into opposing travel lanes at such curves.
- Avoid placing intersections on sharp horizontal or vertical curves where sight distances may be reduced. Intersections should not be placed on either end of a curve unless sufficient sight distance is available.
- Functional areas of adjacent intersections should not overlap.
- Channelizing islands to separate conflicts are important design elements within intersection functional areas. These include properly designed channelized right turns (see section on right-turn channelization in this chapter).
- Intersections that accommodate fixed-guideway transit have special challenges (see section on Transit Design in Chapter 9).

Curb Return Radii Background and Purpose

Related Thoroughfare Design Elements

- Transit design
- On-street parking and configuration
- Right-turn channelization
- Pedestrian refuge islands
- Bicycle lanes

Curb returns are the curved connection of curbs in the corners formed by the intersection of two streets. A curb return's purpose is to guide vehicles in turning corners and separate vehicular traffic from pedestrian areas at intersection corners. The radius of the curve varies, with larger radii used to facilitate the turning of large trucks and buses. Larger radius corners increase the length of pedestrian crosswalks, and increase vehicular turning speeds.

In designing walkable urban thoroughfares, the smallest practical curb-return radii are used to shorten the length of the pedestrian crosswalks. Based on this function, this report suggests a general strategy for selecting curb-return radii design criteria and discusses situations requiring larger design vehicles. The primary benefits of smaller curb-return radii to pedestrians in urban areas include:

- Increasing motorist visibility of pedestrians waiting to cross the street;
- Reducing pedestrian crossing distance (which also benefits vehicles with a shorter cycle length at signalized intersections) and exposure to traffic;
- Providing the shortest accessible route for disabled persons as required under ADA; and
- Reducing speed of turning vehicles and severity of crashes if they occur.

General Principles and Considerations

General principles and considerations regarding curb return radii include the following:

- In walkable areas, the first consideration is keeping crossing distance as short as possible. Consider alternatives to lengthening the curb radius first, then consider lengthening the radius if no other alternative exists.
- Curb-return radii should be designed to accommodate the largest vehicle type that will frequently turn the corner (sometimes referred to as the design vehicle). This principle assumes that the occasional large vehicle can encroach into the opposing travel lane as shown in **Figure 10.8.** If encroachment is not acceptable, alternative routes for large vehicles should be identified.
- Curb-return radii should be designed to reflect the "effective" turning radius of the corner. The effective turning radius takes into account the wheel tracking of the design vehicle utilizing the width of parking and bicycle lanes. Use of the effective turning radii allows a smaller curb-return radius while retaining the ability to accommodate larger design vehicles **(Figure 10.9).**

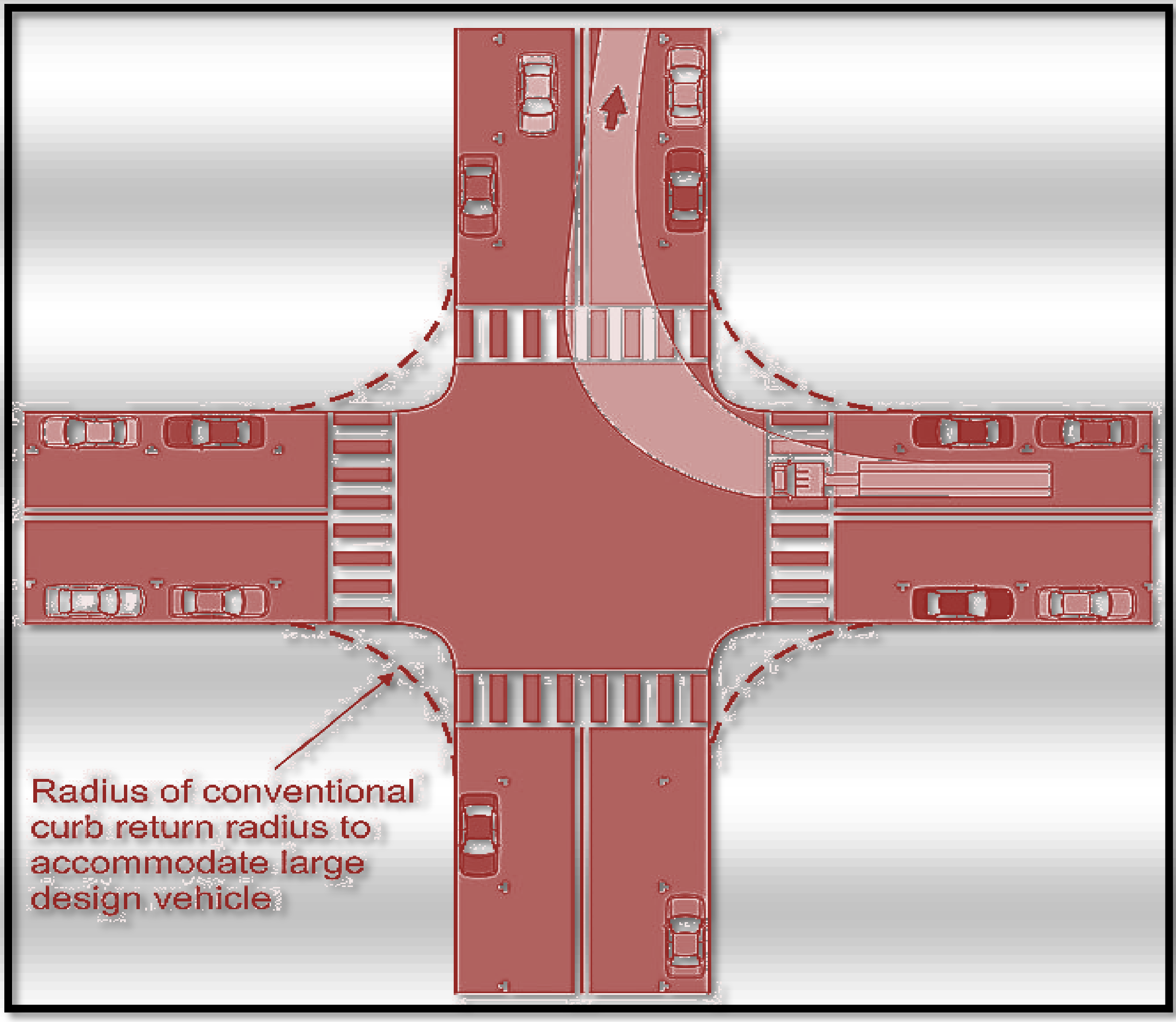


Figure 10.8 Smaller curb-return radii shorten the distance that pedestrians must cross at intersections. The occasional turn made by large trucks can be accommodated with slower speeds and some encroachment into the opposing traffic lanes. Source: Kimley-Horn and Associates, Inc.

