Intersection Design

6.1 Introduction

An intersection is the area where two or more streets join or cross at-grade. The intersection includes the areas needed for all modes of travel: pedestrian, bicycle, motor vehicle, and transit. Thus, the intersection includes not only the pavement area, but typically the adjacent sidewalks and pedestrian curb cut ramps. The intersection is defined as encompassing all alterations (for example, turning lanes) to the otherwise typical cross-sections of the intersecting streets. Intersections are a key feature of street design in four respects:

- **Focus of activity -** The land near intersections often contains a concentration of travel destinations.
- **Conflicting movements -** Pedestrian crossings and motor vehicle and bicycle turning and crossing movements are typically concentrated at intersections.
- **Traffic control -** At intersections, movement of users is assigned by traffic control devices such as yield signs, stop signs, and traffic signals. Traffic control often results in delay to users traveling along the intersecting roadways, but helps to organize traffic and decrease the potential for conflict.
- **Capacity -** In many cases, traffic control at intersections limits the capacity of the intersecting roadways, defined as the number of users that can be accommodated within a given time period.

This chapter describes the considerations and design parameters for intersections. The chapter begins by outlining definitions and key elements, and then describes the characteristics of intersection users, intersection types and configurations, capacity and quality of service considerations, geometric design elements, and other considerations.

6.1.1 Intersection Users

All roadway users are affected by intersection design as described below:

- **Pedestrians.** Key elements affecting intersection performance for pedestrians are: (1) amount of right-of-way provided for the pedestrian including both sidewalk and crosswalk width, accuracy of slopes and cross slopes on curb cut ramps and walkways, audible and/or tactile cues for people with limited sight, and absence of obstacles in accessible path; (2) crossing distance and resulting duration of exposure to conflicts with motor vehicle and bicycle traffic; (3) volume of conflicting traffic; and (4) speed and visibility of approaching traffic.
- **Bicyclists.** Key elements affecting intersection performance for bicycles are: (1) degree to which pavement is shared or used exclusively by bicycles; (2) relationship between turning and through movements for motor vehicles and bicycles; (3) traffic control for bicycles; (4) differential in speed between motor vehicle and bicycle traffic; and (5) visibility of the bicyclist.
- **Motor vehicles.** Key elements affecting intersection performance for motor vehicles are: (1) type of traffic control; (2) vehicular capacity of the intersection, determined primarily from the number of lanes and traffic control (although there are other factors); (3) ability to make turning movements; (4) visibility of approaching and crossing pedestrians and bicycles; and (5) speed and visibility of approaching and crossing motor vehicles.
- **Transit.** When transit operations involve buses, they share the same key characteristics as vehicles. In addition, transit operations may involve a transit stop at an intersection area, and influence pedestrian, bicycle, and motor vehicle flow and safety. In some cases, the unique characteristics of light-rail transit must be taken into account.

Owners and users of adjacent land often have a direct interest in intersection design, particularly where the intersection is surrounded by retail, commercial, historic or institutional land uses. Primary concerns include maintenance of vehicular access to private property, turn restrictions, consumption of private property for right-of-way, and provision of safe, convenient pedestrian access.

6.1.2 Intersection Design Process

The design of intersections follows the planning process outlined in Chapter 2. The need for intersection improvement is identified and various options for addressing this need are considered and analyzed. The specific design elements of intersections may impact any or all potential users. Sections 6.2 through 6.6 define key terms and discuss intersection users, configurations, traffic control, capacity, and quality of service. Section 6.7 describes the ranges of physical dimensions and the operational characteristics of each intersection design element.

6.2 Definitions and Key Elements

The *major street* is typically the intersecting street with greater traffic volume, larger cross-section, and higher functional class. The *minor street* is the intersecting street likely to have less traffic volume, smaller cross-section and lower functional classification than the major street.

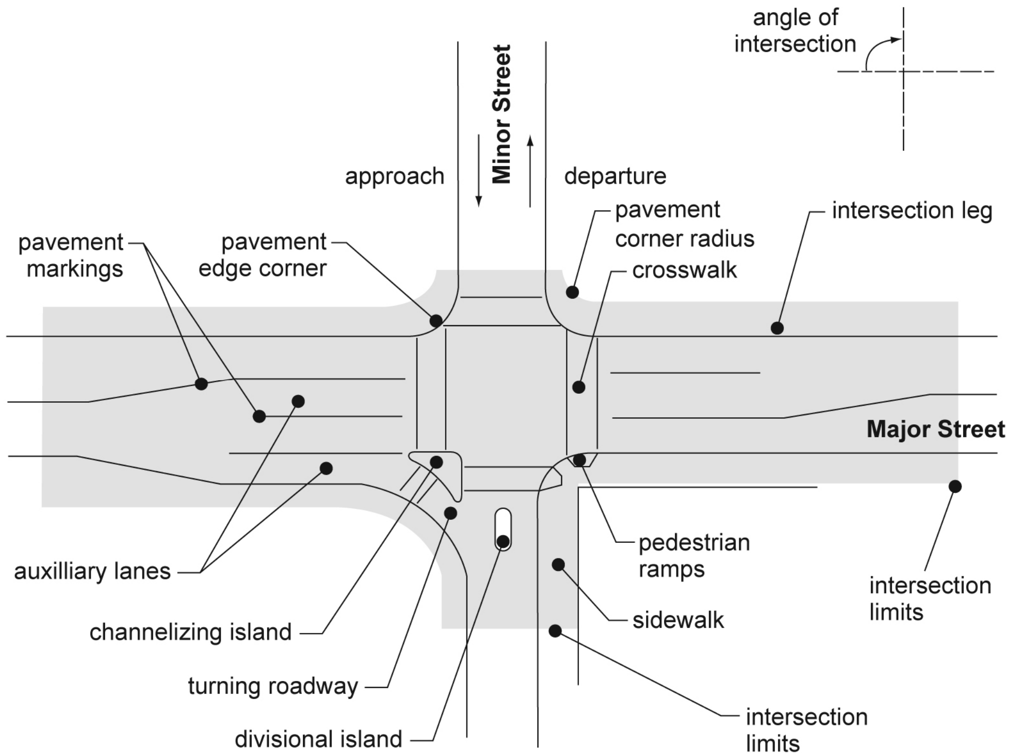
The term *intersection* encompasses not only the area of pavement jointly used by the intersecting streets, but also those segments of the intersecting streets affected by the design. Thus, those segments of streets adjacent to the intersection for which the cross-section or grade has been modified from its typical design are considered part of the intersection. Exhibit 6-1 summarizes the extent and terminology used to define an intersection.

Two geometric features are common to all intersections. The *angle of intersection* is formed by the intersecting streets' centerlines. Where the angle of intersection departs significantly (more than approximately 20 degrees) from right angles, the intersection is referred to as a *skewed intersection*.

Intersection legs are those segments of roadway connecting to the intersection. The leg used by traffic approaching the intersection is the *approach leg*, and that used by traffic leaving is the *departure leg*.

Sidewalks, *crosswalks* and *pedestrian curb cut ramps* are considered to be within the intersection. The *pavement edge corner* is the curve connecting the edges of pavement of the intersecting streets.

Exhibit 6-1
Intersection Terminology



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

In addition to the basic geometric design features, options may be added to improve service for various users. *Auxiliary lanes* are lanes added at the intersection, usually to accommodate turning motor vehicles. They may also be used to add through lanes through an intersection.

Channelizing and divisional islands may be added to an intersection to help delineate the area in which vehicles can operate, and to separate conflicting movements. Islands can also provide for pedestrian refuge.

A *turning roadway* is a short segment of roadway for a right turn, delineated by channelizing islands. Turning roadways are used where right-turn volumes are very high, or where skewed intersections would otherwise create a very large pavement area.

Traffic control devices assign right of way, to both motorized and non-motorized traffic and include traffic signals, pavement markings, STOP signs, YIELD signs, pedestrian signal heads and other devices (such as raised pavement markings, flashing beacons, and electronic blank-out signs).

6.3 User Characteristics

The following sections describe characteristics of intersection users. Pedestrians and bicyclists are presented first, followed by motor vehicle and public transit users. This order of presentation reinforces the need to consider these modes throughout the intersection design process.

6.3.1 Pedestrians

Pedestrian requirements must be fully considered in the design of intersections. There are several important features to consider including:

- **Crossings and Pedestrian Curb Cut Ramp Locations -** Locations should correspond to the placement of sidewalks along approaching streets, and likely crossing locations. Pedestrian curb cut ramps need to ensure accessibility to crossing locations.

- **Walking Speed –** Under normal conditions, pedestrian walking speeds on sidewalks and crosswalks range from 2.5 feet per second to 6 feet per second. Elderly pedestrians and young children will generally be in the slower portion of this range. A walking speed of 3.5 to 4 feet per second for crosswalk signal timing is widely accepted as a guideline for walking speed in crosswalks. The designer should note that the current draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-way* (not adopted at the time of this Guidebook) requires a maximum walk speed of 3.0 feet per second over the entire length of crosswalk plus the length of one pedestrian curb cut ramp.

- **Pedestrian Flow Capacity –** The number of pedestrians per hour that can be accommodated by the facility under normal conditions.

- **Traffic Control, Yielding and Delay -** In addition to pedestrian flow capacity, pedestrians are significantly affected by the type of traffic control installed at an intersection, the specific parameters of the control, and the resulting motor vehicle operations. At STOP controlled, YIELD controlled, and uncontrolled intersections, pedestrians' ability to cross the street and the delay experienced is influenced by the yielding behavior of motor vehicles. At signalized intersections, the length and frequency of time provided for pedestrian crossings, the clarity of information provided, conflicting turning movements, and motor vehicle yielding are key influences on pedestrians' ability to cross the street, and on delay.

6.3.2 Bicyclists

Bicyclists' needs must be integrated into the design of intersections. When traveling with motor vehicles, bicyclists are subject to motor vehicle traffic laws. Important considerations for bicycle accommodation include:

- **Cross-section -** Bicyclists position themselves for their intended destination regardless of the presence of bike lanes or shoulders. If bicycle lanes are present, the design needs to insure that bicyclists can merge to the proper location based on the bicyclist's intended destination.
- **Operating Speed -** At unsignalized intersections, an average bicycle speed of 15 miles per hour can be assumed on the major street. On the minor street, bicyclists usually stop or slow, and travel through the intersection at speeds well below 15 miles per hour. At signalized intersections, bicyclists receiving the green signal proceed through the intersection at an average speed of 15 miles per hour. Bicyclists who have stopped for a signal proceed through the intersection at speeds well below 15 miles per hour.
- **Bicycle Capacity -** The number of bicycles per hour that can be accommodated by the facility under normal conditions.
- **Traffic Control -** Bicyclists are required by law to obey control devices at intersections. Therefore, traffic control devices need to account for bicycle activity. Traffic signals which operate using detection systems (such as loop detection, video camera, and microwave) must be designed and field tested to be sensitive to bicycles. Many of the aspects of traffic control described for motor vehicles (below) also apply to bicyclists.

6.3.3 Motor Vehicles

The following important characteristics of motor vehicles are considered in intersection design:

- **Design Vehicle -** The largest type of motor vehicle that is normally expected to be accommodated through the intersection.
- **Design Speed -** The motor vehicle speed selected on adjoining segments of roadway.
- **Motor Vehicle Capacity -** The number of motor vehicles that can be moved through an intersection under normal conditions.
- **Traffic Control -** Much like other users, motor vehicles are influenced by the type and timing of traffic control installed at an intersection, and number of other users. At roundabouts, STOP controlled, YIELD controlled, and uncontrolled intersections, motor vehicle capacity and delay are influenced by conflicting traffic streams. At signalized intersections, the time provided for each movement, conflicting turning movements, and the volume and mix of other users are key influences on both motor vehicle capacity and delay.

6.3.3.1 Design Vehicle

The design motor vehicle is the largest type of vehicle typically expected to be accommodated on the street. At intersections, the most important attribute of design vehicles is their turning radius, which in turn influences the pavement corner radius and therefore the size of the intersection. Lane width, another feature related to the design vehicle, has some impact on intersection design, but less than turning radius. The design vehicle may also affect the choice of traffic control device and the need for auxiliary lanes.

The design vehicle for intersections is the larger of the design vehicles selected for the intersecting streets. For example, at the intersection of a minor arterial and a local street, the appropriate design vehicle for the intersection is that required by the minor arterial (i.e., "larger" street). Exhibit 6-2, *Typical Design Vehicles at Intersections*, provides general guidance for selecting design vehicles appropriate for intersection design under conditions of normal traffic composition. At locations where collectors intersect with arterials experiencing high truck volumes, the appropriate truck design vehicle should be selected. Sample turning templates for these motor vehicles are provided in Exhibit 6-3.

Exhibit 6-2
Typical Design Motor Vehicles at Intersections

Functional Class of Major Road	Design Motor Vehicle (AASHTO Category) Typical for Intersection
Freeway	(No Intersections)
Major Arterial	Tractor-trailer Truck (WB-65)
Minor Arterial	Tractor-trailer Truck (WB-50)
Major Collector	Single-unit Truck
Minor Collector	Passenger Car (P)
Local Roads and Street	Passenger Car (P)

Notes: Design vehicles from AASHTO A Policy on Geometric Design of Highways and Streets, 2004
Passenger Car (P) applies to Light Trucks and SUV's
SU category can also be used for school and transit buses

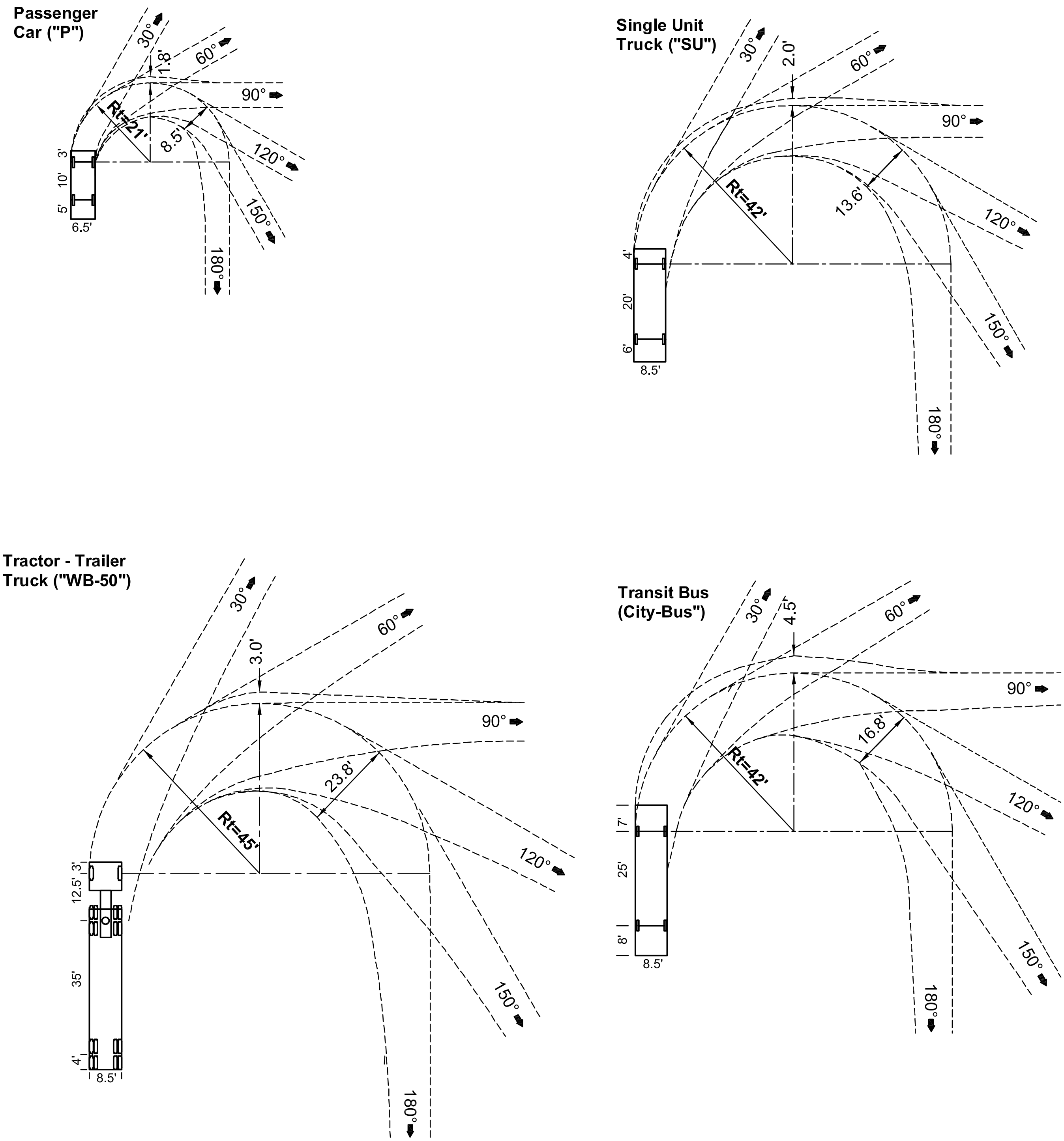
6.3.4 Transit

The design vehicle appropriate for most types of transit service is the "City-Bus" as defined by AASHTO. This vehicle is 40 feet long, 8 feet wide, and has outer and inner turning wheel paths of 42.0 feet and 24.5 feet, respectively. The "mid-size" bus, typically accommodating 22 to 28 passengers, is also used in scheduled transit service. The turning path for the mid-size bus can be accommodated within the single-unit (SU) truck turning path diagram. Tracked transit vehicles, such as trolleys, have turning radii as specified by their manufacturer, and are not accounted for in AASHTO templates. Their interactions with other traffic elements must be taken into account where applicable.

Transit stops are often located at intersections either as a near-side stop on the approach to the intersection or as a far-side stop on the departure leg of the intersection. Location near intersections is particularly advantageous where transit routes cross, minimizing the walking distance needed for passengers transferring between buses.

A bus stop, whether near-side or far-side, requires 50 to 70 feet of curb space unencumbered by parking. On streets without parking lanes or bus bays, buses must stop in a moving traffic lane to service passengers. Passengers typically require 4 to 6 seconds per person to board a bus, and 3 to 5 seconds to disembark. The total amount of time a transit vehicle will block traffic movements can then be estimated using the number of boardings and alightings expected at a stop.

Exhibit 6-3
Sample Vehicle Turning Template



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

Note: Not to scale

6.4 Intersection Types and Configurations

Intersections can be categorized into four major types, as illustrated in Exhibit 6-4, *Intersection Types*.

6.4.1 Simple Intersections

Simple intersections maintain the street's typical cross-section and number of lanes throughout the intersection, on both the major and minor streets. Simple intersections are best-suited to locations where auxiliary (turning) lanes are not needed to achieve the desired level-of-service, or are infeasible due to nearby constraints. Generally, simple intersections provide the minimum crossing distances for pedestrians and are common in low-volume locations.

6.4.2 Flared Intersections

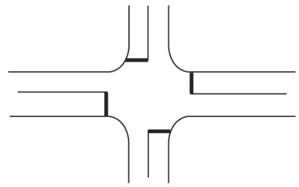
Flared intersections expand the cross-section of the street (main, cross or both). The flaring is often done to accommodate a left-turn lane, so that left-turning bicycles and motor vehicles are removed from the through-traffic stream to increase capacity at high-volume locations, and safety on higher speed streets. Right-turn lanes, less frequently used than left-turn lanes, are usually a response to large volumes of right turns.

Intersections may be flared to accommodate an additional through lane as well. This approach is effective in increasing capacity at isolated rural or suburban settings in which lengthy widening beyond the intersection is: not needed to achieve the desired level-of-service; not feasible due to nearby constraints; or, not desirable within the context of the project.