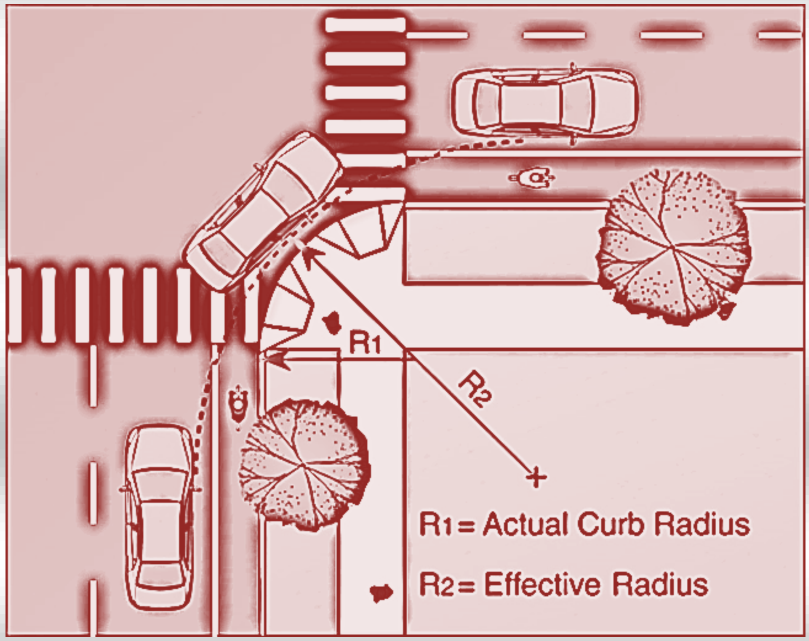


***Figure 10.9** The existence of parking and bicycle lanes creates an "effective" turning radius that is greater than the curb-return radius. Source: Kimley-Horn and Associates, Inc., adapted from the Oregon Bicycle and Pedestrian Plan.*

- In urban centers (C-5) and urban cores (C-6) where pedestrian activity is intensive, curb-return radii should be as small as possible.
- On multilane thoroughfares, large vehicles may encroach entirely into the adjacent travel lanes (in the same direction of travel).
- To help select a design vehicle, identify bus routes to determine whether buses are required to turn at the intersection. Also check transit service plans for anticipated future transit routes. Map existing and potential future land uses along both streets to evaluate potential truck trips turning at the intersection.
- Curb-return radii of different lengths can be used on different corners of the same intersection to match the design vehicle turning at that corner. Compound, spiral, or asymmetrical curb returns can be used to better match the wheel tracking of the design vehicle (see the AASHTO Green Book for the design of spiral and compound curves).
- If large vehicles need to encroach into an opposing travel lane, consider placing the stop line for opposing traffic further from the intersection.
- The designer must consider lane widths, curb radii, locations of parking spaces, grades and other factors in designing intersections. Designers are discouraged from using combinations of minimum dimensions unless the resulting design can be demonstrated to be operationally practical and safe.

Recommended Practice

Flexibility in the design of curb return radii revolves around the need to minimize pedestrian crossing distance, the choice of design vehicle, the combination of dimensions that make up the effective width of the approach and receiving lanes and the curb return radius itself. The practitioner needs to consider the trade-offs between the traffic safety and operational effects of infrequent large vehicles and the creation of a street crossing that is reasonable for pedestrians. The guidelines assume arterial and collector streets in urban contexts (C-3 to C-6) with turning speeds of city buses and large trucks of 5 to 10 mph. The guidance is not applicable to intersections without curbs.

Recommended practices include the following:

• In urban centers (C-5) and urban cores (C-6) at intersections with no vehicle turns, the minimum curb return radii should be 5 feet.

• A curb return radius of 5 to 15 feet should be used where:

1. High pedestrian volumes are present or reasonably anticipated;
2. Volumes of turning vehicles are low;
3. The width of the receiving intersection approach can accommodate a turning passenger vehicle without encroachment into the opposing lane;
4. Large vehicles constitute a very low proportion of the turning vehicles;
5. Bicycle and parking lanes create additional space to accommodate the "effective" turning radius of vehicles;
6. Low turning speeds are required or desired; and
7. Occasional encroachment of turning school bus, moving van, fire truck, or oversized delivery truck into an opposing lane is acceptable.

• Curb radii may need to be larger where:

1. Occasional encroachment of a turning bus, school bus, moving van, fire truck, or oversized delivery truck into the opposing lane is not acceptable;
2. Curb extensions are proposed or might be added in the future; and
3. Receiving thoroughfare does not have parking or bicycle lanes and the receiving lane is less than 12 feet in width.

An alternative to increasing curb-return radii is setting back the stop line of the receiving street to allow large vehicles to swing into opposing lane as they turn. However, setbacks to accommodate right-turn encroachment need to be examined on a case-by-case basis since very tight right turns may require long setbacks.

Recommendations for Curb Radii on Transit and Freight Routes

Truck routes should be designated outside of or on a minimum number of streets in walkable areas to reduce the impact of large turning radii. Where designated local or regional truck routes conflict with high pedestrian volumes or activities, analyze freight movement needs and consider redesigna-tion of local and regional truck routes to minimize such conflicts.

On bus and truck routes, the following guidelines should be considered:

- Curb-return radii design should be based on the effective turning radius of the prevailing design vehicle.
- Where the potential for conflicts with pedestrians is high and large vehicle turning movements necessitate curb radii exceeding 50 feet, evaluate installation of a channelized right-turn lane with a pedestrian refuge island (see the section on pedestrian refuge islands in Chapter 9 and the section on channelized right-turn lanes in Chapter 10). To better accommodate the path of large vehicles use a three-centered compound curve in the design of the island (see the AASHTO Green Book's Chapter 9 for design guidance).
- Where frequent turning of large vehicles takes place, avoid inadequate curb-return radii as they could potentially cause large vehicles to regularly travel across the curb and into the pedestrian waiting area of the streetside.

Justification

Intersections designed for the largest turning vehicle traveling at significant speeds with no encroachment result in long pedestrian crossings and potentially high-conflict areas for pedestrians and bicyclists. Radii designed to accommodate the occasional large vehicle will allow passenger cars to turn at high speeds. In designing walkable urban thoroughfares, the selection of curb returns ranging from 5 to 25 feet in radius is preferable to shorten pedestrian crossings and slow vehicle-turning speeds to increase safety for all users.

Channelized Right-Turns

Background and Purpose

Related Thoroughfare Design Elements

- Curb return radii
- Crosswalks
- Bicycle lanes at intersections
- Transit design

In urban contexts, high-speed channelized right turns are generally inappropriate because they create conflicts with pedestrians and bicyclists and also increase turning speeds. Under some of the circumstances described below, providing channelized right-turn lanes on one or more approaches at a signalized intersection can be beneficial, but unless designed correctly, these right-turn lanes can be undesirable for pedestrians. According to the *Oregon Bicycle and Pedestrian Plan* a well-designed channelization island can:

- Allow pedestrians to cross fewer lanes at a time and judge conflicts separately;
- Provide refuge for slower pedestrians;
- Improve accessibility to pedestrian push-buttons; and
- Reduce total crossing distance, which provides signal-timing benefits.

Right-turning drivers may not have to stop for the traffic signal when a channelized right-turn lane is provided. Even where pedestrian signal heads are provided at the intersection, pedestrians are usually expected to cross channelized right-turn lanes without the assistance of a traffic signal. Most channelized right-turn lanes consist of only one lane, and the crossing distance tends to be relatively short. However, drivers are usually looking to their left to merge into cross-street traffic and are not always attentive to the presence of pedestrians.