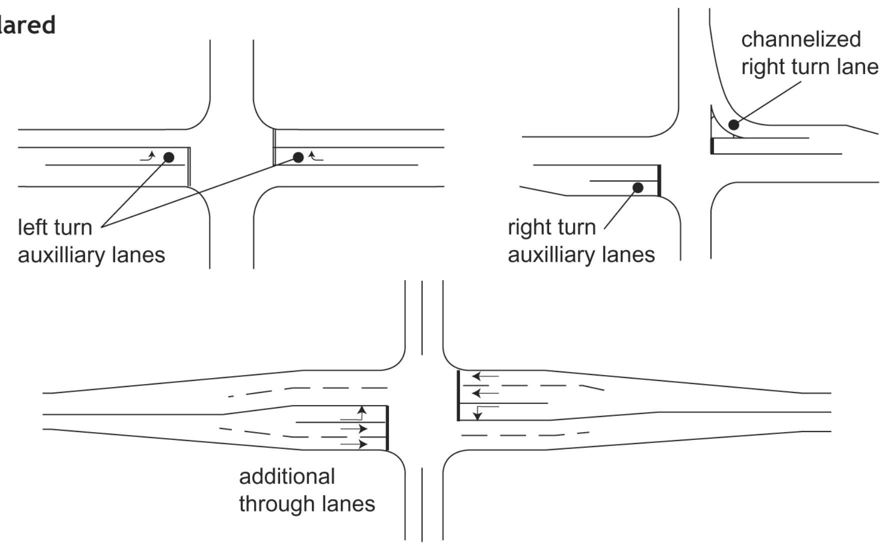
Intersection approaches can be flared slightly, not enough for additional approach lanes but simply to ease the vehicle turning movement approaching or departing the intersection. This type of flaring has benefits to bicycle and motor vehicular flow since higher speed turning movements at the intersection are possible and encroachment by larger turning vehicles into other vehicle paths is reduced. However, adding flare to an intersection increases the pedestrian crossing distance and time.

Exhibit 6-4
Intersection Types

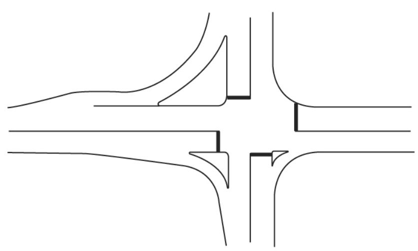
A. Simple



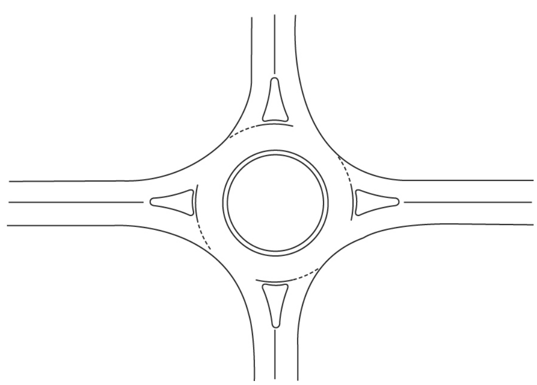
B. Flared



C. Channelized



D. Roundabout



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 3 Elements of Design

6.4.3 Channelized Intersections

Channelized intersections use pavement markings or raised islands to designate the intended vehicle paths. The most frequent use is for right turns, particularly when accompanied by an auxiliary right-turn lane. At skewed intersections, channelization islands are often used to delineate right turns, even in the absence of auxiliary right turn lanes. At intersections located on a curve, divisional islands can help direct drivers to and through the intersection. At large intersections, short median islands can be used effectively for pedestrian refuge.

Channelization islands are also used in support of left-turn lanes, forming the ends of the taper approaching the turn bay, and often the narrow divisional island extending to the intersection. At "T"-type intersections, a channelization island can guide oncoming traffic to the right of the left-turn lane.

Channelized intersections are usually large and, therefore, require long pedestrian crosswalks. However, the channelization islands can effectively reduce the crosswalk distance in which pedestrians are exposed to moving motor vehicles. The design of channelized intersections needs to ensure that the needs of pedestrians are considered, including pedestrian curb cut ramps or "cut-throughs" that allow wheelchair users the same safe harbor as other pedestrians on channelization islands.

6.4.4 Roundabouts

The roundabout is a channelized intersection with one-way traffic flow circulating around a central island. All traffic—through as well as turning—enters this one-way flow. Although usually circular in shape, the central island of a roundabout can be oval or irregularly shaped.

Roundabouts can be appropriate design alternative to both stop-controlled and signal-controlled intersections, as they have fewer conflict points than traditional intersections (eight versus 32, respectively). At intersections of two-lane streets, roundabouts can usually function with a single circulating lane, making it possible to fit them into most settings.

Roundabouts differ from "rotaries" in the following respects:

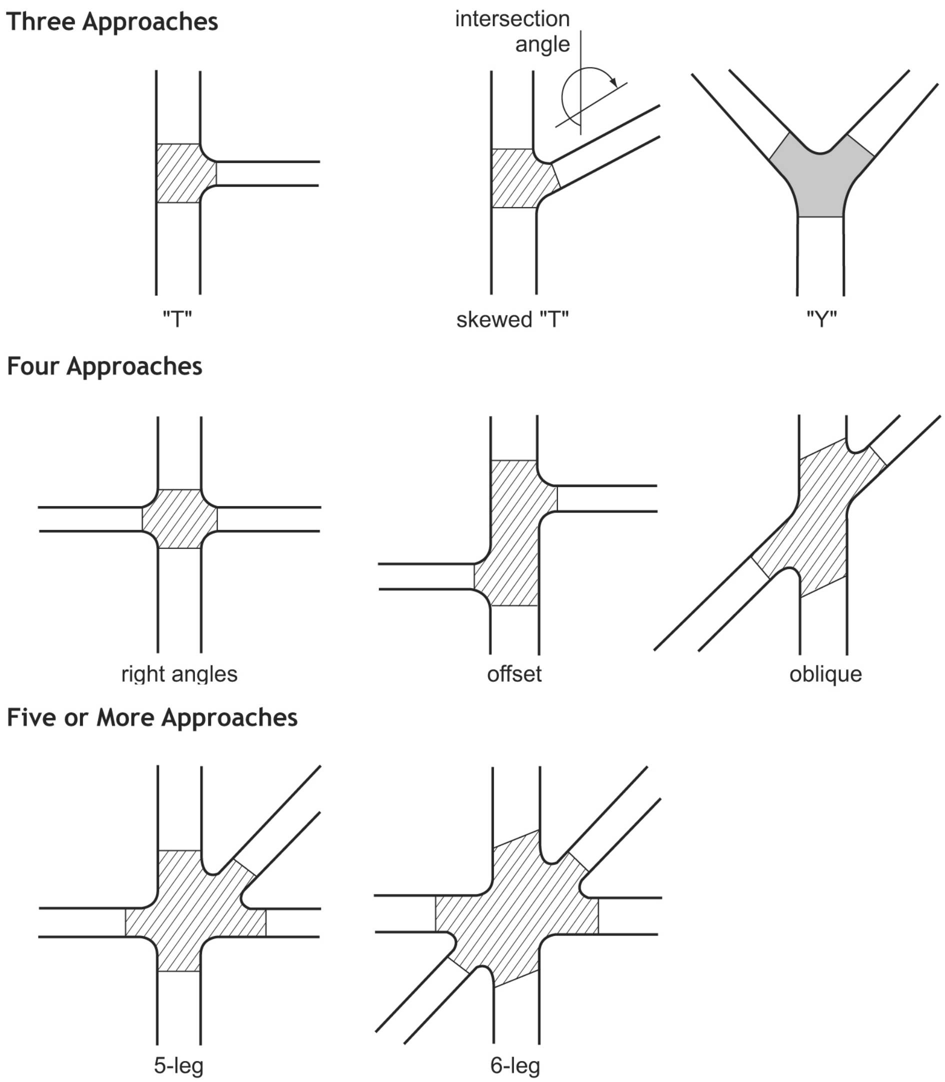
- **Size** – Single lane roundabouts have an outside diameter between 80 and 140 feet, whereas, rotaries are typically much larger with diameters as large as 650 feet.
- **Speed** – The small diameter of roundabouts limits circulating vehicle speeds to 10 to 25 miles per hour, whereas, circulating speeds at rotaries is typically 30 to 40 miles per hour.
- **Capacity** – The slower circulating speeds at roundabouts allow entering vehicles to accept smaller gaps in the circulating traffic flow, meaning more gaps are available, increasing the volume of traffic processed. At rotaries, vehicles need larger gaps in the circulating traffic flow reducing the volume of traffic processed.
- **Safety** – The slower speeds at roundabouts not only reduce the severity of crashes, but minimizes the total number of all crashes, whereas, rotaries typically see high numbers of crashes with a greater severity.

Roundabouts are also considered as traffic-calming devices in some locations since all traffic is slowed to the design speed of the one-way circulating roadway. This is in contrast with application of two-way stop control, where the major street is not slowed by the intersection, or all-way stop control where all traffic is required to stop. Roundabouts can also be considered for retrofit of existing rotaries; however, in cases with very high traffic volumes, traffic signal control may be more suitable.

6.4.5 Typical Intersection Configurations

Most intersections have three or four legs, but multi-leg intersections (five and even six-leg intersections) are not unusual. Examples of intersection configurations frequently encountered by the designer are shown in Exhibit 6-5. Ideally, streets in three-leg and four-leg intersections cross at right angles or nearly so. However, skewed approaches are a regular feature of intersection design. When skew angles are less than 60 degrees, the designer should evaluate intersection modifications to reduce the skew.

Exhibit 6-5
Intersecting Street Configuration and Nomenclature



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

6.5 Traffic Control

Traffic control devices (signals, STOP, or YIELD signs and pavement markings) often control the entry of vehicles into the intersection. Traffic control devices may also be required at intersections of important private driveways with public streets. Examples of important driveways include alleys serving multiple homes, commercial alleys accessing parking, and commercial driveways.

6.5.1 Traffic Control Measures

Potentially conflicting flows (vehicle-to-vehicle or vehicle-to-non-vehicle) are an inherent feature of intersections. At most intersections, therefore, traffic control measures are necessary to assign the right of way. Types of intersection traffic control include:

- Where sufficient visibility is provided in low volume situations, some intersections operate effectively without formalized traffic control. In these cases, normal right of way rules apply.
- Yield control, with traffic controlled by "YIELD" signs (sometimes accompanied by pavement markings) on the minor street approaches. Major street traffic is not controlled.
- All-way yield control on roundabouts.
- Two-way stop control, with traffic controlled by "STOP" sign or beacons on the minor street approaches. Major street traffic is not controlled. The term "two-way stop control" can also be applied to "T" intersections, even though there may be only one approach under stop control. STOP control should not be used for speed reduction.
- All-way stop control, with traffic on all approaches controlled by STOP signs or STOP beacons. All-way stop control can also be a temporary control at intersections for which traffic signals are warranted but not yet installed.
- Traffic signals, controlling traffic on all approaches.
- Flashing warning beacons on some or all approaches.

Generally, the preferred type of traffic control correlates most closely with safety concerns and volume of motor vehicles, bicycles and pedestrians. For intersections with lower volumes, STOP or YIELD control on the cross (minor) street is the most frequently used form of vehicular traffic control.

6.5.1.1 Stop and Yield Control Warrants

Part Two of the *Manual on Uniform Traffic Control Devices* (MUTCD) should be consulted for guidance on appropriate STOP sign usage and placement. In general, STOP signs could be used if one or more of the following exist:

- Intersection of a less important road with a main road where application of the normal right of way rule would not be expected to provide reasonable compliance with the law;
- Street entering a through highway or street;
- Unsignalized intersection in a signalized area; and/or
- High speeds, restricted view, or crash records indicate a need for control by a STOP sign.

STOP signs should be installed in a manner that minimizes the number of vehicles having to stop. At intersections where a full stop is not necessary at all times, consideration should be given to using less restrictive measures, such as YIELD signs. YIELD signs could be used instead of STOP signs if one of the following conditions exists:

- When the ability to see all potentially conflicting traffic is sufficient to allow a road user traveling at the posted speed, the 85th percentile speed, or the statutory speed to pass through the intersection or to stop in a reasonably safe manner;
- If controlling a merge-type movement on the entering roadway where acceleration geometry and/or sight distance is not adequate for merging traffic operation;
- The second crossroad of a divided highway where the median width at the intersection is 30 feet or greater. In this case a STOP sign may be installed at the entrance to the first roadway of a divided highway, and a YIELD sign may be installed at the entrance to the second roadway; and/or
- An intersection where a special problem exists and where engineering judgment indicates the problem to be susceptible to correction by the use of the YIELD sign.

6.5.1.2 Multiway STOP Control

Multiway STOP control can be useful as a safety measure at intersections if certain traffic conditions exist. Safety concerns associated with multiway stops include pedestrians, bicyclists, and all road users expecting other road users to stop. Multiway STOP control is used where the volume of traffic on the intersection roads in approximately equal. The following criteria should be considered for multiway STOP sign installation.

- Where traffic control signals are justified, the multiway STOP is an interim measure that can be installed quickly to control traffic while arrangements are being made for the installation of the traffic control signal;
- A crash problem, as indicated by five or more reported crashes in a 12-month period that are susceptible to correction by a multiway STOP installation. Such crashes include right- and left-turn collisions as well as right-angle collisions;
- Minimum volumes:
  - The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 vehicles per hour for any eight hours of an average day, and
  - The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches (total of both approaches) averages at least 200 units per hour for the same eight hours, with an average delay to minor street vehicular traffic of at least 30 seconds per vehicle during the highest hour, but
  - If the 85^{th} percentile approach speed of the major street traffic exceeds 40mph, the minimum vehicular volume warrants are 70 percent of the above values.
- Where no single criterion is satisfied, but where the second and third criteria are all satisfied to 80 percent of the minimum values. The 85^{th} percentile speed criterion is excluded from this condition.

At higher combinations of major street and minor street volume, traffic signals become the common traffic control measure. Roundabouts should also be considered in these situations. The decision to use traffic signals should follow the “signal warrants” specified in the MUTCD. These warrants are summarized in the following section.

6.5.1.3 Traffic Signal Warrants

Traffic signals should only be considered where the intersection meets warrants in the *Manual on Uniform Traffic Control Devices* (MUTCD). Where warranted and properly installed, traffic signals can provide for an orderly movement of traffic. Compared to stop control, signals can increase the traffic capacity of the intersection, reduce frequency and severity of crashes, particularly right-angle crashes, and interrupt heavy traffic flow to permit other motor vehicles, pedestrians and bicycles to cross the street.

Unwarranted or poorly timed traffic signals can have negative impacts, including excessive delay to vehicular and pedestrian traffic, disrespect for traffic control devices in general, increased "cut through" traffic on inappropriate routes, and increased frequency of crashes. Key features of the MUTCD warrants are:

The satisfaction of a traffic signal warrant or warrants shall not, in itself, require the installation of a traffic control signal. The traffic signal warrant analysis provides guidance *as to locations where signals would not be appropriate and locations where they could be considered further.*

- ***Warrant 1: 8-hour vehicular volume,*** met by 500 to 600 vehicles per hour on the major street (both directions, two-four lanes respectively) and 150-200 vehicles on the minor street (major direction, one-two lanes respectively), for any combination of 8 hours daily. A variation ("interruption of continuous traffic") warrant is met with 750 to 900 vehicles hourly on major street (two-four lanes, both directions), and 75 to 100 vehicles hourly (major direction, one-two lanes), on the minor street. These volumes can be reduced under certain circumstances (see Part 4 of the MUTCD for details).
- ***Warrant 2: four-hour vehicular volume,*** met on two-lane streets when the volume approaching the intersection on both major street approaches combined plus the higher of the minor street approaches is around 900 vehicles hourly, for four hours daily.
- ***Warrant 3: peak hour,*** met on two-lane streets when the volume approaching the intersection on both major street approaches combined plus the higher of the minor street approaches is around 1,200 vehicles in a single peak hour.
- ***Warrant 4: pedestrian volume,*** met with intersection or mid-block pedestrian crossing volumes of at least 100 for each of four hours, or 190 during any one hour, in combination with fewer than 60 hourly gaps of adequate length to allow pedestrian crossing when the volume criteria are satisfied.

- ***Warrant 5: school crossing,*** met with a minimum of 20 students crossing in the highest crossing hour, and less than one acceptable gap in the traffic stream per minute during the highest crossing hour. Engineering judgment and attention to other remedies (such as crossing guards, improved signage, and crossing islands) are strongly recommended.
- ***Warrant 6: coordinated traffic signal system,*** where existing traffic signal spacing does not provide the necessary degree of platooning (grouping) of traffic, as needed to provide a progressive operation.
- ***Warrant 7: crash experience,*** met when crash data indicates a problem remediable by traffic signal installation.
- ***Warrant 8: roadway network,*** met when the street has importance as a principal roadway network or is designated as a major route on an official plan.

As part of the intersection design process, the detailed warrants, as presented in the *Manual on Uniform Traffic Control Devices*, should be followed. Even if warrants are met, a signal should be installed only if it is determined to be the most appropriate traffic control based on the context of the intersection, as signals do not add capacity to an intersection, they are intended to provide order. In many instances, traffic signal installation will require some widening.

6.5.1.4 Pedestrian Travel at Traffic Signals

Traffic signal design should encompass the following principles for accommodating pedestrians:

- In general, the WALK indication should be concurrent with the traffic moving on the parallel approach.
- Timing of pedestrian intervals should be in accordance with MUTCD and ADA requirements.
- Pedestrians should be given the longest possible walk time, while maintaining balance between motor vehicle flow and pedestrian delay. In most cases, the WALK interval should include all of the time in the vehicle green phase, except for the required clearance interval. Although not preferred, the minimum length for the WALK interval on a pedestrian signal indication is 7 seconds, long enough for a pedestrian to step off the curb and begin crossing. In some

limited circumstances, where pedestrian volume is small, walk intervals as short as 4 seconds may be used.

- Signals should be timed to accommodate the average walking speeds of the type of pedestrian that predominantly uses the intersection. (The length of the clearance interval is calculated based on crossing the entire street from curb ramp to curb ramp with an assumed crossing speed of 3.5 feet per second). In areas where a significant portion of expected pedestrians are older or have disabilities, the assumed crossing speed should be reduced to 3.0 feet per second.
- Signal cycles should be as short as possible. Short signal cycles reduce delay, and therefore improve level of service for pedestrians, bicyclists and motor vehicles alike.
- Simple two-phase signals minimize pedestrian waiting time and are therefore preferable for pedestrian service. In some cases, simple two-phase signals also provide the best service for motor vehicle traffic.
- Leading pedestrian intervals (LPI) give pedestrians an advance WALK signal before the motorists get a concurrent green signal, giving the pedestrian several seconds to start in the crosswalk. This makes pedestrians more visible to motor vehicles and allows pedestrians to initiate their crossing without conflict with other traffic.
- Good progression for motor vehicles through a series of signals can be obtained over a wide range of vehicle speeds. In areas with high volumes of pedestrians, a low but well-coordinated vehicle progression speed (20-30 mph) can be used with little or no negative impact on vehicular flow.
- Pedestrian phases incorporated into each signal cycle, rather than on-demand through a call button, may be preferable for some conditions.
- Call button use should be limited to only those locations with traffic-actuated signals (i.e., where the signal does not cycle in the absence of minor street traffic).
- Where call buttons are used, a notification sign should be provided.
- Pedestrian call button actuation should provide a timely response, particularly at isolated signals (i.e., not in a progression sequence),

at mid-block crossings, and during low-traffic periods (night, for example).

- At four-way intersections, curb extensions could be provided to decrease the pedestrian crossing length.
- Pedestrian call buttons and the signals they activate should be maintained in good repair. This requires reliable and predictable button operation, functional signal displays, and the correct orientation of pedestrian signal heads.

Two types of supplemental indications can be used with pedestrian signals. An audible indicator, timed to coincide with the WALK phase, helps vision-impaired pedestrians and may be considered at locations regularly visited by such pedestrians.

The digital "countdown" indication displays the remaining seconds of safe crossing time (i.e., flashing "DON'T WALK" phases or hand/person displays). The countdown is helpful to pedestrians by providing the exact amount of crossing time remaining, thereby allowing them to make their own informed judgment on initiating a crossing, rather than simply following the WALK/DON'T WALK phases. Countdown signals may be considered for crossing approaches with short green time and at locations with high rates of signal-related crashes. Guidelines for the display and timing of countdown indicators are provided in the *Manual on Uniform Traffic Control Devices*. When used, the flashing DON"T WALK counter should end four seconds prior to the onset of the conflicting vehicle movement. However, these four seconds can be included in the clearance interval.

Locating Pedestrian Call Buttons

Pedestrian signal call buttons are used to initiate a pedestrian crossing phase at traffic signals. Where needed, pedestrian call buttons should be located to meet the following criteria:

- The closest call button to a crosswalk should call the pedestrian signal for that crosswalk.
- An arrow indicator should show which crosswalk the button will affect.

- The call button should align with the crosswalk and be visible to a pedestrian facing the crosswalk, unless space constraints dictate another button placement.
- Pedestrian actuated call buttons should be placed in locations that are easy to reach, 30 inches above the sidewalk, facing the sidewalk, clearly in-line with the direction of travel and with at least a 30” by 48” clear, level landing centered on the call button.

Accessible Pedestrian Signal Systems

At signalized intersections, people with vision impairments typically rely on the noise of traffic alongside them as a cue to begin crossing. The effectiveness of this technique is compromised by various factors, including increasingly quiet cars, permitted right turns on red, pedestrian actuated signals and wide streets. Further, low traffic volumes may make it difficult to discern signal phase changes. Technologies are available that enable audible and vibrating signals to be incorporated into pedestrian walk signal systems. The *Manual on Uniform Traffic Control Devices* offers guidelines on the use of accessible pedestrian signals. The Federal Access Board’s draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-Way* requires the use of audible signals with all pedestrian signals.

6.6 Intersection Capacity and Quality of Service

The “capacity” of an intersection for any of its users (motor vehicles, pedestrians, bicyclists, transit vehicles) is the maximum rate of flow of that user type that can be accommodated through the intersection. Typically, capacity is defined for a particular user group without other user groups present. Thus, for example, motor vehicular capacity is stated in terms of vehicles per hour, under the assumption that no other flows (pedestrians, bicycles) are detracting from such capacity.

Multimodal capacity is the aggregate capacity of the intersection for all users of the intersection. In some cases, the maximum multimodal capacity may be obtained while some individual user flows are at less than their individual optimum capacity.

“Level of service” is defined by the *Highway Capacity Manual*, for each type of intersection user. For each user, level of service is correlated to the amount of control delay encountered by the user at the intersection. Control delay, a result of traffic control devices needed to allocate the potentially conflicting flows at the intersection, reflects the difference between travel time through the intersection at free flow versus travel time under the encountered conditions of traffic control. For drivers, control delay consists of time "lost" (from free-flow time) due to deceleration, waiting at signals, STOP or YIELD signs, waiting and advancing through a queue of traffic, and accelerating back to free-flow speed. For pedestrians and bicyclists, deceleration and acceleration times are insignificant, and control delay is largely the time spent waiting at signals, STOP, or YIELD signs.

Levels of service are somewhat correlated to capacity in that levels of service decline as capacity is approached.

6.6.1 Capacity

"Capacity" (the maximum possible flow) differs importantly from "service volumes" (flows associated with the quality of flow, typically stated as "Level of Service" or "LOS"). These two terms are defined, for pedestrian, bicycle, and motor vehicle flow, in the following sections.

6.6.1.1 Pedestrian Flow Capacity

A pedestrian walkway with uninterrupted flow can carry a maximum volume of approximately 1,380 pedestrians per hour for each foot of walkway width. An 8-foot crosswalk, therefore, would have a capacity of 5,500 pedestrians per hour, assuming they have the use of half (4 feet) of the crosswalk. Under the same assumptions, a 12-foot crosswalk would carry a maximum volume, in half its width, of 8,300 hourly pedestrians.

At signalized intersections, each approach will accommodate pedestrian crossings for 10 to 20 percent of the time, reflecting the intervals that pedestrians can begin to cross with assurance of completing their crossing while traffic is stopped for their approach. An 8-foot crosswalk at a typical signalized intersection, therefore, can carry 550 to 1,100 pedestrians per hour.

At unsignalized locations, the time available for pedestrian flow is dictated by motor vehicle volume and length of the crossing. These two factors, which govern the number of "gaps" in the motor vehicle stream available for safe pedestrian crossing, must be measured on-site to establish the pedestrian flow capacity of an unsignalized intersection. The signal warrants in the MUTCD offer guidance on combinations of motor vehicle and pedestrian volumes that may justify a signal, and therefore reflect the pedestrian capacity of unsignalized intersections.

6.6.1.2 Bicycle Flow Capacity

A bicycle lane (4-6 feet in width) can, with uninterrupted flow, carry a volume of around 2,000 bicycles per hour in one direction. At signalized intersections, bicycle lanes receive the same green signal time as motor vehicles, typically 20-35 percent of the total time. The hourly capacity of a bicycle lane, at a signalized intersection, is therefore 400 to 700 bicycles per hour.

At signalized intersections without bicycle lanes, bicycles are part of the approaching vehicular traffic stream. The combined vehicular capacity (motor vehicles as well as bicycles) is established as defined in Section 6.6.1.3.

At unsignalized intersections with bicycle lanes on the major street, the bicycle flow capacity is the uninterrupted flow volume of 2,000 bicycles per hour. For the STOP-controlled (minor street) approach, the flow capacity for bicycles, whether in bicycle lanes or not, is governed by the speed, motor vehicle volume, and number of lanes of major street traffic. These factors require measurement on-site to establish the bicycle flow capacity of STOP controlled approaches.

6.6.1.3 Motor Vehicle Capacity

At unsignalized intersections, motorized vehicle capacity is governed by the ability of motor vehicles (on the minor street) under STOP control or YIELD control to enter or cross the stream of moving motor vehicles on the major street. This capacity is reached as the number of motor vehicles on both major street approaches, plus the number on the busiest minor street approach totals 1,200 motor vehicles in a single peak hour, or totals 900 motor vehicles hourly over a continuous 4-hour period. At these points, entering or crossing the major street from the STOP controlled or YIELD controlled minor street becomes difficult or impossible. Further increases in intersection capacity at STOP controlled or YIELD controlled intersections can be gained by replacing stop or yield control with signal control or a roundabout. Traffic signal warrants 1, 2, and 3 discussed previously provide detailed guidance on specific combinations of major and minor street volumes associated with the transition from STOP control or YIELD control to traffic signal control.

At signalized intersections, motor vehicle capacity is governed by the number of lanes approaching the intersection, the number of receiving lanes, and the amount of green signal time given to the approach. The total green time available decreases as more signal phases and therefore more red and yellow "lost time" are included in the signal sequences.

A simple but reliable measure of a signalized intersection's capacity is its "critical lane volume" capacity (CLV capacity), defined as the maximum sum of conflicting movements that can be moved through the intersection at a given level of service as shown in Exhibit 6-6.

Signalized intersection capacity is neared as the CLV reaches 1,500 hourly motor vehicles for intersections with two signal phases (the minimum possible) or 1,375 to 1,425 for intersections with more than two signal phases.

This simple CLV measure can be used for initial assessment of an intersection's capacity, and also as a reasonableness check on procedures in the *Highway Capacity Manual.* The relationship between CLV capacity and level of service (described in more detail in Section 6.6.2) is summarized in Exhibit 6-7.

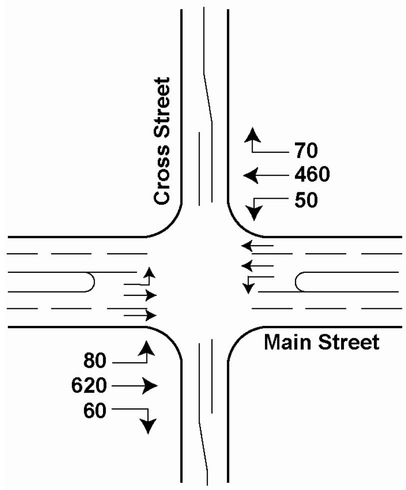
At roundabouts, motor vehicle capacity is governed by the ability of entering traffic to enter the stream of motor vehicles in the circulating roadway. This capacity is neared as the vehicular volume in the circulating roadway (single lane) approaches 1,800 motor vehicles hourly. At this point, entering the stream of circulating motor vehicles within the roundabout becomes difficult or impossible. At this threshold, additional lanes on one or more approaches and a second circulating lane should be considered.

Exhibit 6-6
Computing Critical Lane Volume

Critical lane volume (CLV) is the sum of main street CLV plus the cross street CLV.

The main street CLV is the greater of either: (A) eastbound through and right per lane + westbound left OR (B) westbound through and right per lane + eastbound left.

Similarly, the cross street CLV is the greater of either: (A) northbound through and right per lane + southbound left OR (B) southbound through and right per lane + northbound left.



Example:

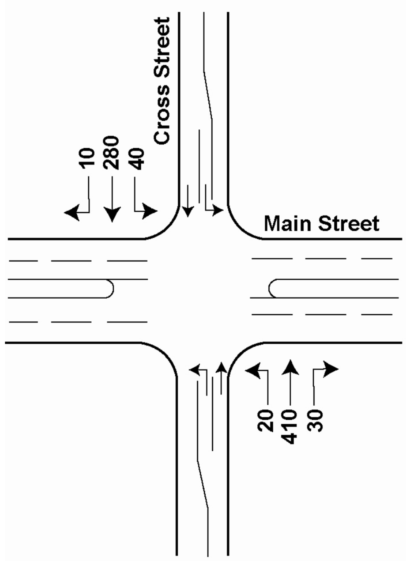
The main street CLV is the larger of either sum:

A. Eastbound through per lane and right turn + opposing left turns: (620 + 60) ÷ 2 + 50 = 390

OR

B. Westbound through per lane + opposing left turns: (460 + 70) ÷ 2 + 80 = 345

Main street CLV is therefore 390.



The cross street CLV is the larger of either sum:

A. Northbound through per lane and right turn + opposing left turn: (410 + 30) + 40 = 480

OR

B. Southbound through per lane + opposing left turn: (280 + 10) + 20 = 310

Cross street CLV is therefore 480.

Total intersection CLV = main street CLV + cross street CLV = 390 + 480 = 870

Notes:

- Critical lane volume (CLV) is the sum of main street CLV plus the cross street CLV.
- The main street CLV is the greater of either: (A) eastbound through and right per lane + westbound left, or (B) westbound through and right per lane + eastbound left.
- Similarly, the cross street CLV is the greater of either: (A) northbound through and right per lane + southbound left, or (B) southbound through and right per lane + northbound left.
- Total intersection CLV = main street CLV + cross street CLV = 390 + 480 = 870.

Source: Transportation Research Board, Circular Number 212, TRB 1980.

Exhibit 6-7
Traffic Flow Related to Critical Lane Volumes[1]

Flow Condition	Corresponding *Highway Capacity Manual* Level of Service	Corresponding Critical Lane Volume (CLV) Vehicles Per Hour — Signal Phases: 2 Phase	3 Phase	4 Phase
Free Flowing (no loaded cycles)	A, B, C	Less than 1200	Less than 1140	Less than 1100
Prevailing Level of Peak-Hour Congestion in Towns and Urban Areas	D	1200 – 1350	1140-1275	1100-1225
Approaching Capacity	E, F	1350 – 1500	1275 - 1425	1225 – 1375

Source: CLV/LOS relationship from Table 6, Transportation Research Circular Number 212, Transportation Research Board, 1980.
1 Based on a peak hour factor of 0.9, limited heavy vehicles, limited turning volumes, and somewhat flat grades.

6.6.1.4 Multimodal Capacity

Under some combinations of users and intersection configuration, achieving a desired flow for one user group diminishes the capacity for another group. Typical situations include:

- Signals with numerous phases (5 to 6 or more) where the "walk" phase is constrained by the green time needed for vehicles on other approaches permitted during the "walk" phase.
- Where buses and other transit vehicles stop for passenger loading/unloading in a lane of traffic approaching or departing an intersection.
- Where exceptionally large volumes of pedestrians crossing an approach require a "walk" phase time greater than the green signal time needed for motor vehicles permitted to move during the same phase.

In situations like these, intersection design should flow from a carefully considered balancing of the needs of the various user groups. However, when determining this balance, the designer also needs to consider that excessive motor vehicle delays can lead to undesirable cut-through traffic patterns on streets not intended for high through volumes. Alternatively, by providing more efficient multimodal opportunities, the motor vehicle demand may be reduced through user modal choice.

6.6.2 Level of Service (LOS)

Level-of-service is one measure of user satisfaction with an intersection. For all users, level-of-service is linked to average delay.

6.6.2.1 Pedestrian Level of Service

Pedestrian level of service is defined by the delay experienced by the pedestrian at the intersection. Exhibit 6-8 summarizes pedestrian level of service for signalized and unsignalized intersections, and roundabouts. The Exhibit also summarizes, for the various levels of service, the propensity for pedestrians to engage in unsafe crossing behavior by accepting dangerously small gaps in traffic for crossing, or ignoring traffic signal indications.

Exhibit 6-8
Pedestrian Level of Service (LOS) Criteria at Intersections

Level of Service	Average Delay to Pedestrian (seconds)			Likelihood of Risk Taking Behavior
	Unsignalized Intersections	Signalized Intersections	Roundabout	
A	Less than 5.0	Less than 10.0	Less than 5.0	Low
B	5.1 – 10.0	10.1 – 20.0	5.1 – 10.0	
C	10.1 – 20.0	20.1 – 30.0	10.0 – 20.0	Moderate
D	20.1 – 30.0	30.1 – 40.0	20.1 – 30.0	
E	30.1 – 45.0	40.1 – 60.0	30.1 – 45.0	High
F	Greater than 45.0	Greater than 60.0	Greater than 45.0	

Source: Highway Capacity Manual, 2000

At unsignalized intersections, the delay in crossing the major street (i.e., approaches not controlled by STOP control) is the time needed for pedestrians to receive a gap in traffic adequate to cross safely. Gaps are, in turn, related to the volume of traffic and the likelihood of driver’s yielding the right of way to a pedestrian in the crosswalk. Pedestrians crossing STOP controlled or YIELD controlled approaches do not have to wait for a gap in traffic, but wait for the first vehicle in line to yield right of way. Pedestrian crossings across STOP controlled or YIELD controlled approaches are likely to have a significantly better level of service than crossings at the uncontrolled approaches.

At signalized intersections, the delay to pedestrians is that time spent waiting for the next signal phase permitting safe crossing. Where pedestrian indications are present, this signal phase begins with the WALK display. Where pedestrian indications are not present, the signal phase permitting crossing begins with the red signal indication on the intersection approach to be crossed.

The average delay to pedestrians (i.e., the average time spent waiting for the next signal phase permitting safe crossing) is less than one-half the total signal cycle length. Typically, these cycle lengths are 60 to 90 seconds, resulting in pedestrian delay of 30 to 45 seconds. Longer signal cycles, such as the 120-180 second cycles on major arterials, result in corresponding higher delays (60-90 seconds respectively) for pedestrians. Typically, short signal cycle lengths, therefore, provide better pedestrian level of service than long cycle lengths.

At roundabouts, pedestrians may walk further than at a signalized intersection due to the diameter of the circulating roadway. However, pedestrians cross only a single lane of traffic at a time, taking refuge in the splitter island. Actual delay is likely to be comparable or less than at a normally situated crosswalk.

6.6.2.2 Bicycle Level of Service

Where there is no bicycle lane or shoulder being used by bicyclists, bicycles are considered to be part of the stream of vehicular traffic and they experience the same control delay that would accrue to a motor vehicle in their position in traffic. For streets without bicycle lanes or shoulders, therefore, the bicycle level of service is computed the same as for motor vehicles as described below.

Bicyclists in their lane (or shoulder) “bypass” stopped motor vehicles, and therefore seldom experience delay due to queuing. Delay due to queuing of bicycles is a factor only with extraordinary volumes. Therefore, for bicyclists in bicycle lanes or shoulders at signalized intersections, the average delay can be estimated as one-half of the signal red and yellow time facing that approach. This reflects bicycle arrivals at random, with average delay therefore one-half of the maximum. Level of service for bicycles at signalized intersections is summarized in Exhibit 6-9.

Exhibit 6-9
Bicycle Level of Service (LOS) Criteria at Signalized Intersections

Level of Service	Average Delay to Bicyclist (seconds)
A	Less than 10.0
B	10.1 – 20.0
C	20.1 – 30.0
D	30.1 – 40.0
E	40.1 – 60.0
F	Greater than 60

Source: Highway Capacity Manual, 2000
Delay can be estimated as 0.5 (red and yellow signal time) on bicyclist's approach.

Bicyclists can experience substantial delay at intersections when they are not detected by the traffic signal system. This failure to be detected may result in longer waits for a green signal, inability to obtain a green arrow for a left turn, or a decision to proceed on red.

At unsignalized locations, bicycles on the major street are not likely to be delayed because they have priority over minor street vehicles. Bicyclists crossing or entering the major street from a STOP controlled minor street are delayed by the amount of time required to find an acceptable gap. Field measurement of this time, during peak as well as off-peak periods, is the preferred method of establishing this delay.

At roundabouts, bicycles generally experience the same delays as motor vehicles as they "take the lane" in approaching the circulating roadway.

6.6.2.3 Motor Vehicle Level of Service (LOS)

Motor vehicle level of service (LOS) at an intersection is defined by the *Highway Capacity Manual* in terms of delay experienced by a motor vehicle traveling through the intersection during the busiest (peak) 15 minutes of traffic of the day. Typically, delay is averaged over all approaches with traffic controls (STOP, YIELD, or signal). It can also be computed separately for each approach or each lane group (adjacent lanes with at least one movement in common; for example one lane with through movement adjacent to a lane with through/right-turn movement). Exhibit 6-10 provides motor vehicular level-of-service criteria at intersections.

Exhibit 6-10
Motor Vehicular Level of Service (LOS) Criteria at Intersections

Level of Service (LOS)	Delay, Seconds per Vehicle[1]		
	Unsignalized Intersections	Signalized Intersections	Roundabout
LOS A	Less than 10.0	Less than 10.0	Less than 10.0
LOS B	10.1 to 15.0	10.1 to 20.0	10.1 to 15.0
LOS C	15.1 to 25.0	20.1 to 35.0	15.1 to 25.0
LOS D	25.1 to 35.0	35.1 to 55.0	25.1 to 35.0
LOS E	35.1 to 50.0	55.1 to 80.0	35.1 to 50.0
LOS F	Greater than 50.0	Greater than 80.0	Greater than 50.0

Source: Highway Capacity Manual, (HCM 2000) Transportation Research Board, 2000
1 Delay is "control delay" as defined in HCM 2000, and includes time for slowing, waiting in queues at the intersections, and accelerating back to free-flow speed.

Improving Vehicular Level of Service at Intersections

When attempting to improve the motor vehicular level-of-service at intersections, the designer should work to ensure that the measures to improve motor vehicular level of service do not have a disproportionately negative impact on other intersection users. There are several techniques commonly used to achieve this objective as described in the following paragraphs.

Changing the type of traffic control (for example, transitioning from STOP control to signalization or to a roundabout) may add motor vehicular capacity at intersections. At intersections already signalized, more capacity may be gained from replacing fixed-time signal control with motor vehicle, bicycle and pedestrian-actuated control.

Auxiliary left-turn and right-turn lanes (see Section 6.4.2) increase intersection capacity by removing slowing or stopped vehicles from lanes otherwise usable by through traffic. Auxiliary through lanes (see Section 6.4.2) can be appropriate at isolated signalized intersections and increase intersection capacity. However, the length of the auxiliary lanes for the receiving leg will determine the ability of this extra through traffic to merge. If auxiliary lanes are too short, they may congest the intersection and block the minor street traffic, and fail to reduce delay.

The designer should also note that adding auxiliary lanes increases the crossing distance for pedestrians. The designer should ensure that the level of service increases provided for motor vehicles do not result in large degradations in LOS for other users. Where widening to provide auxiliary lanes is planned, the designer should consider crossing islands and other features to ensure the ability for pedestrians to cross.

At roundabouts, capacity can be increased by an additional approach lane and a corresponding section of additional circulating lane.

Adding parallel links of street network may reduce traffic volumes at an intersection, thereby eliminating or postponing the need to increase its capacity.

6.6.2.4 Multimodal Level of Service

As described throughout this section, the designer should strive to achieve the highest level of service for all intersection users, given the context and demands encountered. The intersection level of service commonly found in various area types is shown in Exhibit 6-11. The designer needs to understand the potential impact that intersection geometrics and traffic control will have on level of service for all modes. Generally, the designer should try to improve or maintain existing levels of service. In most instances, the designer should not propose a design that provides a level-of-service improvement for one user group at the expense of another.