Figure 10.10 A channelized right-turn lane typically provides a pedestrian refuge island and an uncontrolled crosswalk. Source: Dan Burden, walklive.org.

General Principles and Considerations

The general principles and considerations regarding channelized right turns include the following:

- Avoid using channelized right-turn lanes where pedestrian activity is or is expected to be significant. If a channelized right-turn lane is unavoidable, use design techniques described in this report to lessen the impact on pedestrians.
- Exclusive right-turn lanes should be limited. A right-turning volume threshold of 200-300 vehicles per hour is an acceptable range for the provision of right-turn lanes. Once determined that a right-turn lane is necessary, a well-designed channelization island can help slow down traffic and separate conflicts between right-turning vehicles and pedestrians **(Figure 10.10).**
- If channelized right-turn lane is justified, design it for low speeds (5 to 10 mph) and high-pedestrian visibility.
- For signalized intersections with significant pedestrian activity, it is highly desirable to have pedestrians cross fully under signal control. This minimizes vehicle-pedestrian conflicts and adds to the comfort of pedestrians walking in the area.

Recommended Practice

Recommended practices regarding channelized right-turn lanes include the following:

- The provision of a channelized right-turn lane is appropriate only on signalized approaches where right-turning volumes are high or large vehicles frequently turn and conflicting pedestrian volumes are low and are not expected to increase greatly.
- Where channelized right-turn lanes already exist at a high-pedestrian-activity signalized intersection, pedestrians can best be served by installing pedestrian signals to the right-turn lane crossing. This enables the pedestrian to cross the legs of the intersection fully under signalized control.
- Removing channelized right-turn lanes also makes it possible to use signing, such as NO TURN ON RED, turn-prohibition signs, or exclusive pedestrian signal phases to further assist pedestrians in safely crossing the street.
- When channelized right-turn lanes are justified for traffic capacity or large vehicle purposes, the following practices should be used:

- Provide a low-angle right turn (about 112 degrees). This angle slows down the speed of right-turning vehicles and improves driver visibility of pedestrians within and approaching the crosswalk **(Figure 10.11**).
- Use longitudinal crosswalk striping for visibility and place crosswalks so that a motorist has a clear view of pedestrians.
- A well-illuminated crossing point should be placed where drivers and pedestrians have good sight distance and can see each other in advance of the crossing point. Unless no other choices are available, the crossing point should not be placed at the point where right-turning drivers must yield to other vehicles and therefore might not be watching for pedestrians.
- Provide accessible islands. The island that forms the channelized right-turn lane must be a raised island of sufficient size (at least 120 square feet) for pedestrians to safely wait in a position where they are at least 4 feet from the face of curb in all directions. A painted island is not satisfactory for pedestrians. The island also has to be large enough to accommodate accessible features, such as curb ramps (usually in three separate directions) or channels cut through the raised island that are flush with the surrounding pavement. If the crossing of the right-turn lane is signalized, the island needs to be large enough to contain pedestrian push buttons.

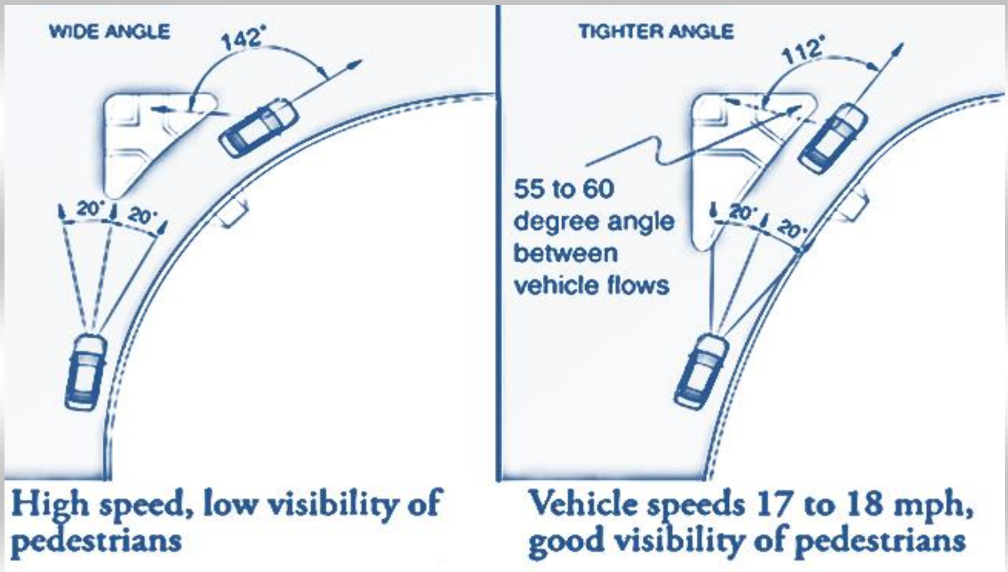


Figure 10.11 The preferred design of a channelized right-turn lane uses an approach angle that results in a lower speed and improved visibility. Source: Kimley-Horn and Associates, Inc., adapted from an illustration by Dan Burden.

(Extended text description: The diagram depicts two designs of a channelized right-turn lane. The first shows a wide angle design with a high-speed, low visibility of pedestrians with a 20 degree to 142 degreen angle. The second design shows a tighter angle showing a 20 degree to 112 degree angle, with a 55 to 60 degree angle between vehicle flows.)

- Unless the turning radii of large vehicles, such as tractor-trailers or buses must be accommodated, the pavement in the channelized right-turn lane should be no wider than 16 feet. For any width right-turn lane, mark edge lines and cross-hatching to restrict the painted width of the travel way of the channelized right-turn lane to 12 feet to slow smaller vehicles.

- If vehicle-pedestrian conflicts are a significant problem in the channelized right-turn lane, it might be appropriate to provide signing to remind drivers of their legal obligation to yield to pedestrians crossing the lane in the marked crosswalk. Regulatory signs such as the TURNING TRAFFIC MUST YIELD TO PEDESTRIANS (R10-15) or warning signs such as the PEDESTRIAN CROSSING (W11-2) could be placed in advance of or at the crossing location.
- Signalize the channelized right-turn movement to eliminate significant vehicle-pedestrian conflicts. Signalization may be provided when there is/are (1) multiple right-turning lanes; (2) something inherently unsafe about the unsignalized crossing, such as poor sight distance or an extremely high volume of high-speed right-turning traffic; or (3) high pedestrian-vehicle crash experiences.