Exhibit 6-11
Common Intersection Level-of-Service Ranges by User Group and Area Type

	Level-of-Service Ranges		
	Pedestrian	**Bicycle**	**Motor Vehicle**
Rural Natural	A-B	A-C	A-C
Rural Village	A-C	A-D	A-E(1)
Rural Developed	A-C	A-C	A-C
Suburban High Density	B-E	C-E	C-E
Suburban Village/Town Center	A-D	C-E	C-F(1)
Suburban Low Density	A-C	A-C	A-D
Urban Park	A-C	A-D	B-E
Urban Residential	A-C	B-D	C-E
Urban Central Business District	A-D	B-E	D-F(1)

1 In these instances, queuing at intersections becomes critical in that there should not be impacts that extend to adjacent intersections.

Source: MassHighway

6.7 Geometric Design Elements

The following sections describe many of the detailed design elements associated with intersections including intersection alignment, pavement corner radii, auxiliary lanes, channelization islands, roundabouts, median openings, pedestrian curb cut ramps and crosswalks, bicycle lane treatments, and bus stops.

6.7.1 Intersection Alignment

Intersection alignment guidelines control the centerlines and grades of both the major and minor streets, in turn establishing the location of all other intersection elements (for example, edge of pavement, pavement elevation, and curb elevation).

6.7.1.1 Horizontal Alignment

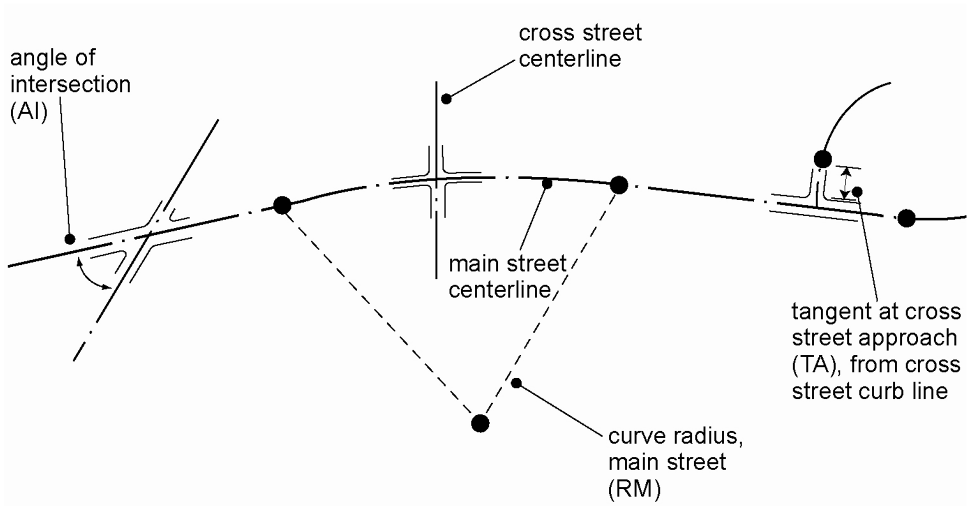
Ideally, streets should intersect as close to right angles as practical. Skewed intersections can reduce visibility of approaching motor vehicles and bicycles, require higher degrees of traffic control, require more pavement to facilitate turning vehicles, and require greater crossing distances for pedestrians.

Guidelines for the maximum curvature at intersections are given in Exhibit 6-12. Curvature through an intersection affects the sight distance for approaching motorists, and may require additional traffic control devices (warning signs, stop signs, signals, pavement markings or roundabouts). On higher-speed roads, superelevation on curves may incline the cross slope of the intersection in a manner uncomfortable to motorists, or in conflict with intersection vertical alignment guidelines described below.

The minimum tangent at cross-street approach (TA) shown in Exhibit 6-12 helps to assure necessary sight distance at the intersection, and to simplify the task of driving for motorists approaching the intersection.

Often, in steep terrain, a permissible grade cannot be achieved with the horizontal alignment guidelines. Typically, this design challenge is resolved by adhering to vertical alignment criteria, while incorporating the necessary flexibility in the horizontal guidelines.

Exhibit 6-12
Horizontal Alignment Guidelines at Intersections



Design Speed (MPH)	Minimum Angle of Intersection (AI, degrees)			Minimum Curve Radius, Main Street (RM, feet)	Minimum Tangent Cross Street Approach (TA, feet)
	Arterial Major Street	Collector Major Street	Local Major Street		
15	60	60	60	45	30
20	60	60	60	85	30
25	60	60	60	155	30
30	60	60	60	250	30
35	60	60	60	365	45
40	60	60	60	500	45
45	65	60	60	660	45
50	65	65	60	835	60
55	65	65	65	1065	60
60	70	65	65	1340	60

Source: MassHighway

6.7.1.2 Vertical Alignment

The major street and minor street profile influence the vertical alignment of an intersection.

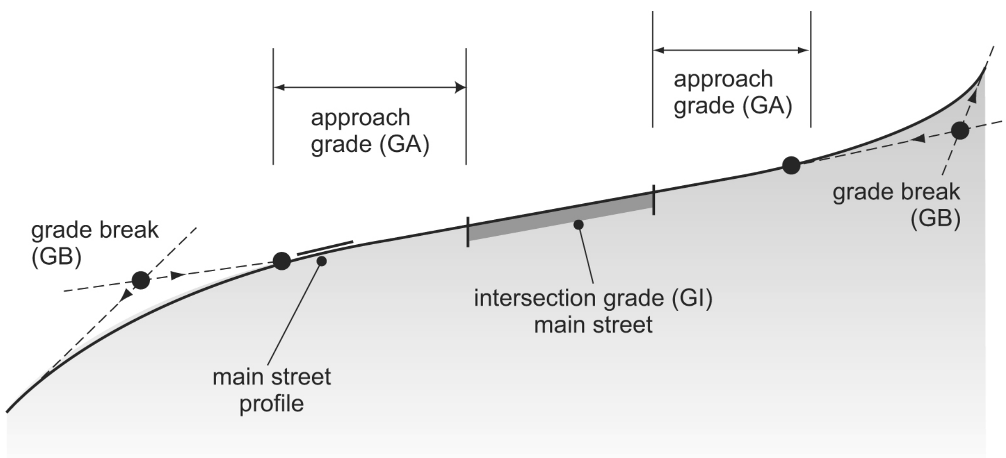
Major Street Profile

The intersection approach grade in the uphill direction, as shown in Exhibit 6-13, affects the acceleration of motor vehicles and bicycles from a stopped condition, and therefore can have an impact on vehicular delay at the intersection. The intersection approach grade in the downhill direction affects the stopping distance of approaching motor vehicles and bicycles.

The length of vertical curves between the non-intersection grade and the intersection approach grades is governed by the guidelines for vertical alignment discussed in Chapter 4.

The intersection grade is the slope of the pavement within the intersection itself. Excessive intersection grade can cause tall vehicles (trucks, buses) to tip while turning. Intersection grade can also have an impact on accessibility for pedestrians with disabilities, by creating a grade on crosswalks.

Exhibit 6-13
Vertical Alignment Guidelines



Design Speed (mph)	Maximum Intersection Grade (GI, %)	Maximum Grade Break (GB, %)	Minimum Length of Approach Grade (GA, feet)
15	5	6	20
20	5	5	40
25	5	4	40
30	5	3	60
35	5	2	60
40	4	2	70
45	4	2	70
50	3	2	70
55	3	1	70
60	3	1	70
65	2	0.5	70
70	2	0.5	70

Source: MassHighway

Minor Street Profile

The profile of the minor street, as shown in Exhibit 6-14, is subject to the same vertical alignment criteria as the major street; however, several inherent features of a minor street, particularly its lower level of usage, will most likely permit a lower design speed for the minor street compared to the major street.

Where the minor street is under STOP or YIELD control (Exhibit 6-14, Part A), the crown of the major street is typically carried through the intersection. Meeting this major street cross-section can result in minor street grades near the intersection that are steeper than that which would occur with the major street crown removed.

At intersections where the major street retains the crown through the intersection, the minor street crown is gradually reduced, typically starting at the beginning of the approach grade, and completed slightly outside the intersection.

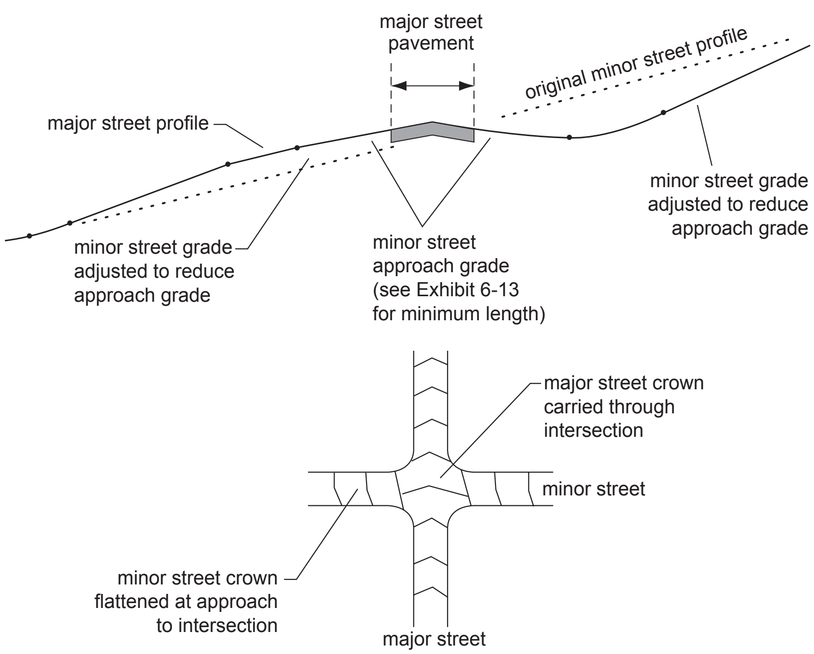
At intersections with signal control, it is customary to remove the crown from both the major street and the minor street. This removal of the crown is advisable for the comfort and safety of motor vehicle drivers and bicyclists proceeding, on either street, at the design speed through a green signal indication. At intersections with all-way STOP control, it may be desirable to remove the crown from both intersecting streets, to emphasize that all approaches are equal in terms of their traffic control.

Eliminating the crown on the major street can, under many circumstances, reduce the amount of modification that must be done to the minor street profile (Exhibit 6-14 Part B). The major street cross slope can be inclined in the same direction at the minor street profile, thereby permitting approach grades on the minor street to be accommodated with minimal alteration to the original minor street profile. Where both major street and minor street crowns are eliminated, their removal is accomplished gradually, typically over the length of the approach grade. Whether crowned or not, pavement grades within the intersection should not exceed the values given in Exhibit 6-13.

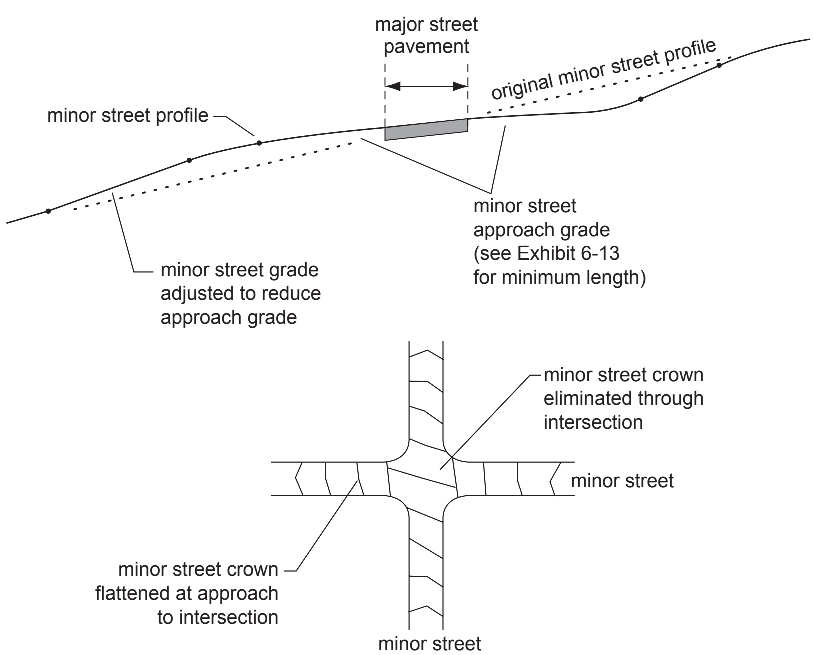
In addition to meeting the vertical profile guidelines as stated above, intersection approaches on both main and minor streets are subject to the intersection sight triangle requirements (see Chapter 3). Under some circumstances, these sight triangle requirements may dictate approach grades or length of approach grades differing from those indicated in the vertical alignment guidelines above.

Exhibit 6-14
Pavement Cross-slope at Intersections

A. Major Street Retains Crown (Stop or Yield control on cross street)



B. Major Street Crown Removed: Signal Control



Source: Transportation Association of Canada

6.7.2 Pavement Corner Radius

The pavement corner radius—the curve connecting the edges of pavement of the intersecting streets—is defined by either the curb or, where there is no curb, by the edge of pavement. The pavement corner radius is a key factor in the multimodal performance of the intersection. The pavement corner radius affects the pedestrian crossing distance, the speed and travel path of turning vehicles, and the appearance of the intersection.

Excessively large pavement corner radii result in significant drawbacks in the operation of the street since pedestrian crossing distance increases with pavement corner radius. Further, the speed of turning motor vehicles making right turns is higher at corners with larger pavement corner radii. The compounded impact of these two measures—longer exposure of pedestrians to higher-speed turning vehicles—yields a significant deterioration in safety and quality of service to both pedestrians and bicyclists.

The underlying design control in establishing pavement corner radii is the need to have the design vehicle turn within the permitted degrees of encroachment into adjacent or opposing lanes. Exhibit 6-15 illustrates degrees of encroachment often considered acceptable based on the intersecting roadway types. These degrees of encroachment vary significantly according to roadway type, and balance the operational impacts to turning vehicles against the safety of all other users of the street. Although the Exhibit provides a starting point for planning and design, the designer must confirm the acceptable degree of encroachment during the project development process. The designer should use also use vehicle turning templates presented earlier in this chapter and in AASHTO's *A Policy on the Geometric Design of Highways and Streets* to confirm appropriate pavement corner designs.

At the great majority of all intersections, whether curbed or otherwise, the pavement corner design is dictated by the right-turn movement. Left turns are seldom a critical factor in corner design, except at intersections of one-way streets, in which case their corner design is similar to that for right turns at intersections of two-way streets. The method for pavement corner design can vary as illustrated in Exhibit 6-16 and described below.

- **Simple curb radius**: At the vast majority of settings, a simple radius (curb or pavement edge) is the preferred design for the pavement corner. The simple radius controls motor vehicle speeds, usually minimizes crosswalk distance, generally matches the existing nearby intersection designs and is easily designed and constructed.
- **Compound curves or taper/curve combinations**: Where encroachment by larger motor vehicles must be avoided, where turning speeds higher than minimum are desirable, or where angle of turn is greater than 90 degrees, compound curves can define a curb/pavement edge closely fitted to the outer (rear-wheel) vehicle track. Combinations of tapers with a single curve are a simple, and generally acceptable, approximation to compound curves.
- **Turning roadways**: A separate right-turn roadway, usually delineated by channelization islands and auxiliary lanes, may be appropriate where right-turn volumes are large, where encroachment by any motor vehicle type is unacceptable, where higher speed turns are desired, or where angle of turn is well above 90 degrees.

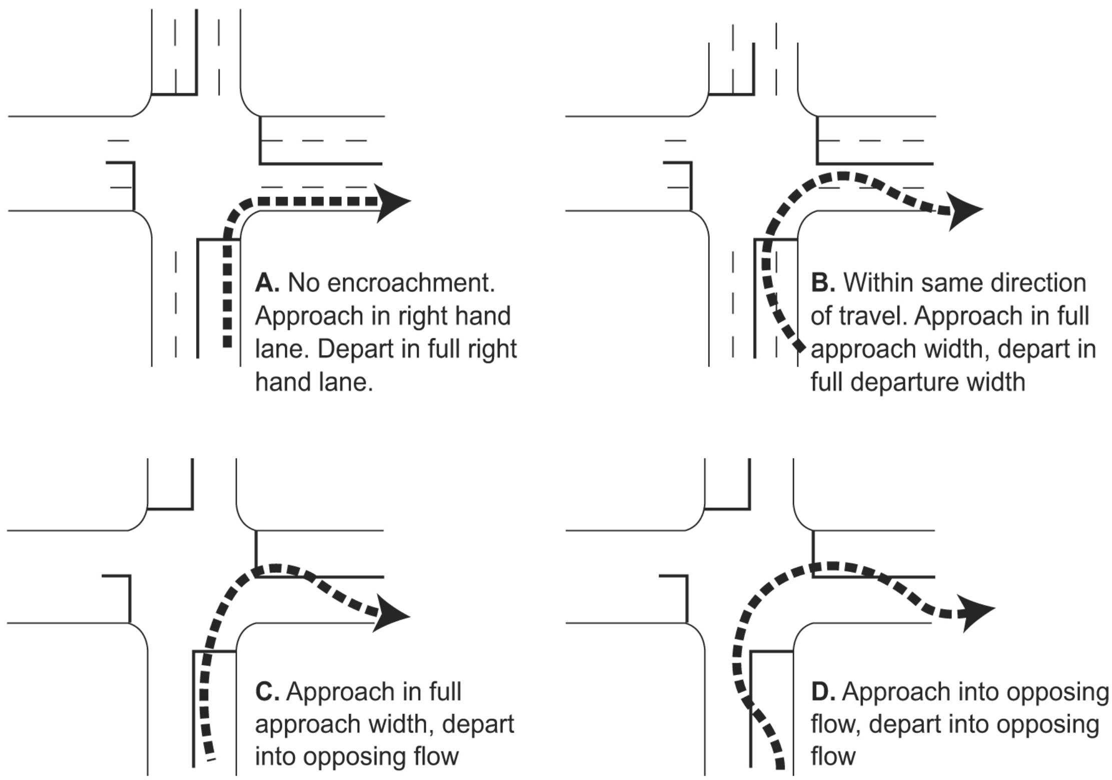
6.7.2.1 Simple Curb Radius

Pavement corner design at simple intersections is controlled by the following factors:

- The turning path of the design motor vehicle. Design motor vehicles appropriate for the various roadway types are summarized in Section 6.3.3 of this chapter.
- The extent (if any) of encroachment, into adjacent or opposing traffic lanes, permitted by the design motor vehicle determined from Exhibit 6-15.
- The "effective" pavement width on approach and departure legs is shown in Exhibit 6-17. This is the pavement width usable, by the design motor vehicle, under the permitted degree of encroachment. At a minimum, effective pavement width is always the right-hand lane and therefore usually at least 11-12 feet, on both the approach and departure legs. Where on-street parking is present, the parking lane (typically 7-8 feet) is added to the effective width on those legs (approach, departure or both) with on-street parking. Typically, legs with on-street parking have an effective pavement width of around 20 feet. The effective width may include encroachment into adjacent or opposite lanes of

traffic, where permitted. A maximum of 10 feet of effective width (i.e., a single lane of traffic) may be assumed for such encroachment.

Exhibit 6-15
Typical Encroachment by Design Vehicle

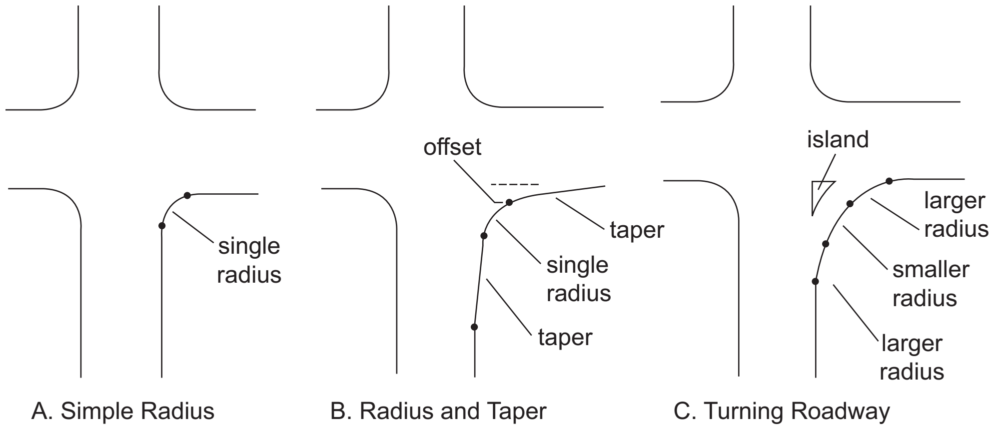


To (Departure Street)

From (Approach Street)	For Tractor/Trailer (WB 50)			For Single-Unit Truck (SU)			For Passenger Car (P)		
	Arterial	**Collector**	**Local**	**Arterial**	**Collector**	**Local**	**Arterial**	**Collector**	**Local**
Arterial (Art)	A	B	C	A	B	C	A	A	A
Collector (Col)	B	B	C	B	B	C	A	A	A
Local (Loc)	B	D	D	C	C	D	A	B	B

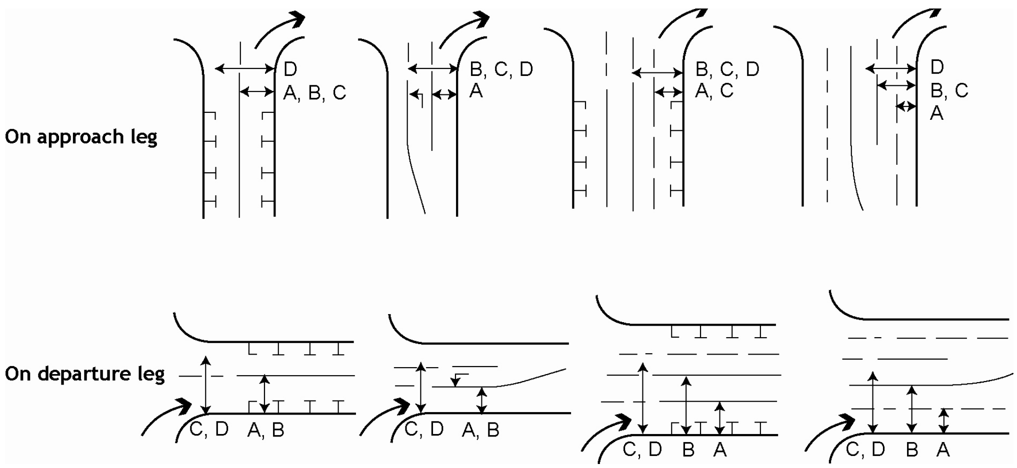
A, B, C, D defined in above diagrams.
Note: Cases C and D are generally not desirable at signal controlled intersections because traffic on stopped street has nowhere to go.
Source: Adapted from ITE Arterial Street Design Guidelines.

Exhibit 6-16
Methods for Pavement Corner Design



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

Exhibit 6-17
Effective Pavement Widths



Note: The letters A, B, C, and D refer to the typical encroachment conditions illustrated in Exhibit 6-15.
Source: MassHighway

Exhibit 6-18 summarizes the simple curb radius needed for various design motor vehicles, reflecting the extent of encroachment and effective pavement width. General guidelines can be concluded for right-angle (90 degree) intersections:

- A 15-foot simple curb radius is appropriate for almost all right-angle (90 degree) turns on local streets. This radius permits passenger cars to turn with no encroachment and accommodates the single unit (SU) truck with acceptable degrees of encroachment. The occasional tractor/trailer truck (WB-50) can also negotiate the 15-foot corner radius within its acceptable degree of encroachment.
- Where the major street is a collector street, a 20-30 foot radius is likely to be adequate. Where parking is present, yielding an effective width of 20 feet, the typical design motor vehicle for the intersection (the SU truck) can turn with less than a 20 foot corner radius, without encroachment. On single lane approaches and departures, with no on-street parking, the SU vehicle can be accommodated with a 25-foot radius and an 8-foot encroachment (i.e., a 20 foot effective width) on the departure. At locations where no encroachment can be tolerated, a radius of 40 feet will permit the SU truck to approach and depart within a single lane.
- For arterial streets where the WB-50 truck is the design vehicle, a 35-foot radius is adequate under most circumstances of approach and departure conditions. However, with a single approach and departure lane, and with no encroachment tolerated, a radius as high as 75 feet is required. In this situation, a turning roadway with channelization island may be a preferable solution.

At skewed intersections (turn angle greater than 90 degrees), the simple radius required for the SU and WB-50 vehicle is significantly larger than that needed for 90 degree intersections. Curve/taper combinations or turning roadways may be appropriate in these situations.

Exhibit 6-18
Simple Radius for Corner Design (Feet)

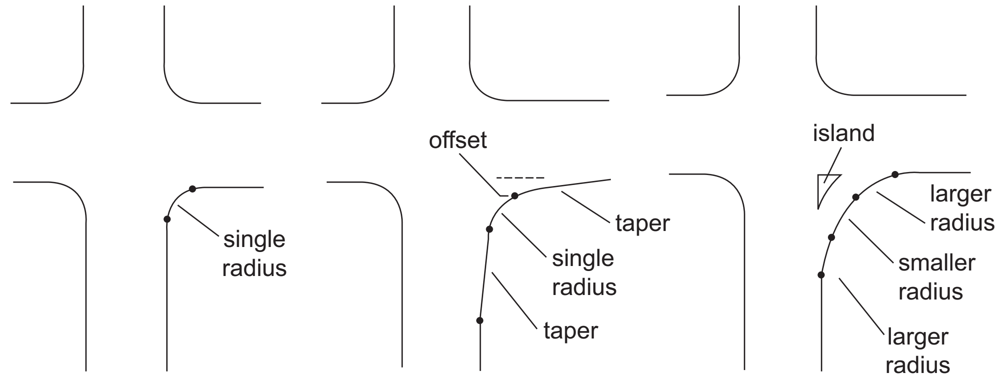
Turn Angle and Effective Width on Approach Leg (feet)	Effective Width on Departure Leg (Feet)							
	Passenger Car (P)		Single-unit Truck (SU)			Tractor-Trailer (WB-50)		
	12	20	12	20	24	12	20	24
90° Turn Angle								
12 Feet	10	5	40	25	10	75	35	30
20 Feet	5	5(a)	30	10	5	70	30	20
24 Feet	(b)	(b)	25	5	5(a)	70	25	15
120° Turn Angle								
12 Feet	25	10	60	35	25	105	65	50
20 Feet	10	5(a)	50	25	20	95	50	40
24 Feet	(b)	(b)	45	20	15	95	50	35
150° Turn Angle								
12 Feet	50	25	130	90	75	170	130	105
20 Feet	30	10	110	75	60	155	115	95
24 Feet	(b)	(b)	100	65	55	155	110	80

Source: P, SU and WB-50 templates from *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
(a) Minimum buildable. Vehicle path would clear a zero radius.
(b) Maximum of 20 feet (one lane plus parking) assumed for passenger car operation.

6.7.2.2 Curve/Taper Combinations

The combination of a simple radius flanked by tapers can often fit the pavement edge more closely to the design motor vehicle than a simple radius (with no tapers). This closer fit can be important for large design motor vehicles where effective pavement width is small (due either to narrow pavement or need to avoid any encroachment), or where turning speeds greater than minimum are desired. Exhibit 6-19 summarizes design elements for curve/taper combinations that permit various design motor vehicles to turn, without any encroachment, from a single approach lane into a single departure lane.

Exhibit 6-19
Curve and Taper Corner Design

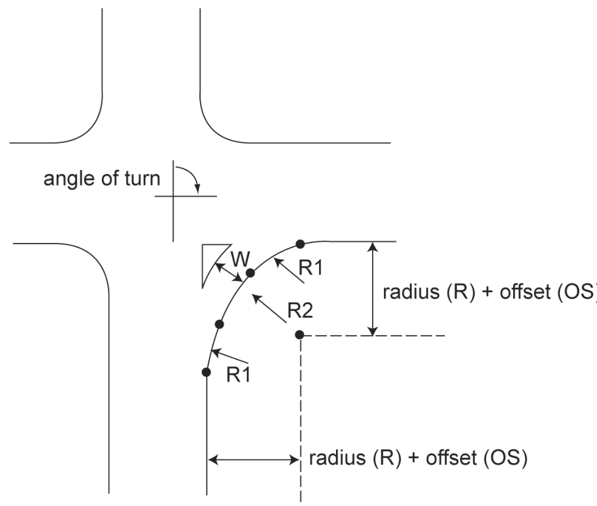


Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

Curve and Taper Corner Design Elements

Angle of Turn (Degrees)	Design Vehicle	Radius (R, feet)	Offset (OS feet)	Taper Length (T, feet)
75	P	25	2	20
	SU	45	2	20
	WB -50	65	3	45
90	P	20	2.5	25
	SU	40	2.0	20
	WB -50	60	4.0	60
105	P	20	2.5	-
	SU	35	3.0	-
	WB -50	55	4.0	60
120	P	20	2.0	-
	SU	30	3.0	-
	WB -50	45	4.0	60
150	P	18	2.0	20
	SU	30	4.0	32
	WB -50	35	7.0	42

Exhibit 6-20
Turning Roadways and Islands



Turning Roadway, Edge of Pavement			
Angle of Turn (Degrees)	**Design Vehicle**	**Radius (feet) R1-R2-R1**	**Offset (OS feet)**
75	P	100-75-100	2.0
	SU	120-45-120	2.0
	WB -50	150-50-150	6.5
90	P	100-20-100	2.5
	SU	120-40-120	2.0
	WB -50	180-60-180	6.5
105	P	100-20-100	2.5
	SU	100-35-100	3.0
	WB -50	180-45-180	8.0
120	P	100-20-100	2.0
	SU	100-30-100	3.0
	WB -50	180-40-180	8.5
150	P	75-20-75	2.0
	SU	100-30-100	4.0
	WB -50	160-35-160	7.0

Note: W (width) should be determined using the turning path of the design vehicle.

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.3 Auxiliary Lanes

The design elements of three auxiliary lanes types are described in the following sections: left-turn lanes, right-turn lanes, and through lanes. Deceleration and taper distances provided below should be accepted as a desirable goal and should be provided for where practical. However, in urban areas it is sometimes not practical to provide the full length of an auxiliary lane. In such cases, at least part of the deceleration must be accomplished before entering the auxiliary lane. Chapter 9 of AASHTO's *Geometric Design of Highways and Streets* provides more information for the designer.

6.7.3.1 Left-Turn Lane Design Elements

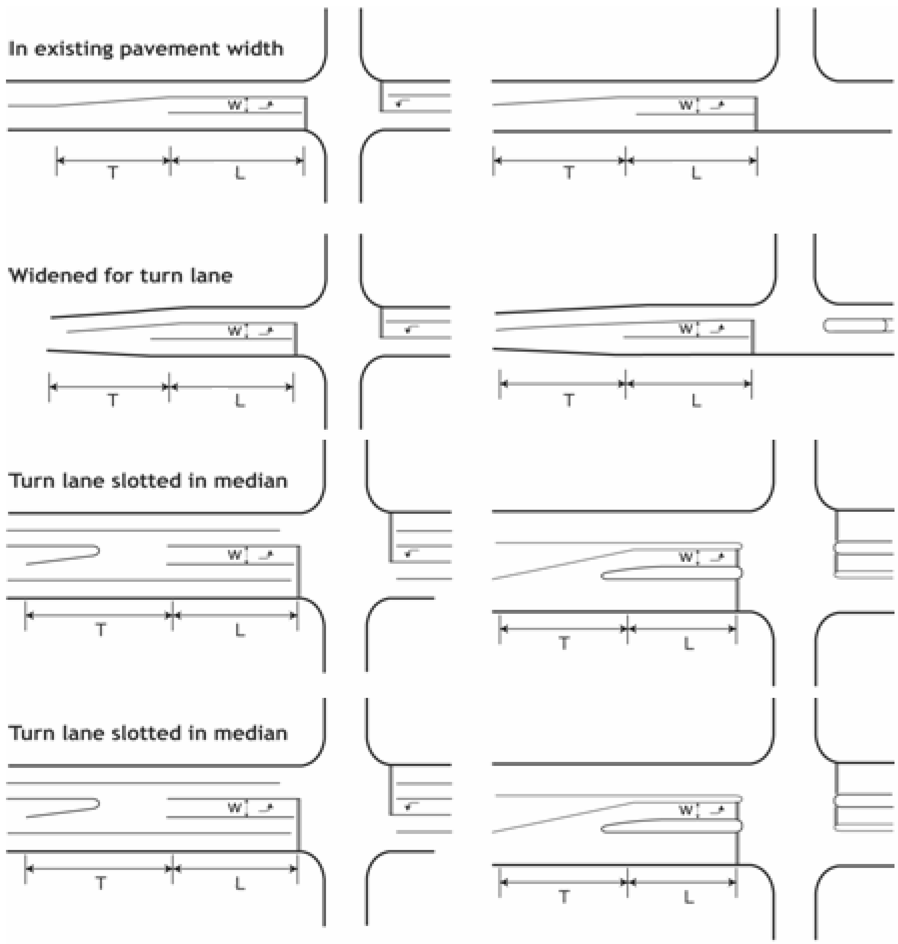
Left-turn lanes remove stopped or slow-moving left-turning motor vehicles from the stream of through traffic, eliminating the primary cause of rear-end crashes at intersections. The safety benefits of left-turn lanes increase with the design speed of the road, as they greatly reduce both the incidence and severity of rear-end collisions. Left-turn lanes also improve capacity by freeing the travel lanes for through traffic only.

The safety and capacity benefits of left-turn lanes apply to all vehicular traffic, motorized as well as non-motorized. However, left-turn lanes add to the pedestrian crossing distance and pedestrian crossing time. The additional street width needed for left-turn lanes may require land taking or removal of on-street parking.

The lengths of left-turn lanes, illustrated in Exhibit 6-21, depend on the volume of left-turning motor vehicles and the design speed. The length of taper required to form the left-turn lane varies with design speed. At signalized intersections, a conservative guideline for determining the storage length of a left-turn lane is 150 percent (1.5 times) of the length of the average number of left-turning vehicles arriving during a single signal cycle in the peak hour.

A more analytical guideline for the length of required storage lane is to obtain the expected length of the left-turn queue and associated probabilities from intersection analysis computations (computerized versions of *Highway Capacity Manual* methodology or derivative programs such as SYNCHRO). Typically, left-turn lanes are sized to accommodate the maximum length of queue for the 95th percentile traffic volumes, a queue length that is exceeded on only 5 percent of the peak-hour traffic signal cycles.

Exhibit 6-21
Left-Turn Lane Design Guidelines



Dimensions for Left-Turn Lane Elements (feet)

Design Speed (mph)	Lane Width (W, feet)	Deceleration Distance (feet)[1]	Storage Distance[2] (feet)	Length of Lane[2] (L, feet)	Taper Length (T, feet)[3]	Widened Taper Length (T, feet)
15-25	10	115	50	165	100	See Note 4
30-35	10	170	50	220	100	See Note 4
40	10-11	275	75	350	110	See Note 4
45	10-11	340	75	415	150	See Note 4
50	11-12	410	75	485	180	See Note 4
55	11-12	485	75	560	180	See Note 4
60	12	530	75	605	180	See Note 4

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

1 For deceleration grades of 3 percent or less.

2 Storage distance and therefore total lane length (L) are based on an unsignalized left-turn volume of 100 vehicles hourly. For larger volumes, compute storage need by formula or from intersection analysis queue calculation.

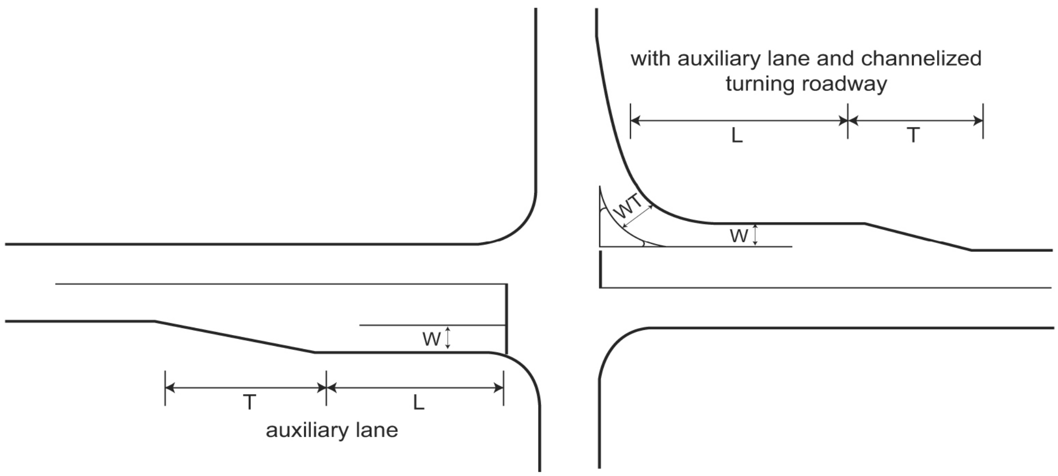
3 This taper length is not applicable for "widened for turn lane" cases, see note 4.

4 For "widened for turn lane" cases, use $T = WS^2/60$ for speeds less than 45 mph and T = WS for speeds 45 mph and greater.

6.7.3.2 Right-Turn Lane Design Elements

Right turn lanes are used to remove decelerating right-turning motor vehicles from the traffic stream, and also to provide an additional lane for the storage of right-turning motor vehicles. Where the right-turn volume is heavy, this removal of the turning motor vehicle from the traffic stream can also remove a primary cause of rear-end crashes at intersections. Design elements for right-turn lanes are summarized in Exhibit 6-22.

Exhibit 6-22
Right-Turn Lane Design Guidelines



Dimensions for Right-Turn Lane Elements (feet)						
Design Speed[1] (mph)	Lane Width (W. feet)	Turning Lane Width (WT, feet)	Deceleration Distance (feet)	Storage Distance[2] (feet)	Length of Lane[2] (L, feet)	Taper Length (T, feet)
15-25	10	14	115	50	165	100
30-35	10	14	170	50	220	100
40	10-11	15	275	60	335	110
45	10-11	15	340	60	400	150
50	11-12	15	410	60	470	180
55	11-12	16	485	60	545	180
60	12	16	530	60	590	180

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

1 Based on grades of less than three percent for speeds less than 60 mph. Based on grades of less than two percent for speeds greater than 60mph.

2 Storage distance and therefore total lane length (L) are based on an unsignalized right-turn volume of 100 vehicles hourly. For larger volumes, compute storage need by formula or from intersection analysis queue calculation.

Right-turn lanes provide a safety and capacity benefit for motorized traffic. However, in areas of high pedestrian or bicyclist activity, these benefits may be offset by the additional pavement width in the intersection, higher speeds of motor vehicular turning movements, and vehicle/bicyclist conflict created as motorists enter a right-turn lane across an on-street bicycle lane or across the path of bicycle traffic operating near the curb.

6.7.3.3 General Criteria for Right-Turn and Left-Turn Lanes

Criteria for considering installation of left-turn lanes are summarized in Exhibit 6-23. These criteria are based on a combination of left-turning motor vehicle volumes plus opposing through motor vehicle volumes at unsignalized locations. For example, if 330 vehicles per hour travel eastbound at 40 mph and five percent are turning left, an exclusive left-turn lane is warranted once the westbound volume exceeds 800 vehicles per hour.

Considerable flexibility should be exercised in considering left-turn lanes. Typically, they involve little impact to the setting, while generally yielding large benefits in safety and user convenience. Left-turn lanes may be desirable in many situations with volumes well below those stated. These include to destinations of special interest (shopping, major institutions, etc.), or for locations with marginal sight distance on the main road or a consistent occurrence of rear-end crashes.

Where there is a need for multiple, closely spaced left-turn lanes (due to driveways or small blocks), it may be advisable to designate a continuous center lane as a "two-way left turn lane" (TWLTL) as discussed in Chapters 5 and 15.

Criteria for the installation of right-turn auxiliary lanes are more judgmental than the numerical guidelines for their left-turn lane counterpart. Positive and negative indicators (i.e., conditions favoring or arguing against right-turn lanes) are summarized in Exhibit 6-24.