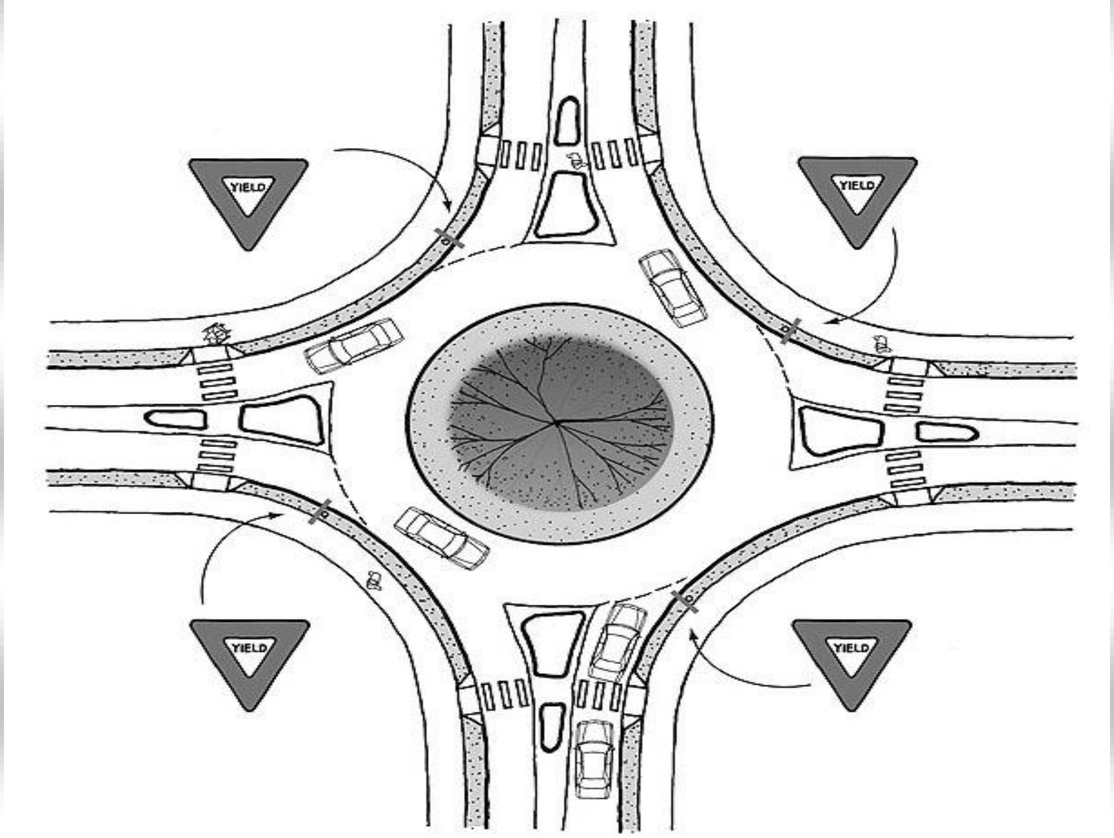


Figure 10.12 A typical single-lane modern roundabout design provides yield control on all approaches and deflects approaching traffic to slow speeds. Source: Community, Design + Architecture, adapted from an illustration in Roundabouts, An Informational Guide (FHWA).

Modern Roundabouts

Background and Purpose

Related Thoroughfare Design Elements

- Pedestrian refuge islands
- Transit design
- Bicycle treatments at intersections
- Bus stops at intersections
- Bicycle lanes

Modern roundabouts are an alternative form of intersection control that is becoming more widely accepted in the United States. In the appropriate circumstances, significant benefits can be realized by converting stop-controlled and signalized intersections into modern roundabouts. These benefits include improved safety, speed reduction, reduction in certain types of vehicle crashes, opportunities for aesthetics and urban design, and operational functionality and capacity.

Studies conducted in the United States and published by the Federal Highway Administration in *Roundabouts: An Informational Guide* (2000) indicate that modern single-lane roundabouts in urban areas can result in up to a 61 percent reduction in all crashes and a 77 percent reduction in injury crashes when compared with stop-controlled intersections. When signalized intersections are replaced by modern single-lane roundabouts in urban areas, they have resulted in up to a 32 percent reduction in all crashes and up to a 68 percent reduction in injury crashes.

There remain some concerns regarding roundabouts and pedestrian and bicycle safety and how the disabled are accommodated. Care should be taken in areas with particularly high pedestrian volumes to provide adequate crosswalk widths and island dimensions to serve the volume of pedestrians moving around the roundabout. Double-lane roundabouts are of particular concern to pedestrians with visual impairments and bicyclists.

General Principles and Considerations

The purpose of a modern roundabout is to increase vehicle capacity at the intersection, slow traffic and reduce the severity of collisions. They are not generally used to enhance pedestrian and bicycle safety. Roundabouts are not always the appropriate solution. General principles and considerations for the design of modern roundabouts include the following:

- The application of roundabouts requires close attention to a number of issues, including:
- Type of design vehicle;
- Use by disabled and visually impaired persons; and
- Effects on pedestrian route directness.
- A modern roundabout should be designed to reduce the relative speeds between conflicting traffic streams and the absolute speed of vehicles to improve pedestrian safety. The curved path that vehicles must negotiate slows the traffic. Vehicles entering need to be properly deflected and yield to traffic already in the circulating roadway of the roundabout **(Figure 10.12).**
- Selecting a roundabout as the appropriate traffic control for an intersection requires location-specific analysis. Intersections with more than four legs are also good

candidates for conversion to modern roundabouts, as are streets intersecting at acute angles.

- Locating pedestrian crossings at least 25 feet from the roundabout entry point.
- Accomodating bicyclists by (1) preferably mixing with the flow of vehicular traffic (but without pavement markings delineating a bicycle lane) or (2) alternatively, use of a slip ramp from the street to the sidewalk proceeding around the intersection along separate paths, which is usually combined with pedestrian facilities. This situation can create conflicts between bicyclists and pedestrians that must be addressed through good design and signage, and it is inconvenient for the bicyclist. To accommodate different ability levels of bicyclists, both options could be implemented at the same roundabout unless specific conditions warrant otherwise.
- Single-lane roundabouts **(Figure 10.13)** may typically accommodate up to 20,000 entering vehicles per day, depending on a location-specific analysis. A double-lane roundabout typically accommodates up to 40,000 vehicles per day. Capacity analyses should be conducted to determine peak hour operating conditions and levels of service. Specific dimensions need to accommodate such volumes, as are determined using roundabout analysis tools. Refer to *Roundabouts: An Informational Guide* (FHWA 2000) for more information.
- If considering a double-lane roundabout on a boulevard, carefully evaluate pedestrian crossings. It may be desirable to provide crosswalks at midblock locations away from the roundabout. Double-lane roundabouts are not recommended in areas with high levels of pedestrian and bicycle activity.
- Intersections near active railroad-grade crossings are typically not good candidates for roundabouts since traffic would be blocked in all directions when trains are present.

Figure 10.13 Typical layout of a single lane modern roundabout. Source: Kimley-Horn and Associates, Inc.

- Sight distance for drivers entering the roundabout should be maintained to the left so that drivers are aware of vehicles and bicycles in the circle. Visibility across the center of the circle is not critical.
- Roundabouts provide an opportunity to visually enhance the area. Appropriate landscaping is encouraged, even in the center island. However, for safety, pedestrians

are not permitted to walk to the center island. Thus, water features or features that might attract pedestrians to the center island should be discouraged.

- Proper signing and pavement markings should be designed for motorists, bicyclists and pedestrians in advance of and at the location of the roundabout. Consideration should be given to the use of a "yield line" where appropriate, as per Section 3B.16 of the *Manual on Uniform Traffic Control Devices* (MUTCD)
- (FHWA 2009).
- At some locations, pedestrian volumes may be high enough to warrant signal control of roundabout approaches to provide gaps for vehicles (since pedestrians have the right of way). Pedestrian-demand signals may be required at multilane roundabout crossings in order to create and identify gaps for some types of pedestrians: for example, children, the elderly and people who have visual or cognitive impairments.