Exhibit 6-23
Criteria for Left Turn Lanes

A. Unsignalized Intersections, Two-Lane Roads and Streets:

Design Speed	Opposing Volume (motor vehicles per hour)	Advancing Motor Vehicle Volume (vehicles per hour) 5% Left Turns	10% Left Turns	20% Left Turns	30% Left Turns
30 mph or less	800	370	265	195	185
	600	460	345	250	225
	400	570	430	305	275
	200	720	530	390	335
40 mph	800	330	240	180	160
	600	410	305	225	200
	400	510	380	275	245
	200	640	470	350	305
50 mph	800	280	210	165	135
	600	350	260	195	170
	400	430	320	240	210
	200	550	400	300	270
60 mph	800	230	170	125	115
	600	290	210	160	140
	400	365	270	200	175
	200	450	330	250	215

B. Signalized Intersections:

Left-Turn Lane Configuration	Minimum Turn Volume
Single exclusive left-turn lane	100 motor vehicles per hour
Dual exclusive left-turn lane	300 motor vehicles per hour

Source: *Highway Capacity Manual*, 2000

Exhibit 6-24
Criteria for Right-Turn Lane Placement

Positive Criteria (Favoring Right-Turn Placement)	Negative Indicators (Arguing Against Right-Turn Lane Placement)
High speed arterial highways	In residential areas
High right-turn motor vehicle volumes	In urban core areas
High right-turn plus high cross-street left-turn volumes	On walking routes to schools
Long right-turn queues	Where pedestrians are frequent
Intersection capacity nearly exhausted	Low right turn volumes
History of crashes involving right-turning vehicles	
Little to no pedestrian activity	

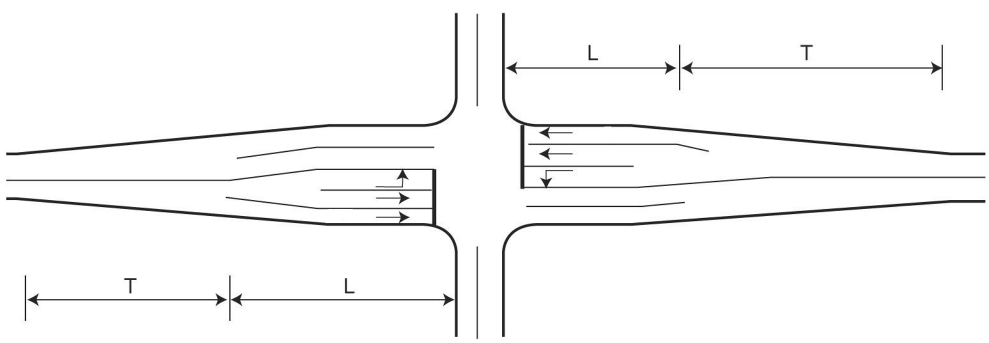
Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.3.4 Auxiliary Through Lane Design Elements

Short segments of additional through lane (widening a street through a signalized intersection) can be an effective way of increasing intersection capacity at relatively "isolated" intersections (for example, in rural areas and in settled areas with a minimum of about one-mile spacing between signalized intersections).

Where through lanes are provided, motorists approaching the intersection arrange themselves into two lanes of traffic and merge back to a single lane of traffic on the departure side of the intersection. Merging under acceleration (i.e., on the departure side of the intersection) works well, since gaps (spaces between motor vehicles) are increasing as vehicles accelerate, leaving numerous opportunities to merge as the traffic stream leaves the intersection. Design elements for auxiliary through lanes are given in Exhibit 6-25.

Exhibit 6-25
Auxiliary Through Lane Design Guidelines



Dimensions for Auxiliary Through-Lanes (feet)			
Design Speed (mph)	**Lane Width (feet)**	**Taper Length (T, feet)[1]**	**Length of Lane (L, feet)**
15-25	10	$WS^2/60$	See Note 2
30-35	10	$WS^2/60$	See Note 2
40	10-11	$WS^2/60$	See Note 2
45	10-11	WS	See Note 2
50	11-12	WS	See Note 2
55	11-12	WS	See Note 2
60	12	WS	See Note 2

1 W is the lateral shift required to form the additional through lane.

2 L should be based on anticipated queue derived from intersection operations analysis.

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections and the Manual on Uniform Traffic Control Devices

6.7.4 Channelization Islands

Channelization islands are used to:

- Delineate the area in which motor vehicles can operate;
- Reduce the area of motor vehicle conflict;
- Bring motor vehicle merging into a safer (smaller) angle of merge; and
- Provide pedestrian refuge.

Ideally, channelization islands are raised above pavement level, typically to curb height (6 inches). Less preferably, they may be flush with the pavement level. Both raised and flush islands may be constructed of a variety of materials, including conventionally finished concrete, scored concrete, or rigid pavers of various types. Some general criteria for the dimensions of channelization islands include:

- Triangular islands should be a minimum of 100 square feet in surface area with one side at least 15 feet in length. Linear islands should be at least 2, and preferably 3 feet or more wide. If they contain signs, they should be at least 4 feet wide. If they intersect pedestrian crosswalks or contain signs, they should be at least 6 feet wide with maximum 1.5 percent slope. The minimum length of linear islands should be 25 feet.
- Channelization islands should contain at-grade passages for bicycle lanes, wheelchair and pedestrian paths, and should generally be placed to avoid impeding bicycle movement, whether or not bicycle lanes are present.
- The edges of channelization islands should be offset from the travel lanes, to guide drivers smoothly into the desired path. Typically, a 2-foot offset is appropriate.

Typical arrangements and applications of channelization are shown in Exhibit 6-26.

6.7.4.1 Right-turn Channelization Islands

A small channelization island can delineate a right-turn lane at a simple intersection (i.e., where neither the approach nor departure lane is flared). This type of channelization is appropriate for large-radius corners. A more common use for the right-turn channelization island is at flared intersections, where a deceleration lane flare is provided on the approach to the intersection, sometimes combined with an acceleration lane flare on the departure side. The largest channelization islands are typically found where an auxiliary right-turn lane is provided on both the approach and departure side of the intersection.

Right-turn channelization islands can benefit pedestrians crossing the affected approaches by providing an interim refuge in the crosswalk. This refuge permits pedestrians to devote full attention to crossing the right-turn lane without needing to assure a safe crossing for the rest of the street. From the channelization island, pedestrians can then proceed across the through lanes of traffic without the complicating factor of crossing the right-turn movement.

6.7.4.2 Divisional Islands

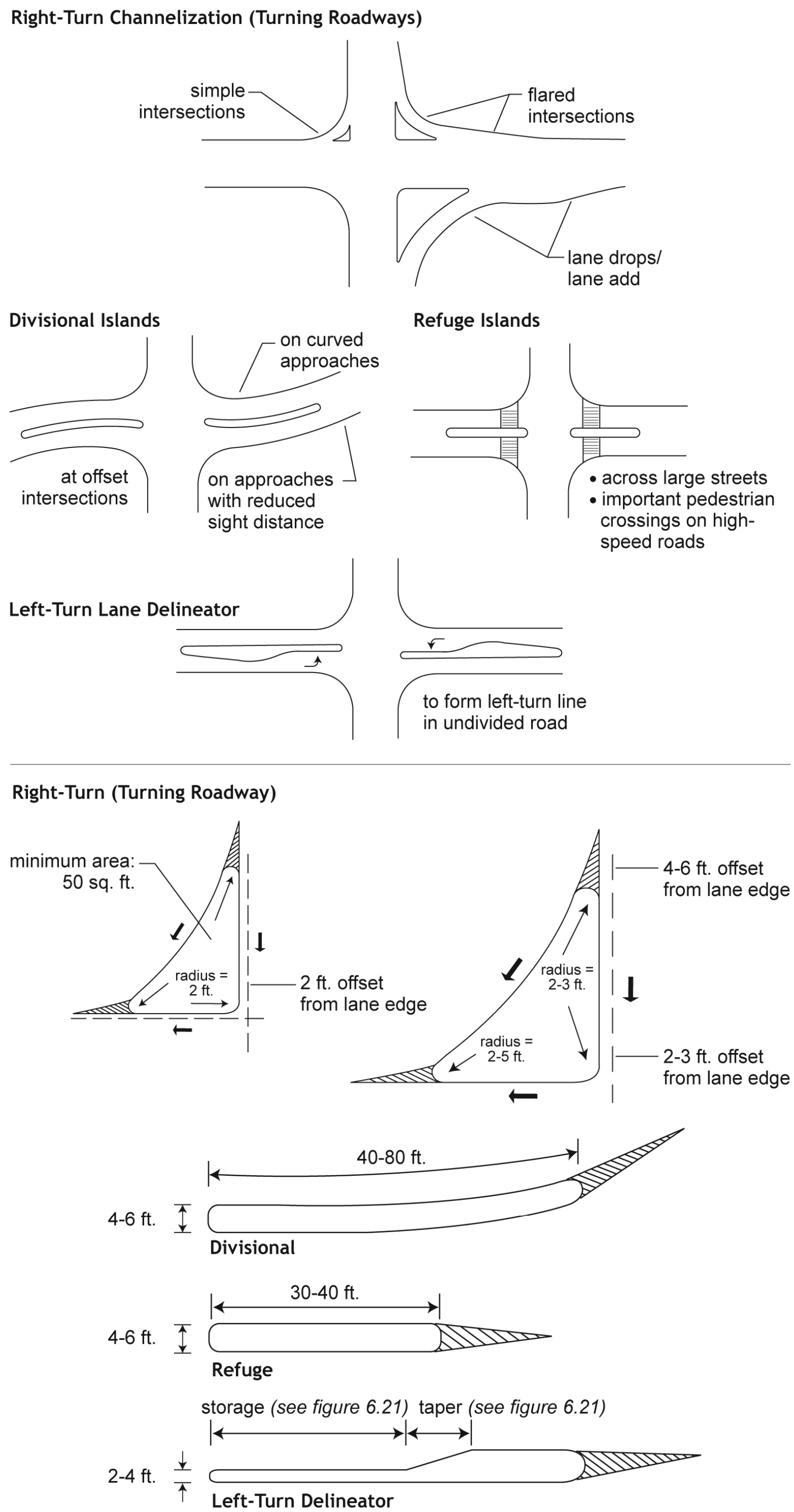
Divisional islands are useful in dividing opposing directions of traffic flow at intersections on curves, or with skewed angles of approach. In such instances, they can improve the safety and convenience for approaching motorists. Although superficially similar to medians, divisional islands differ from them in their short length and relatively narrow width and are discussed further later in this chapter and in Chapter 16.

6.7.4.3 Left-Turn Lane Delineator Islands

The left-turn delineator island resembles a short section of median island, with triangular striping to guide traffic around it. At the intersection end of the island, it is narrowed to provide storage for left-turning motor vehicles and bicycles.

On undivided streets, the left-turn lane delineator island is used to form the left-turn bay. At its upstream nose (i.e., on the approach to the intersection), the island and associated striping shifts the through traffic lane to the right, creating room for the taper and left-turn bay.

Exhibit 6-26
Channelization Islands



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.5 Roundabout Geometric Design Elements

The key elements of geometric design for roundabouts are shown in Exhibit 6-27 and include:

- The circulating roadway, which carries motor vehicles and bicycles around the roundabout in a counterclockwise direction.
- The central island, defining the inner radius of the circulating roadway around it.
- A core area within the central island, from which motor vehicles are excluded.
- A truck apron area on the outer perimeter of the central island, traversable by large motor vehicles.
- The inscribed circle, defined by the outer edge of the circulating roadway.
- Splitter islands, on all approaches, separating the entering from the exiting traffic.
- Crosswalks across approach and departure roadways.

The key design element of the roundabout is its outer diameter, the inscribed circle diameter (ICD). This dimension determines the design of the circulating roadway and central island within it. The alignment of approach and departure roadways and the resulting splitter islands are also established by the inscribed circle. For further information on roundabout design refer to the FHWA publication *Roundabouts: An Informational Guide,* June 2000.

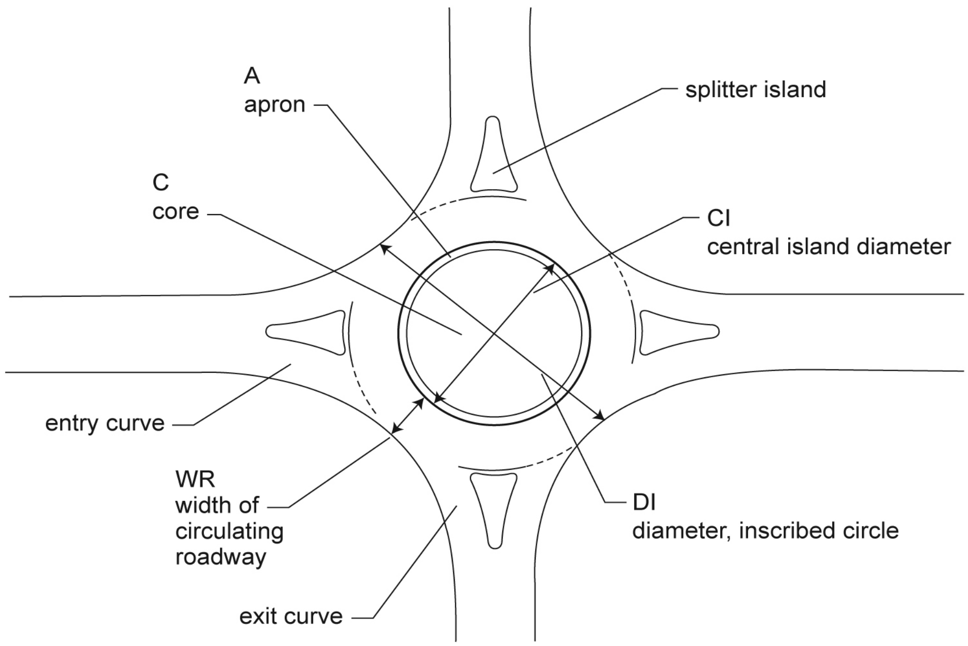
6.7.5.1 Inscribed Circle

The ICD is derived from the motor vehicle. The inscribed circle is established by the outer turning radius of the design vehicle, plus a margin for contingencies encountered in normal operation.

6.7.5.2 Width of Circulating Roadway

The width of the circulating roadway is established from the turning path of the design vehicle plus a margin to allow for normal operating contingencies. The critical turning movement is the left turn, requiring a 270 degree movement around the circle which, in turn, produces the largest swept motor vehicle path and thereby establishes the width of the circulating roadway.

Exhibit 6-27
Circle Dimensions, Single Lane Roundabout



Functional Class Major Street	Design Vehicle	Circle Dimensions (feet)		Central Island		
		Diameter, Inscribed Circle (DI, feet)	Width, Circulating Roadway (WR, feet)	Core (C, feet)	Apron (A, feet)	Total (CI, feet)
Arterial	Tractor/Trailer (WB -50)	100-130	29-35	55-95	5-10	65-100
Collector	Single Unit Truck (SU)	80-100	17-21	50-80	5-10	60-85
Local	Passenger Car (P)	45-80	16	25-60	3-5	30-65

Note: The design vehicle should be the largest vehicle expected to be accommodated on the street.

Source Roundabouts: An Informational Guide, FHWA June 2000.

6.7.5.3 Central Island

The diameter of the central island is derived from the diameter of the inscribed circle less the width of the circulating roadway. Typically, central islands consist of a core area not intended to be traversed by motor vehicles and bicycles, bordered by a truck apron of a slightly raised pavement not intended to be used by vehicles smaller than a school bus, but available for the inner rear wheel track of larger motor vehicles.

6.7.5.4 Entry and Exit Curves

The entry radius can be varied as desired to achieve the desired entry speed. Curvature is limited only by the need to provide sufficient clearance for the design vehicle.

Entrance roadways are designed so that the continuation of the inside edge of the entry curve joins tangentially to the central island, while the outside edge of the entry curve joins smoothly and tangentially to the outside edge of the circulating roadway. Typically, the entry radii (measured at the outside pavement edge) range from 30 to 100 feet.

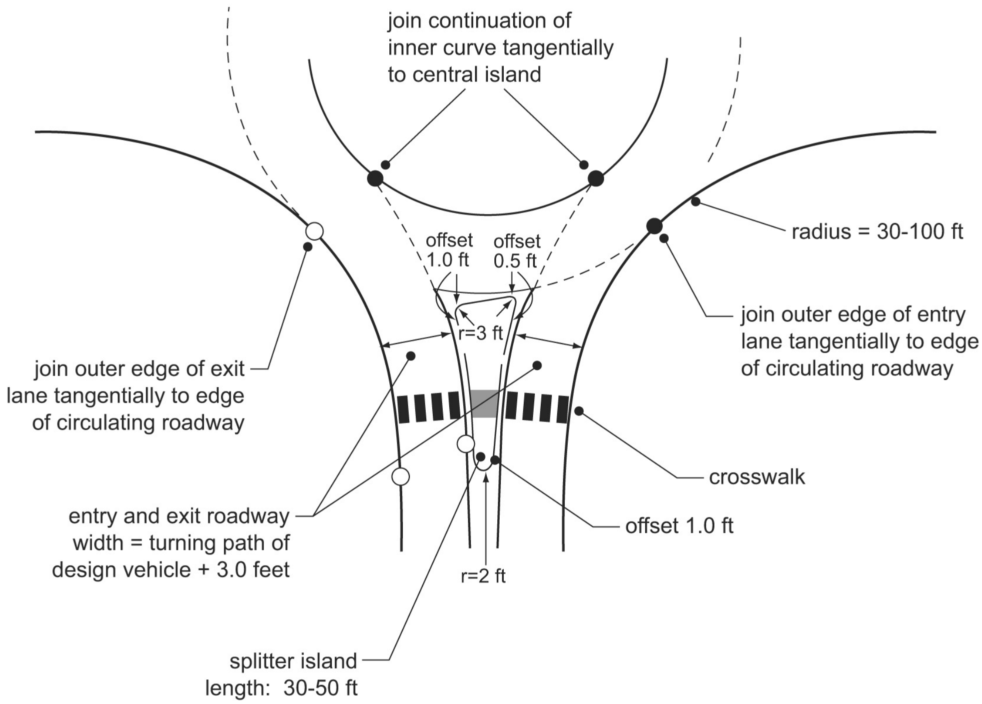
Exit curves join tangentially to the inner and outer diameters of the roundabout in the same manner as the entry curve. The outside exit curve joins smoothly and tangentially to the outside edge of the circulating roadway, while the inside curve, if continued, would join tangentially to the central island. As with the entry curve, the width of the roadway should accommodate the design motor vehicle. The exit path radius (measured at the centerline of the exit curve) should be at least as great as the motor vehicle path around the circulating roadway, so that drivers do not reduce speed upon leaving the circle, or, failing that, overrun the exit curve and collide with the splitter island. Frequently, exit curves have larger radii than entry curves, to reduce the possibility of congestion at the exit points. However, the exit speed should also be influenced by the accommodation of pedestrians and bicyclists.

6.7.5.5 Splitter Islands

Splitter islands are formed by the separation between the entry and exit lanes as illustrated in Exhibit 6-28. Splitter islands guide motor vehicles and bicycles into the roundabout, separate the entering and exiting traffic streams, assure a merge between entering and circulating traffic at an angle of less than 90 degrees, and assist in controlling speeds. Further, splitter islands provide a refuge for pedestrians and bicyclists, and can be used as a place for mounting signs. Larger splitter islands afford the opportunity for attractive landscaping, but signs and landscaping must not obstruct sight distance for approaching motorists.

Splitter islands should be at least 50 feet in total length to properly alert drivers to the roundabout. The splitter island should extend beyond the end of the exit curve to assure that exiting traffic has completed its turn, and to prevent it from crossing into the path of on-coming traffic.

Exhibit 6-28
Entry/Exit Lanes, Single Lane Roundabouts



Source: Roundabouts: An Informational Guide, FHWA, June 2000.

6.7.6 Intersection Median Openings

At intersections where one or both of the streets have divided roadways separated by a median, the design of the median becomes an element in the intersection design. Two factors control the design of the ends of medians at intersections:

1) The turning path of motor vehicles and bicycles making a left turn from the minor street into the major street controls the location and shape of the end of the median in the departure leg of the major street; and,

2) The left turn from the major street into the minor street determines the location and configuration of the median end on the approach leg of this movement.

Right-turn movements are seldom a factor in median opening design. However, the presence of a median may limit the effective pavement width for motor vehicles and bicycles making a right turn. Effective pavement width, as previously discussed, has a large bearing on the corner radius needed for right turns.

6.7.6.1 Design Vehicles for Median Openings

The design vehicle for median openings is the same as the design vehicle selected for the intersection. Roads with medians are likely to be classified as arterial roads, with the appropriate design vehicle therefore being the WB-50 truck. However, for some median openings, the passenger car (P) or single unit truck (SU) design vehicle may be appropriate.

6.7.6.2 Permitted Encroachment at Median Openings

At intersections of streets with medians, turning vehicles may be permitted to encroach into adjacent lanes, according to guidelines discussed earlier. However, on divided highways, encroachment into opposing lanes of traffic is physically impossible, due to the median. Some categories of encroachment, therefore, even though permissible, may not be available for the turn in question.

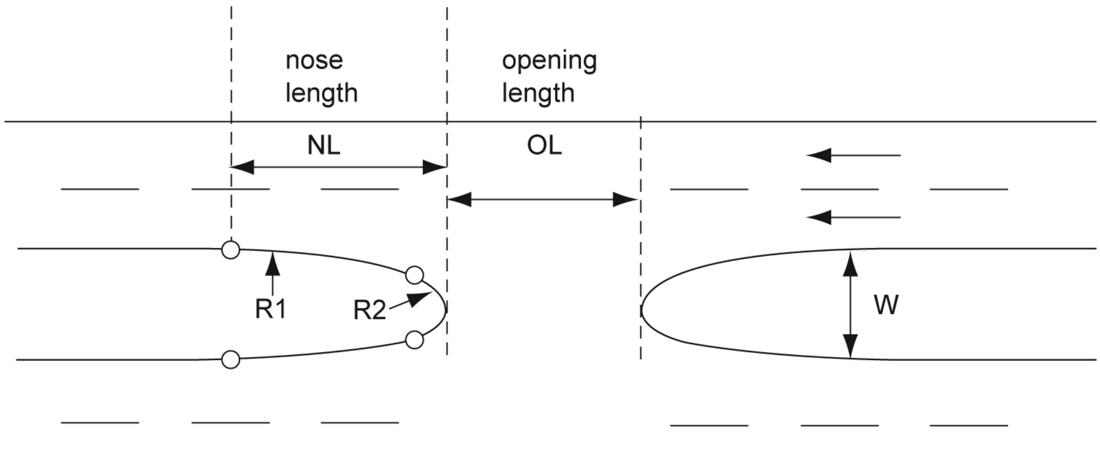
6.7.6.3 Median and Design Controls

The left-turn movement from the minor street into the departure leg of the major street controls the placement and shape of the affected median island. Similarly, the left turn from the divided major street into the minor street controls the placement and shape of the affected median island on that approach leg of the intersection. Where both the major street and the minor street are divided, the four possible left turns control the location and shapes of all four median islands.

6.7.6.4 Median Openings

An important design element is the length of the median opening, as summarized in Exhibit 6-29. Opening dimensions are given for two configurations of median end: semi-circular and bullet-nose. Median openings are given for the three categories of design vehicle addressed throughout this chapter: passenger car (P), single unit truck (SU), and the tractor/50-foot trailer (WB-50).

Exhibit 6-29
Median Openings



Length of Median Opening (OL, feet)

Width of median (W, feet)	Passenger Car (P) Semicircular	Passenger Car (P) Bullet nose	Single Unit Truck (SU) Semicircular	Single Unit Truck (SU) Bullet nose	Tractor/Trailer Truck (WB-50) Semicircular	Tractor/Trailer Truck (WB-50) Bullet nose
4	76	76	96	96	146	122
6	74	60	94	76	144	115
8	72	53	92	68	142	110
10	70	47	90	62	140	105
12	68	43	88	58	138	100
14	66	40 min	86	53	136	96
16	64	40 min	84	50	134	92
20	60	40 min	80	44	130	85
24	56	40 min	76	40 min	126	78
28	52	40 min	72	40 min	122	73
32	48	40 min	68	40 min	118	67
36	44	40 min	64	40 min	114	62
40	40 min	40 min	60	40 min	100	57
50	40 min	40 min	50	40 min	95	48
60	40 min	40 min	40 min	40 min	90	40 min
70	40 min	40 min	40 min	40 min	80	40 min
80	40 min	40 min	40 min	40 min	70	40 min
100	40 min	40 min	40 min	40 min	50	40 min
110	40 min	40 min	40 min	40 min	40 min	40 min
120	40 min	40 min	40 min	40 min	40 min	40 min

Note: R1, R2 and NL determined by design vehicle turning paths.
Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.7 Pedestrian Crosswalks

Crosswalks are a critical element of intersection design. Crosswalks are essential for designating the appropriate path of travel for a pedestrian through the intersection. Crosswalks are defined by pavement markings, textured pavement, and colored pavement as described below. Several techniques are available to shorten pedestrian crossings and for improving crosswalk visibility, as described below.

6.7.7.1 Crosswalk Pavement Markings

Pavement markings indicate to pedestrians the appropriate route across traffic and remind turning motor vehicle drivers and bicyclists of potential conflicts with pedestrians. The crosswalk edge nearest to the intersection should be aligned with the edge of the sidewalk nearest to the road. Accepted crosswalk markings are shown in Exhibit 6-30. When different pavement treatments are used, crosswalks must be bounded by parallel bars. At signalized intersections, all crosswalks should be marked. At unsignalized intersections, crosswalks should be marked when they:

- Help orient pedestrians in finding their way across a complex intersection;
- Help show pedestrians the shortest route across traffic with the least exposure to motor vehicles and bicycles, and to traffic conflicts; or
- Help position pedestrians where they can best be seen by on-coming traffic.

When used without other intersection treatments, crosswalks alone should not be installed within uncontrolled environments when speeds are greater than 40 mph. All crosswalks on the entries and exits of roundabouts should be marked. Crosswalks are typically located one car length back from the yield line or circulating roadway at single-lane roundabouts. For more information, refer to the *Manual on Uniform Traffic Control Devices*.

6.7.7.2 Vehicular Stop Bar Placement

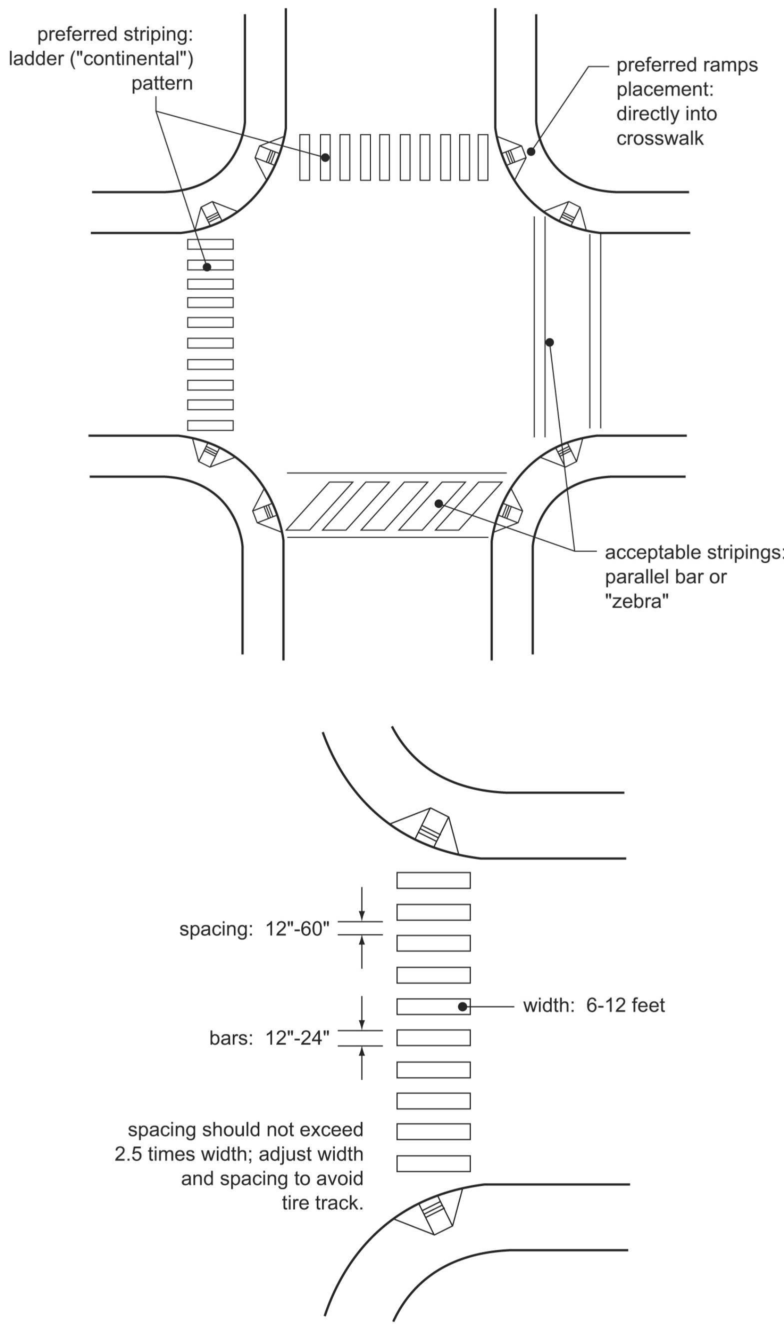
Where crosswalks are provided across a street with a stop line or with traffic signals, there should be a minimum 4-foot spacing between the outer edge of the crosswalk and the nearest edge of the stop bar. Stop bars should be dimensioned in accordance with guidelines in the MUTCD.

6.7.7.3 Methods to Reduce Pedestrian Crossing Distance

Marked or unmarked, crosswalks should be as short as possible. At all intersections, reducing the time pedestrians are in the crosswalk improves pedestrian safety and motor vehicle and bicycle movement.

At signalized intersections, reducing the pedestrian crossing distance can improve capacity for both motor vehicles (longer green time) and for pedestrians (longer WALK interval).

Exhibit 6-30
Crosswalk Elements



Source: Manual on Uniform Traffic Control Devices (MUTCD), FHWA, Washington DC, 2003.

Curb Extensions

Curb extensions shorten the crossing distance, provide additional space at the corner, allow pedestrians to see motor vehicles and be seen by motor vehicle drivers before entering the crosswalk, and keep parking away from crosswalks. Curb extensions are discussed further in Chapter 16.

Crossing Islands and Medians

Raised medians and triangular channelization islands can be used to interrupt extremely long crosswalks. These raised areas:

- Allow pedestrians to cross fewer lanes at a time, reducing exposure time;
- Provide a refuge so that slower pedestrians can wait for a break in the traffic stream;
- Allow pedestrians to focus on traffic from only one direction at a time;
- Reduce the total distance over which pedestrians are exposed to conflicts with motor vehicles; and,
- May provide easily accessible location for pedestrian signal call buttons.

In general, fifty feet is the longest uninterrupted crossing a pedestrian should encounter at a crosswalk, but islands and medians are also appropriate for shorter distances. Islands and medians should not be used to justify signal timing that does not allow pedestrians to complete their crossing in one cycle. Crossing islands are discussed further in Chapter 16.

6.7.7.4 Improving the Visibility of Pedestrian Crossings

Safe pedestrian crossing is dependent on awareness by motorists of the pedestrian. Methods to improve the visibility of pedestrians, in addition to curb extensions, sometimes include textured crosswalks, raised crosswalks, and flashing beacons at mid-block locations as discussed further in Chapter 16.

6.7.7.5 Pedestrian Crossing Prohibitions

Some intersection crossings include conflicts between pedestrians and motor vehicle traffic that are especially dangerous; however, prohibiting pedestrian crossing should be considered only in very limited circumstances, for example:

- Where it would be very dangerous for pedestrians to cross, as where visibility (for pedestrians, motorists or bicyclists) is obstructed and the obstruction cannot be reasonably removed, and where signalization is not an option.
- Where so many legal crosswalks exist that they conflict unreasonably with other modes, as on an arterial street with multiple offset or "T" intersections.

Crosswalks at “T” and offset intersections should not be closed unless there is a safer crosswalk within 100 feet of the closed crosswalk. "Pedestrians Use Marked Crosswalk" signs should be used for crosswalks closed to reduce an excess of crosswalks on a street with “T” or offset intersections. "No Pedestrian Crossing" signs should be used for crosswalks closed for pedestrian safety.

6.7.8 Pedestrian Curb Cut Ramps

There are two preferred configurations of pedestrian curb cut ramps. These configurations include several design elements. Both the configurations and design elements are described in the following sections. Designs for these ramps are provided in MassHighway’s *Standard Construction Details*.

6.7.8.1 Ramp Types

Pedestrian curb cut ramps at marked crossing shall be wholly contained within the markings, excluding any flared sides. Two types of ramp configurations are preferred—perpendicular ramps and parallel ramps. The first has a ramp leading at right angles from the sidewalk into a crosswalk, while the second has a ramp leading into a landing that is flush with the street surface. A third type, a diagonal ramp, is discouraged but permissible for certain specific intersection conditions (see below) under specific conditions.

Perpendicular

Whenever possible, 521 CMR requires that a pedestrian curb cut ramp is oriented so that the fall line of the ramp is in line with the crosswalk and perpendicular to the curb. Where conditions are not constrained, the designer should locate the ramp so that both conditions can be met. A minimum four feet level landing with a cross slope designed at a maximum of 1.5% for each approach at the sidewalk and street level within the designated crosswalk is required.

Parallel

Parallel curb cut ramps are used where the available space between the curb and the property line is too tight to permit the installation of both a ramp and a landing. A minimum four foot landing is necessary between the two ramps.

Diagonal or Apex

Diagonal or "apex" curb cut ramps are single perpendicular pedestrian curb cut ramps located at the apex of the corner. Diagonal ramps are only permitted under the following specific conditions by 521 CMR:

a. *Driver or pedestrian line of sight to or from the front of the level landing on the ramp is impaired, preventing safe observation of crosswalks or approaching traffic at the intersection by a significant immovable or unalterable streetscape feature such as a building structure or historic element, etc.*

b. *Stop line is beyond the allowed limit as stated in the Manual on Uniform Traffic Control Devices.*

c. *Vaults containing electrical, telecommunication, etc. that are under or on the existing sidewalk.*

d. *Large radius corners (30 feet or greater).*

When using diagonal or apex curb cut ramps, there must be a 4 foot level landing at the base (street) level of the ramp that is within the marked crosswalk.

6.7.8.2 Design Elements

Key design elements of pedestrian curb cut ramps include the ramped section, landing areas and side flares as described below.

Ramp Section

The minimum slope possible (given curb heights and sidewalk width) should be used for any pedestrian curb cut ramp. The maximum curb cut ramp slope is 8.33% in the built condition with a cross slope of no more than 2% in the built condition. To ensure that the build conditions do not exceed thee maximums, designers should use standards specifications of 7.5 percent for slopes and 1.5 percent for cross-slopes.

The minimum width of a pedestrian curb cut ramp is at least 3 feet, with 4 feet preferred, exclusive of flared sides. A curb cut ramp shall have a detectable warning that extends the full width and length of the curb ramp. Detectable warnings shall comply with the *ADA Accessibility Guidelines for Buildings and Facilities.*

Curb cut ramps and their approaches shall be designed so that water will not accumulate on walking surfaces. Surfaces of pedestrian curb cut ramps shall be stable, firm, and slip-resistant.

Landings

The basic principle is that every curb cut ramp must have a landing at the top and at the bottom. The landing at the top of a ramp should be a minimum of four feet long (5 feet preferred) and at least the same width as the center curb cut ramp itself. It should be designed to slope no more than 1.5% in any direction, allowing the built condition to slope no more than 2%. A single landing may serve as the top landing for one ramp and the bottom landing for another.

When perpendicular ramps run directly into a crosswalk, the landing at the bottom will be in the roadway. The landing, at least 4 feet long, should be completely contained within the crosswalk pavement markings and should not have a running slope when built no greater than 5 percent. When the parallel ramp landing is within the sidewalk or corner area where a person using a wheelchair may have to change direction, the landing must be a minimum of five feet long and at least as wide as the ramp, although a width of five feet is preferred. The landing may not slope more than 2% when built (1.5% in design) in any direction.

Flares

Flares are graded transitions from the ramp section to the surrounding sidewalk. Flares are typically not part of the route for people using wheelchairs. Flares may be steeper than the ramp where there is a 4-foot deep level landing at the top of the ramp's center landing. The maximum slope of the flare shall be 10% (9% in design). If the landing depth at the top of a pedestrian curb cut ramp is less than four feet, then the slope of the flared side shall not exceed 8.33% in the built condition (7.5% design).

When intersections are located on a hill, it is possible that the side flares ramp can never meet the 8.33% maximum slope requirement. In this situation, the Massachusetts Architectural Access Board may grant a variance to use a steeper side flare slope, typically at least 15 feet long.

Returned Curbs

Flares are not necessary where pedestrians would not normally walk across the ramp, such as where the ramp edge abuts grass, other landscaping, or other non-walking surface. Pedestrian curb cut ramps may have returned curbs or other well-defined edges only when the ramp itself is sloped at 8.33% maximum, and there is no pedestrian approach from either side of the ramp. Such edges shall be parallel to the direction of pedestrian flow, and the adjacent area should clearly prohibit pedestrian use with, for example, plantings, railings, street furniture, etc. The bottom of ramps with returned curbs shall have a four foot minimum clear, level landing that does not extend into a travel lane and is within the crosswalk markings.

6.7.9 Bicycle Lanes at Intersections

On streets without bicycle lanes, a bicyclist's travel through intersections reflects the bicyclist's accommodation at adjacent non-intersection street segments. Where bicyclists share a lane with motorists, they continue through intersections in this shared-lane mode of accommodation. Where a road shoulder is present and used by bicyclists, they approach and depart intersections on the road shoulder or in the travel lane.

On streets with bicycle lanes, the design of bicycle lanes at intersections is complicated by the need to accommodate numerous turning movements by both motorists and bicyclists, often with limited available space. Intersection design is based on the assumption that:

- Motorists making right turns should make their turn from as close to the right-hand curb as practical;
- Bicyclists going straight ahead should be to the left of right turning traffic; and,
- Bicyclists turning left should turn from a left turn lane or the left side of a combination through/left lane.

The bicycle lane marking is a 6-inch wide white solid stripe. Near intersections, the solid stripe should be replaced by a broken line stripe (two-foot–long stripes separated by six-foot-long spaces) where bicycles and vehicles merge. The outer bicycle lane marking is skip striped all the way to the stop bar at controlled intersections, and to the extension of the property line at uncontrolled intersections. The skip stripe alerts bicyclists to the potential for motorists to be crossing their path and encourages safe merging in advance of the intersection. The lanes should resume on the far side of the intersection. When a bicycle lane intersects with a one-way street, or where right turns are prohibited, the bicycle lane markings are solid all the way to the intersection.