Recommended Practice

Table 10.2 provides guidance for the selection of modern roundabouts for various thoroughfare types and presents general design parameters. There are three general roundabout design philosophies in use in the United States. First, many older traffic circles and rotaries are being eliminated or redesigned to modern roundabouts. Second, the Australian model of smaller-diameter and slower speed roundabouts is gaining popularity in the United States, as is the third, the British model of larger-diameter, multilane, higher-speed roundabouts. The designer should reference the planning section of FHWA's informational guide to aid in the decision-making process.

Justification

Roundabouts exist at more than 15,000 intersections in Europe and Australia, with decades of successful operation, research and improvements. Introduced into the United States in the 1990s, modern roundabouts are much improved over older American traffic circles and rotaries. Significant benefits related to crash and delay reduction are cited by researchers based on conversion of four-way stop-controlled and signal-controlled intersections in eight states.

Table 10.2 Recommended Practice for Modern Roundabouts

Parameter	Minimum "Mini-Roundabout"	Urban Compact Roundabout	Urban Single-Lane Roundabout	Urban Double-Lane Roundabout*
Maximum Entry Speed (mph)	15	15	20	25
Design Vehicle	Bus and single-unit truck drive over apron	Bus and single-unit truck	Bus and single-unit truck WB-50 with lane encroachment on truck apron	WB-67 with lane encroachment on truck apron
Inscribed circle diameter (feet)	45 to 80	80 to 100	100 to 130	150 to 180
Maximum number of entering lanes	1	1	1	2
Typical	10,000	15,000	20,000	40,000

capacity (vehicles per day entering from all approaches)				
Applicability by Thoroughfare Type:				
Boulevard	Not Applicable	Not Applicable	Not Applicable	Applicable
Arterial Avenue	Not Applicable	Not Applicable	Applicable	Applicable
Collector Avenue	Applicable	Applicable	Applicable	Not Applicable
Street	Applicable	Applicable	Applicable	Not Applicable

* Note the pedestrian and bicycle conflicts are inherent in multilane roundabouts unless they are signalized.

Pedestrian Treatments at Intersections—Crosswalks

Background and Purpose

Related Thoroughfare Design Elements

- Midblock crossings
- Channelized right turns
- Curb extensions
- Curb-return radii
- Modern roundabouts
- Pedestrian refuge islands

Crosswalks are used to assist pedestrians in crossing streets. The definition provided in the MUTCD of an unmarked crosswalk makes it clear that unmarked crosswalks can exist only at intersections, whereas the definition of a marked crosswalk makes it clear that marked crosswalks can exist at intersections "or elsewhere." Crosswalks also provide the visually impaired with cues and wayfinding, as long as they have appropriate contrast.

If sidewalks exist on one or more quadrants of the intersection at a signalized or unsignalized intersection, then crosswalks are legally present at the intersection whether they are marked or not. Even if sidewalks do not exist at the intersection, in some states crosswalks may be legally present.

Even if unmarked crosswalks legally exist at a signalized intersection, it is almost always beneficial to provide marked crosswalks from the perspective of pedestrian safety. Marked crosswalks alert drivers approaching and traveling through the intersection of the potential presence of pedestrians. Marked crosswalks also direct legal pedestrian movements to desirable crossing points.

If an unmarked crosswalk legally exists across a stop-controlled approach to an intersection, it is usually not necessary to mark the crosswalk. However, if engineering judgment determines that pedestrian safety or the minimization of vehicle-pedestrian conflicts is especially important, then providing a marked crosswalk along with advanced warning signs and markings would be appropriate.

General Principles and Considerations

In designing thoroughfares, the issue of crosswalks is not isolated to an individual intersection. The intent of CSS in walkable areas is to create an environment in which pedestrians and bicycles are expected and to support this expectation with consistent and uniform application of signing, markings and other visual cues for motorists and pedestrians. The following principles and considerations should help guide the planning or design of pedestrian crossings:

- Assume that pedestrians and bicyclists want and need safe access to all destinations that are accessible to motorists. Additionally, pedestrians will want to have access to destinations not accessible to motorists.
- Typical pedestrian and bicyclist generators and destinations include residential neighborhoods, schools, parks, shopping areas and employment centers. Most transit stops require that pedestrians be able to cross the street.
- Pedestrians need safe access at many uncontrolled locations, including intersections and midblock locations.
- Pedestrians must be able to cross streets at regular intervals. Unlike motor vehicles, pedestrians should not be expected to go more than 300 to 400 feet out of their way to take advantage of a controlled intersection.
- Intersections provide the best locations to control motorized traffic to permit pedestrian crossings.
- In order to effectively indicate to motorists that they are in, or approaching, a pedestrian area and that they should expect to encounter pedestrians crossing the street, the design of the crosswalk must be easily understood, clearly visible and incorporate realistic crossing opportunities for pedestrians.

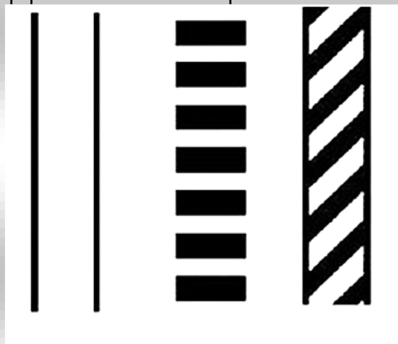


***Figure 10.14** The three primary types of crosswalk markings (from left to right) are transverse, longitudinal and diagonal. Source: Kimley-Horn and Associates, Inc.*

Figure 10.15 Crosswalks with colored bricks contrast with concrete pavement. However, over time, colored bricks stain and lose contrast. Painted stripes marking brick or colored concrete crosswalks would increase their visibility. Otherwise use standard crosswalk markings for long-term visibility. Source: Kimley-Horn and Associates, Inc.

- There are three primary marking options: transverse, longitudinal and diagonal (zebra) lines **(Figure 10.14).** The placement of lines for longitudinal markings should avoid normal wheel paths, and line spacing should not exceed 2.5 times the line width.
- At unsignalized or uncontrolled crossings, special emphasis longitudinal or diagonal markings should be used to increase visibility. High-contrast markings also aid people with vision impairments, but no MUTCD provisions for the use of high-contrast pavement markings has yet been developed.
- In highly urban areas (C-5 and C-6), at compact signalized intersections and at other locations with higher levels of pedestrian activity, pedestrian signals should automatically show the WALK sign without requiring activation.
- Although it is not a traffic control device, colored and textured crosswalk design treatments are sometimes used between transverse lines to further delineate the crosswalk, provide contrast for the visually impaired, provide tactile feedback to drivers and improve aesthetics **(Figure 10.15).**

Care should be taken to ensure that the material used in these crosswalks is smooth, nonslip and visible. Avoid using a paver system that may shift and/or settle or that induces a high degree of vibration in wheelchair wheels.

Recommended Practice

The following practice is recommended:

- Provide marked crosswalks at urban signalized intersections for all legs of the intersection; and
- Provide a marked crosswalk across an approach controlled by a STOP sign where engineering judgment determines there is significant pedestrian activity and pedestrian safety or the minimization of vehicle-pedestrian conflicts is especially important at that

particular location (also see section titled Design Elements for Intersections in Walkable Areas in this chapter).

Justification

Marked crosswalks are one tool to get pedestrians safely across the street and they should be used in combination with other treatments (such as curb extensions, pedestrian refuge islands, proper lighting and so forth). In most cases, marked crosswalks alone (without other treatments) should not be installed within an uncontrolled environment when speeds are greater than 40 mph according to AASHTO's *Guide for the Planning, Design and Operation of Pedestrian Facilities* (2004b) and FHWA's *Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations* (2002).

Pedestrians can legally cross the street at any intersection, whether a marked crosswalk exists or not. To enhance awareness by motorists, install crosswalks on all approaches of signalized intersections. If special circumstances make it unsafe to do so, attempt to mitigate the circumstance.

Curb Extensions Background and Purpose

Curb extensions (also called nubs, bulb-outs, knuckles, or neck-downs) extend the line of the curb into the traveled way, reducing the width of the street. Curb extensions typically occur at intersections but can be used at midblock locations to shadow the width of a parking lane, bus stop, or loading zone. Curb extensions can provide the following benefits:

- Reduce pedestrian crossing distance and exposure to traffic;
- Improve driver and pedestrian visibility at intersections;
- Separate parking maneuvers from vehicles turning at the intersections;
- Visually and physically narrow the traveled way, resulting in a calming effect;
- Encourage and facilitate pedestrian crossing at preferred locations;
- Keep vehicles from parking too close to intersections and blocking crosswalks;
- Provide wider waiting areas at crosswalks and intersection bus stops;
- Reduce the effective curb-return radius and slow turning traffic;
- Provide space for level landings and clear space required at pedestrian push buttons, as well as double perpendicular curb ramps with detectable warnings; and
- Provide space for streetscape elements if extended beyond crosswalks.

Curb extensions serve to better define and delineate the traveled way as being separate from the parking lane and streetside. They are used only where there is on-street parking and the distance between curbs is greater than what is needed for the vehicular traveled way.

Related Thoroughfare Design Elements

- Curb-return radii
- Channelized right turns
- Lane width
- Crosswalks
- Midblock crossings
- Bus stops at intersections
- Bus stops in the traveled way

General Principles and Considerations

General principles and considerations regarding curb extensions include the following:

- Curb extensions may be used at intersections in any context zone but are emphasized in urban centers (C-5), urban cores (C-6) and other locations with high levels of pedestrian activity.
- Curb extensions help manage conflict between modes, particularly between vehicles and pedestrians. The curb extension is an effective measure to improve pedestrian safety and comfort and might contribute to slower vehicle speed.
- The design of the curb extension should create an additional pedestrian area in the driver's field of vision, thereby increasing the visibility of pedestrians as they wait to cross the street, as shown in **Figure 10.16.**

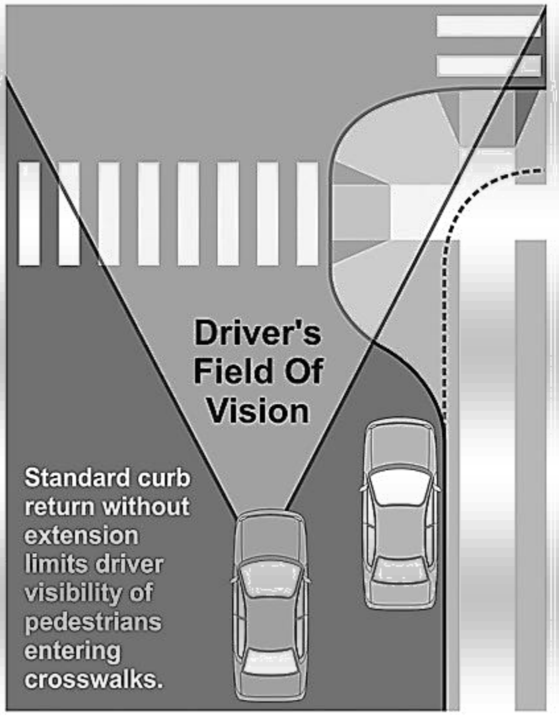


Figure 10.16 Curb extensions can improve pedestrian visibility and reduce crossing distance. Source: Digital Media Productions.

- Curb extensions are used only where there is on-street parking and where only a small percentage of turning vehicles are larger than the design vehicle.
- Curb extensions are not applicable to intersections with exclusive right-turn lanes adjacent to the curb, or intersections with a high volume of right-turning trucks or buses turning into narrow cross streets.
- Carefully consider drainage in the design of curb extensions to avoid interrupting the flow of water along the curb, thus pooling water at the crosswalk.
- Curb extensions work especially well with diagonal parking, shadowing the larger profile of the row of parking and providing large areas in the pedestrian realm.
- Adjusting the curb-return radius can accommodate emergency vehicles and large design vehicles. An "effective" radius can accommodate the design vehicle through the use of a mountable (or flush with pavement) extension with bollards to delineate the pedestrian area as shown in **Figures 10.17** and **10.18.** Flush curb extensions are frequently combined with raised intersections. However, care should be taken to provide adequate vehicle turning paths outside the designated pedestrian waiting area.

- Where bicycle lanes exist, the curb extension must be outside the width of the bicycle lane.
- Design curb-extension radii to allow street cleaning vehicles to reach and turn all inside and outside corners. Normally this requires a radius of 15 feet. This will also help stormwater flow in the gutters around corners.
- Ensure good street lighting not only for pedestrians but so that the extension is visible to drivers at night and in adverse weather.

Figure 10.17** **A mid block crossing with a flush curb in New Zealand. Pedestrians are separated from passing vehicles with bollards. Source: Community, Design + Architecture.

Figure 10.18 Use of contrasting material and bollards to delineate the pedestrian and vehicle areas. Source: Kimley-Horn and Associates, Inc.

Recommended Practice

The following practices are recommended when designing curb extensions on urban thoroughfares:

- Reduce crossing width at intersections by extending the curb line into the street by 6 feet for parallel parking and to within 1 foot of stall depth with angled parking. Ensure that the curb extension does not extend into travel or bicycle lanes.

- Apply the appropriate curb-return radius in the design of a curb extension. If necessary, use three-centered or asymmetric curb returns to accommodate design vehicles.
- Where buses stop in the travel lane, curb extensions can be used to define the location of the stop and create additional waiting areas and space for shelters, benches and other pedestrian facilities.
- When possible, allow water to drain away from the curb extension. In other cases a drainage inlet may need to be installed and connected to an existing underground storm-drain system.
- Curb extensions are usually constructed integral with the curb. In retrofit projects, curb extensions may be constructed away from the curb to allow drainage along the original flow-line **(Figure 10.19).** Consider that this design might require additional maintenance to keep the flowline clear.
- When considering construction of curb extensions where an existing high road crown exists, reconstruction of the street might be necessary to avoid back draining the sidewalk toward abutting buildings. Slot drains along the sidewalk may provide an alternate solution.
- Sidewalks, ramps, curb extensions and crosswalks should all align with no unnecessary meandering.

Justification

Curb extensions in unused or underutilized street space can be used to shorten pedestrian crossing distance, increase pedestrian visibility and provide additional space for pedestrian queuing and support activity. Extensions can increase safety, efficiency and attractiveness.

Figure 10.19 Curb extensions may be used as landscaping or hardscape opportunities. This example shows a retrofit curb extension with drainage retained between the extension and the curb. Source: Community, Design + Architecture.

Bicycle Lane Treatment at Intersections

Background and Purpose

Selecting appropriate bicycle lane treatments at intersections requires providing uniformity in facility design, signs and pavement markings for bicyclists and motorist safety. The objective is to promote a clear

Related Thoroughfare Design Elements

- Bicycle lanes
- Curb extensions
- Right-turn channelization
- Lane width understanding of safe paths through all intersection movements for bicyclists and motorists.

General Principles and Considerations

General principles and considerations regarding bicycle lane treatment at intersections include the following:

- Since bicyclists ride on the right-hand side of adjacent motor vehicle traffic, bicyclists desiring to travel straight through an intersection conflict with motor vehicles that are making a right turn at the intersection. On intersection approaches that have a shared through/right-turn lane, bicyclists not turning right need to position themselves in the center of the through/right lane to safely traverse the intersection and avoid conflicts with right-turning vehicles. For this reason, the bike lane, if used, should be dashed on the approach to the intersection stop bar to indicate that the motorist should share the space with the bicyclists.
- Similarly, bicycle lanes should be dashed in bus stops to encourage buses to pull all the way to the curb.
- On intersection approaches that have an exclusive right-turn lane, the bicycle lane should be positioned to the left of the right-turn lane. Drivers of right-turning motor vehicles moving into the turn lane have an obligation to yield to any present bicyclists. The higher-speed motor vehicle is usually approaching the beginning of the turn lane from behind the bicyclist and has a better view of the potential conflict.
- A more complex situation exists when an exclusive right-turn lane is created by dropping a through lane. The bike lane can typically transition from the right of the right-turn lane to the left of the right-turn lane with a shift in alignment.
- Where there are numerous left-turning bicyclists, a left-turn bicycle lane may be provided on an intersection approach. This lane is located between the vehicular left-turn lane and the adjacent through lane so that bicyclists can keep to the outside as they turn left.
- On approaches to roundabout intersections, the bicycle lane needs to be terminated 100 feet before the crosswalk, yield line or limit of circulatory roadway and should not be provided on the circulatory roadway of the roundabout intersection.

Recommended Practice

The recommended practice for bicycle lane treatment at intersections on urban thoroughfares is shown in **Table 10.3.**

Justification

At intersections, bicyclists proceeding straight through and motorists turning right must cross paths unless the cyclist moves to the center of the through-right travel lane. Therefore, striping bike lanes up to the stop bar conflicts with this movement. Striping and signing configurations that encourage crossings in advance of the intersection in a weaving fashion reduce conflicts at the intersection and improve bicycle and motor vehicle safety. Similarly, modifications such as special sight distance considerations, wider roadways to accommodate on-street lanes, special lane markings to channelize and separate bicycles from right-turning vehicles, provisions for left-turn bicycle movements and special traffic signal designs (such as conveniently located push buttons at actuated signals or even separate signal indications for bicyclists) also improve safety and operations and balance the needs of both transportation modes when on-street bicycle lanes or off-street bicycle paths enter an intersection.

Bus Stops at Intersections

Background and Purpose

Walkable thoroughfare design for bus stops at intersections emphasizes an improved environment for pedestrians and techniques for efficient transit operations. Design considerations for buses are addressed in detail in the section on midblock bus stops in Chapter 9.

Table 10.3 Recommended Practice for Bicycle Lane Treatment at Intersections on Walkable Urban Thoroughfares

Intersection Conditions and Related Recommendations
With pedestrian crosswalks
Bike lane striping should not be installed across any pedestrian crosswalks, and, in most cases, should not continue through any street intersections.
With no pedestrian crosswalks
Bike lane striping should stop at the intersection stop line, or the near side cross street right-of-way line projection, and then resume at the far side right-of-way line projection. Dash the bike lane prior to the stop line per MUTCD, to warn both motorists and cyclists of the need to prepare for right-turn movements at the intersection. Bike lane striping may be extended through complex intersections with the use of dotted or skip lines.
Parking considerations
The same bike lane striping criteria apply whether parking is permitted or prohibited in the vicinity of the intersection.
Bus stop on near side of intersection or high right-turn volume at unsignalized minor intersections with no stop controls
A 6 to 8-inch solid line should be replaced with a dashed line with 2-foot dashes and 6-foot spaces for the length of the bus stop. Bike lane striping should resume at the outside line of the crosswalk on the far side of the intersection. In the area of a shared through/right turn, the solid bike lane, if used, should be dashed to the stop bar to indicate that the right-turning motorist should share the space with bicyclists.
Bus stop located on far side of the intersection
Solid white line should be replaced with a dashed line for a distance of at least 80 feet from the crosswalk on the far side of the intersection.
T-intersections with no painted crosswalks

Bike lane striping on the far side across from the T-intersection should continue through the intersection area with no break. If there are painted crosswalks, bike lane striping on the side across from the T-intersection should be discontinued through the crosswalks.

Pavement markings

Bike lane markings should be installed according to the provisions of Chapter 9C of the MUTCD.

The standard pavement symbols are one of two bicycle symbols (or the words "BIKE LANE") and an optional directional arrow as specified in the MUTCD. Symbols should be painted on the far side of each intersection. Pavement markings should be white and reflectorized.

Signs

Bike lanes should be accompanied by appropriate signing at intersections to warn of conflicts (see Chapter 9B of the MUTCD).

Actuation at Traffic Signals

If bike lane extends to the stop bar, provide a detector in the lane and appropriate pavement marking to indicate where the bicyclist should stop.

If the bicyclist shares a travel lane, provide a detector (and pavement marking) in the center of the lane.

If in-pavement or video detection is not possible, install a push-button on the curb accessible to the bicyclist.

Related Thoroughfare Design Elements

- Lane width.
- Curb extensions.
- Bus stops in the traveled way.
- Curb-return radius.
- Crosswalks.

Recommended Practice

Placement of Bus Stops at Intersections

The preferred location for bus stops is the near side or far side of an intersection. This location provides the best pedestrian accessibility from both sides of the street and connection to intersecting bus routes. While not preferred, bus stops on long blocks may be placed at a midblock location or to serve a major transit generator (See Chapter 9). Guidance and considerations related to bus stops at intersections include the following:

- Consider a near-side stop on two-lane thoroughfares where vehicles cannot pass a stopped bus.
- Consider a far-side stop on thoroughfares with multiple lanes where vehicular traffic may pass uncontrolled around the bus.
- On thoroughfares where vehicular traffic is controlled by a signal, the bus stop may be located either near side or far side, but far side is preferable.
- Where it is not desirable to stop the bus in a travel lane and a bus pullout is warranted, a far side or midblock stop is generally preferred. As with other elements of the roadway, consistency of stop placement lessens the potential for operator and passenger confusion.

- When locating a bus stop in the vicinity of a driveway, consider issues related to sight distance, blocking access to development and potential conflicts between automobiles and buses.
- The approach to a bus stop from the sidewalk to the bus must be fully accessible as defined by the U.S. Access Board. Bus stop access must in every case include a safe and accessible street crossing.

It must also contain a loading area of at least 5 feet by 8 feet for wheelchairs to board. (see Chapter 9)

The placement of bus stops at intersections varies from site to site. However, general considerations for the placement of bus stops at intersections include the following:

- When the route alignment requires a left turn, the preferred location for the bus stop is on the far side of the intersection after the left turn is completed.
- When the route alignment requires a left turn and it is infeasible or undesirable to locate a bus stop far side of the intersection after the left turn, a midblock location is preferred. A mid-block bus stop should be located far enough upstream from the intersection so a bus can maneuver into the proper lane to turn left.
- If there is a high volume of right turns at an intersection or when the transit route turns right at an intersection, the preferred location for a stop is on the far side of the intersection.
- In circumstances where the accumulation of buses at a far-side stop would spill over into the intersection and additional length is not available, the stop should be placed on the near side of the intersection.
- At complex intersections with dual right- or left-turn lanes, far-side stops are preferred because they remove the buses from the area of complicated traffic movements.
- When there is substantial transfer activity between two bus routes on opposite sides of the street, placing one stop near side and one at the adjacent far-side location can minimize the number of crossings required to transfer between buses.

Table 10.4 summarizes the advantages and disadvantages of far-side and near-side bus stop placements.

Curb Extension Bus Stops (Bus Bulbs)

A curb extension may be constructed along streets with on-street parking. Curb extensions may be designed in conjunction with bus stops to facilitate bus operations and passenger access. The placement of a bus stop on a curb extension should follow the same guidelines as those previously stated (a near-side stop is preferred on two-lane streets where vehicles cannot pass a stopped bus; in the case of a street with multiple lanes where vehicular traffic may pass uncontrolled around the bus, a far-side stop is preferred for sight distance issues).

Table 10.4 Advantages and Disadvantages of Far side and Near side Bus Stops

Far Side Bus Stops	
Advantages	Disadvantages
- Minimizes conflict between buses and right turning vehicles traveling in the same direction - Minimizes sight distance problems on approaches to the intersection	- If bus stops in travel lane, could result in traffic queued into intersection behind the bus (turnout will allow traffic to pass around the stopped bus) - If bus stops in travel lane, could result in rear-end accidents as motorists fail to

• Encourages pedestrians to cross behind the bus • Minimizes area needed for curbside bus zone • If placed just beyond a signalized intersection in a bus turnout, buses may more easily re-enter the traffic stream • If a turnout is provided, vehicle capacity through intersection is unaffected • Can better take advantage of traffic signal priority for buses	anticipate stopped traffic • May cause passengers to access buses further from crosswalk • May interfere with right turn movement from cross street • May obscure sight distance for crossing vehicles • If signal priority not in use, bus may have to stop twice, once at signal and then at bus stop
Near Side Bus Stops	
Advantages	**Disadvantages**
• Minimizes interference when traffic is heavy on the far side of an intersection • Allows passengers to access buses close to crosswalk • Driver may use the width of the intersection to pull away from the curb • Allows passengers to board and alight when the bus is stopped for a red light • Provides the driver with the opportunity to look for oncoming traffic, including other buses with potential passengers	• Stopped bus interferes with right turns • May cause sight distance problem for approaching traffic, cross-street traffic and pedestrians • If located in a pullout or shoulder or at a signalized intersection, a traffic queue may make it difficult for buses to re-enter the traffic stream • Prohibits through traffic movement with green light, similar to far side stop without a bus turnout • May cause pedestrians to cross in front of the bus at intersections • Limits use of traffic signal priorities

Source: *Bus Stop Safety and Design Guidelines Manual,* Orange County Transportation Authority and Kimley-Horn and Associates, Inc.

A bus stop on the near side of a single-lane approach of an uncontrolled intersection should completely obstruct the traffic behind it. Where it is not acceptable to have stopped buses obstruct a lane of traffic and a bus turnout is justified according to the criteria presented in Chapter 9 (section on midblock bus stops), a bus stop may be placed on the far side in the parking lane just beyond the curb extension. It might be appropriate to place a bus stop on a far-side curb extension at an uncontrolled intersection if the warrants for a bus pullout are not met and its placement will not create a traffic hazard.

Near-side curb extensions are usually about 6 feet in width and of sufficient length to allow passengers to use the front and back doors of a bus. A near-side curb extension bus stop is shown in **Figure 10.20.**

Besides reducing the pedestrian crossing distances, curb extensions with near-side bus stops can reduce the impact to parking (compared to typical bus zones), mitigate traffic conflicts with autos for buses merging back into the traffic stream, make crossing pedestrians more visible to drivers and create additional space for passenger queuing and amenities, such as a shelter and/ or a bench.

Figure 10.20 A near-side curb extension bus stop. Source: Kimley-Horn and Associates, Inc.

In areas where curb extensions are desired, but it is not acceptable to have the bus stop in the travel lane, a far-side pullout area can be created in the parking lane. This location and design eliminates the safety hazard of vehicles passing the bus prior to entering the intersection. However, bus stop length will likely be increased over the normal far-side length because of the need to add an approach taper to the stop downstream from the curb extension.

Queue Jumpers

Queue jumpers provide priority treatment for buses along arterial streets by allowing buses to bypass traffic queued at congested intersections. Queue jumpers evolved from the need to reduce bus delays at intersections or other congested locations. In the past, traffic engineers constructed bus turnouts to move buses out of the traffic stream while they are stopped for passengers. Bus turnouts introduce significant travel time penalties to bus patrons because buses are delayed while attempting to reenter the traffic stream. Queue jumpers provide the double benefit of removing stopped buses from the traffic stream to benefit the general traffic and getting buses through congested intersections so as to benefit bus operations.

Queue jumpers consist of a near-side right-turn lane (buses excepted) and a far-side bus stop and/or acceleration lane. Buses are allowed to use the right-turn lane to bypass traffic congestion and proceed through the intersection. Additional enhancements to queue jumpers could include an exclusive bus-only lane upstream from the traffic signal, extension of the right-turn lane to bypass traffic queued at the intersection, or advanced green indication allowing the bus to pass through the intersection before general traffic does.

Queue Jumper With an Acceleration Lane
This option includes a near-side right-turn lane (buses excepted), near-side bus stop and acceleration lane for buses with a taper back to the general purpose lanes on the far-side of the intersection.

Queue Jumper With a Far-Side Bus Stop
This option may be used when there is a heavy directional transfer to an intersecting transit route. Buses can bypass queues either using a right-turn lane (buses excepted) or an exclusive bus queue jump lane. Since the bus stop is located on the far side, a standard transition can be used for buses to reenter the traffic stream. Queue jumpers at urban thoroughfare intersections should be considered when:

1. High-frequency bus routes have an average headway of 15 minutes or less;

2. Forecasted traffic volumes exceed 500 vehicles per hour in the curb lane during the peak hour and right-turn volumes exceed 250 vehicles per hour during the peak hour; and

3. Intersection operates at an unacceptable level of service (defined by the local jurisdiction).