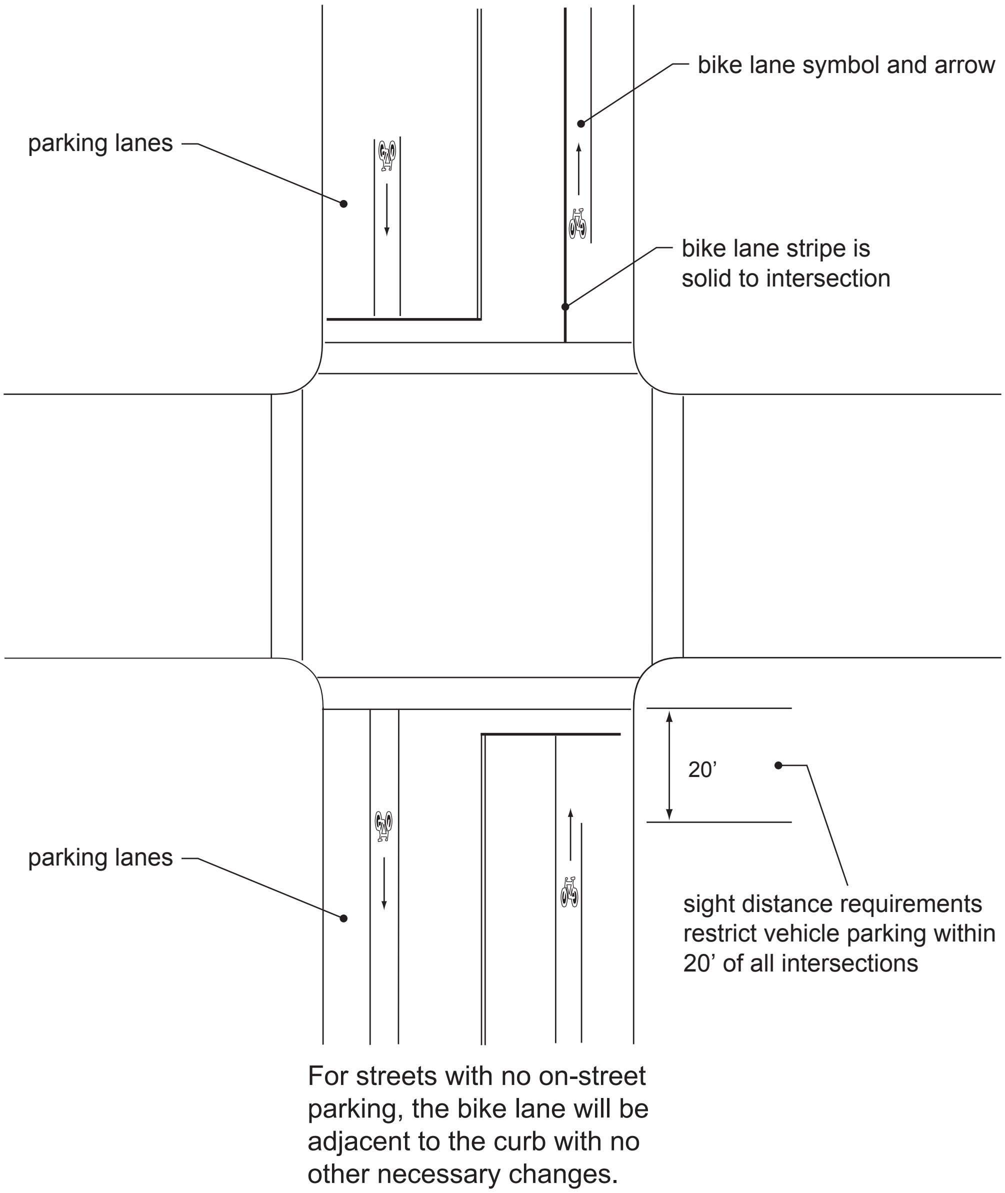
Bicycle lane stripes should not be extended through a pedestrian crosswalk or any street intersection. Exceptions include dashed lines through some complex intersections, and the bicycle lane striping on the side across from the T-intersection should continue through the intersection area with no break.

A typical configuration for bicycle lanes at a simple intersection is illustrated in Exhibit 6-31.

6.7.9.1 Intersections with Bus Stops

Where there is a bus or other transit stop, either near side or far side, the 6-inch solid line should be replaced by two-inch dots separated by six- foot spaces for the length of the bus stop.

Exhibit 6-31
Bicycle Accommodation at a Simple Intersection



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.7.9.2 Flared Intersections

Right turn lanes should be used only where justified by a traffic study since they force right-turning vehicles and through bicyclists to cross paths. Where right turn lanes are on streets with bicycle lanes as shown in Exhibit 6-32, the curb lane is designated with markings and signs indicating "Right Turn Only Except for Bicycles." This improves safety for bicyclists by preventing through motorists from passing on the right while still allowing through bicyclists to use the lane. Signs also indicate that motorists should yield the shared lane to the bicyclist. When the width allows, the bicycle lane is dotted to encourage right-turning vehicles to merge right. The bicycle lane then continues for a minimum of 30 feet until the stop bar.

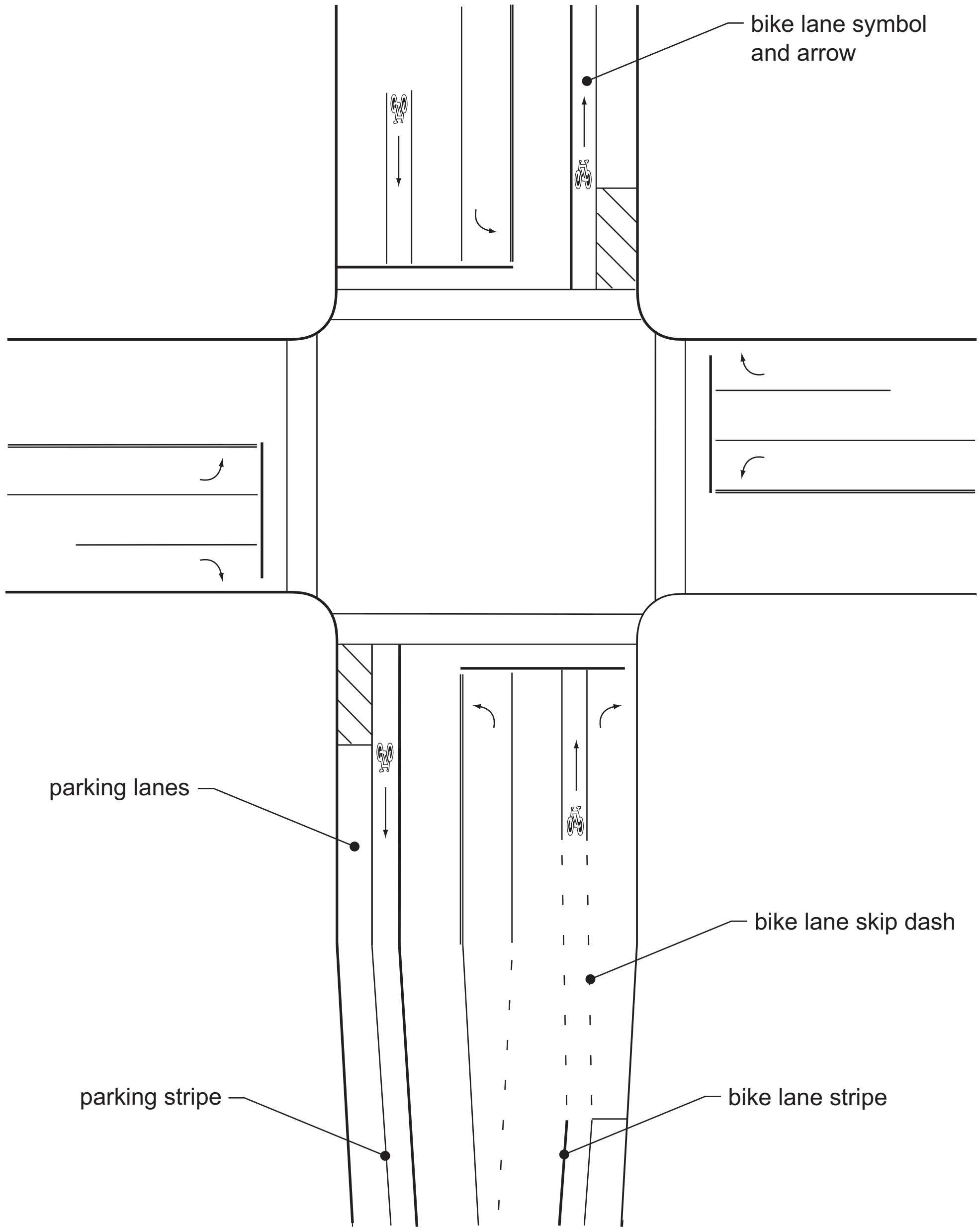
The bicycle lane should not be placed to the left of a right turn lane in three circumstances:

- **Heavy right turn volumes -** At four-legged intersections with heavy right-turn volumes and where it is expected that most bicyclists will make a right-turn (such as where the straight through move leads to a minor side street), the bicycle lane should be placed on the right.

- **T-intersections -** Bicycle lanes should be placed to the right of the right-turn lane. Where left-turn volumes are heavy, a bicycle left-turn lane may be placed between the vehicle left-turn and right-turn lanes.

- **Optional right/straight and right-turn only lanes -** Striped bicycle lanes should end with the beginning of the taper for the right-turn lane, resuming on the far side of the intersection.

Exhibit 6-32
Bicycle Accommodation at a Flared Intersection



For flared intersections with left-turn lanes, the bicycle lane treatment remains.

Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.7.9.3 Bicycle Lanes at Roundabouts

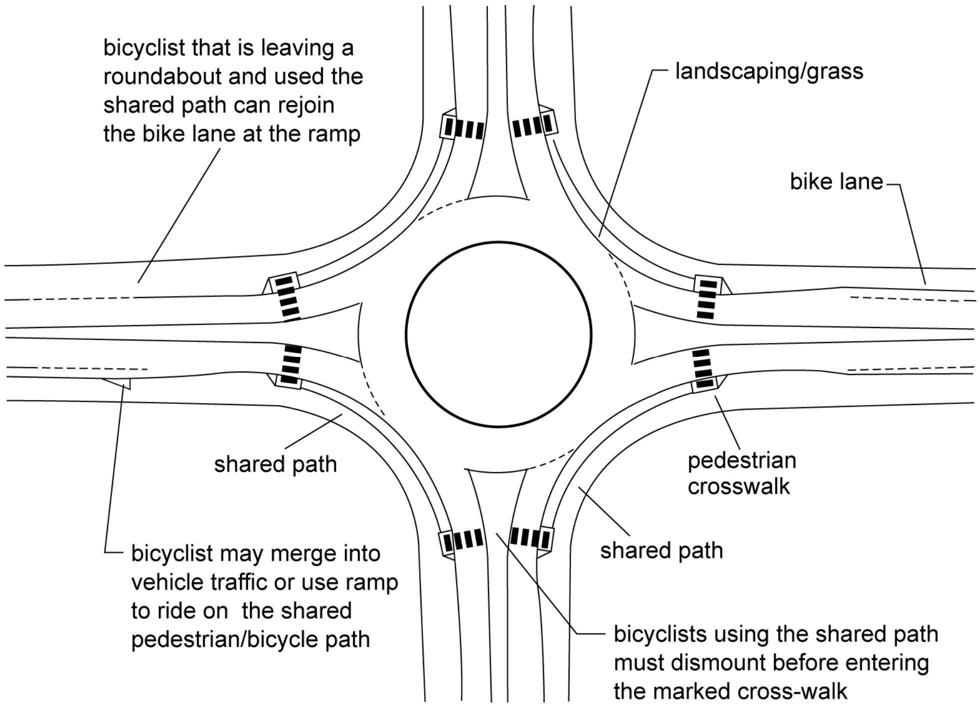
Roundabout design should accommodate bicyclists with a wide range of skills and comfort levels in mixed traffic. Bicyclists have the option of either mixing with traffic or using the roundabout as a pedestrian, as illustrated in Exhibit 6-33.

- Where bike lanes are present, low-speed (approximately 12 to 15 mph) and single-lane roundabouts allow for safe mixing of bicycles and motor vehicles within the roundabout. This option will likely be reasonably comfortable for experienced bicyclists. Bicyclists will often keep to the right on the roundabout; they may also merge left to continue around the roundabout. Motorists should treat bicyclists as other vehicles and not pass them while on the circulatory roadway. The bicycle lane should be discontinued about 100 feet prior to low-speed roundabouts to indicate that bicyclists should either mix with motor vehicle traffic or exit to the shared use path.

- On the perimeter of roundabouts, there should be a sidewalk that can be shared with bicyclists. Less-experienced bicyclists (including children) may have difficulty and discomfort mixing with motor vehicles and may be more safely accommodated as pedestrians in some instances. Bicycle lanes leading toward a roundabout should be discontinued at the beginning of the entry curve of the roundabout, ending in a ramp leading toward a shared use bicycle pedestrian path around the roundabout. Bicycle lanes should resume on the end of the exit curve, beginning with a ramp from a shared use path.

Bicyclists require particular attention within higher speed and double lane roundabouts, especially in areas with moderate to heavy motor vehicle volume. It may sometimes be possible to provide bicyclists with grade separation or an alternative route along another street that avoids the roundabout, which should be considered as part of overall planning. The provision of alternative routes should not be used to justify compromising the safety of bicycle traffic through the roundabout because experienced bicyclists and those with immediately adjacent destinations will use it.

Exhibit 6-33
Bicycle Accommodations at Roundabouts



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.8 Other Considerations

Several other considerations important for intersection design are described in the following sections including: sight triangles; intersection spacing; bus stop considerations; other types of roadway crossings; mid-block path crossings; and highway-railroad grade crossings; and driveways.

6.8.1 Intersection Sight Triangles

The intersection sight triangle is a triangular-shaped zone, sufficiently clear of visual obstructions to permit drivers entering the intersection to detect any hazards or conflicts and react accordingly. Intersection sight distance and sight triangles are discussed further in Chapter 3.

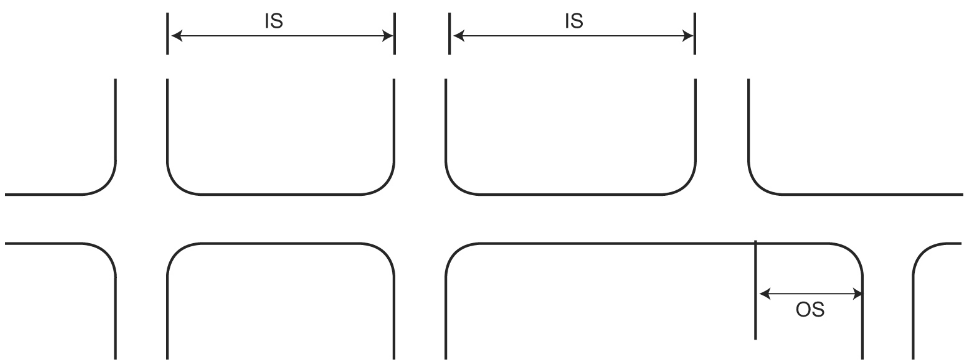
6.8.2 Intersection Spacing

A primary purpose of intersection spacing guidelines is to minimize the possibility of conflicts in traffic operations between adjacent intersections. Examples of such conflicts are queues of traffic extending from one intersection through an adjacent intersection, or intersection spacing that precludes the possibility of traffic signal progression between intersections. On arterials, intersection spacing requirements are intended to minimize the "friction" arising from signal control and turning movements at intersections. Intersection spacing can also influence the pedestrian connectivity along a corridor since crossing opportunities are often located at intersections.

6.8.2.1 Spacing Between Public Street Intersections

Guidelines for spacing between public streets are given in Exhibit 6-34. In most situations, only a minimum spacing is recommended. However, for streets in urban areas, maximum spacings are also recommended to enable a proper density of connecting street network.

Exhibit 6-34
Intersection Space Guidelines



Design Speed (mph)	Spacing (feet) Between: Intersections (IS, feet)	Offset Intersections (OS, feet)
15-30	200	50
35-40	250	75
45-50	350	150
50 +	500	500

Source: Adapted from Congress for the New Urbanism (CNU), AASHTO, 2005

Frequently, intersection spacing is not a controllable element of intersection design, and the spacing is "given" as a fixed condition. In such circumstances, spacing guidelines are not applicable. However, in many situations, particularly involving areas of new development, intersection spacing is an important part of the context, and should be considered in light of the above guidelines.

6.8.2.2 Spacing between Signalized Intersections

Frequently, criteria for the desirable spacing of signalized intersections are confused with that for spacing of all intersections, whether signalized or not. Good signal progression in both directions simultaneously requires signal spacing of approximately 1,200 feet or more, well beyond the ideal spacing for intersections in village, town center, and urban settings. However, signalized intersections, spaced for good signal progression, can be combined with non-signalized intersections, yielding overall intersection spacing with small blocks (ideally around 200 feet) appropriate for urban settings. Mid-block crossings should be spaced no closer than 300 feet from a signalized intersection, unless the proposed control signal will not restrict the progressive movements of traffic.

Good connectivity to the signalized intersections along the major street can be assured with a well connected network of local and collector streets parallel to the major street. With such a network in place, turning movements can be made at all locations, signalized and unsignalized, during non-peak hours. During peak hours, motorists and bicyclists wanting to enter or cross the major street can choose to use the signalized intersections.

6.8.3 Transit Stop Considerations

From the point of view of bus operations, it is desirable to have bus stops located near intersections so that bus riders can approach easily from both the street carrying the bus route and from the minor streets. Further, it is desirable to integrate bus stops with the adjoining pedestrian system (sidewalks, shared use paths and crosswalks) and also with any adjoining bike path/lane system. With respect to intersections, bus and other transit stops may be either:

- Near side, located on the approach leg of the intersection; or,
- Far side, located on the departure leg of the intersection.

Bus and other transit stops at intersections, while advantageous for bus service, create challenges for other vehicle flows, as well as non-motorized travel:

- If the bus stop is in its own lane (typically an extension of parking lanes toward the interior of the block), it must reenter the traffic stream after completing a stop. If, on the other hand, the bus stops in a lane of traffic, it blocks that lane for the duration of the stop.
- At far-side stops, a stopped bus may cause following vehicles to back up through the intersection.
- At near-side stops, where the stopped bus is outside the traffic stream, the reentry of the bus into the traffic stream is likely to occur at a pedestrian crosswalk. At unsignalized locations, this presents a vehicle/pedestrian conflict possibility. Even at signalized intersections, bus drivers may begin their exit from their loading space during the red signal phase, thus conflicting with crossing pedestrians.
- Bus stops and accessible on-street parking will compete for the location nearest the intersection. The locations of both should be resolved with input from the local disability commission, regional independent living center, and transit agency.

The challenges associated with bus stops at intersections are addressed through the following design guidelines:

- Far-side bus stops are generally preferable to near-side stops.
- It is desirable to separate bus loading areas from moving lanes of traffic. Where on-street parking is generally present on the street, such a loading area can be gained by restricting the parking in the vicinity of the intersection. On streets without on-street parking, bus bays may be considered.
- Parking should be restricted for a distance of 60 feet from the beginning of the pavement corner radius. The designated bus loading area should not extend closer than 20 feet to the pavement corner radius. These dimensions apply to both near-side and far-side bus stops.
- Bus pullouts, under some circumstances, may be appropriate at intersection areas. However, the drawback of pullouts—difficulty for the bus in reentering the traffic stream—can be problematic near intersections. Pullouts are more likely to be acceptable at far-side stops, where the exiting bus vehicle is more likely to

encounter acceptable gaps in the traffic stream, compared to a near-side stop on the approach leg of the intersection.

The design of pedestrian and bicycle connections, bus bays, and on-street parking requires additional focus around intermodal facilities such as commuter rail, subway, park & ride and light-rail stations. Design of these facilities is overviewed in Chapter 12.

6.8.4 Mid-Block Path Crossings

At intersections, shared use paths (for pedestrians, bicyclists and other non-motorized users) are accommodated as intersection crosswalks, as described in Section 6.7.8. Where paths cross streets at locations other than at intersections, they should conform to the following guidelines for "mid-block" crossings (the MUTCD provides further guidance on placement and spacing):

- Mid-block path crossings should be used only where needed. Factors likely to produce this need are existing route of paths, availability of right-of-way for path extensions, distance to alternate crossing locations at intersections, and topography.
- Mid-block path crossings should be installed only where stopping sight distance is fully adequate for vehicular traffic on the street being crossed.
- Mid-block path crossings should provide adequate sight distance for pedestrians, bicycles and other users of the path.
- Where mid-block path crossings exceed 60 feet in length, a median island should be considered. Median islands provide the dual benefit of providing a refuge for crossing path users, reducing the size of gap in traffic needed to cross the street safely, and may help alert approaching motorists and bicyclists to the presence of the crossing.
- Median islands should be at least 6 feet wide, to shield bicycles or more than one pedestrian.
- Trees along the roadside at the path crossing, and in larger medians, can call attention of on-coming motorists to the presence of the trail crossing. However, trees and other landscaping should not be allowed to infringe on the sight distance of pedestrians or motorists in the vicinity of the crossing.

- All median or channelizing islands should have pedestrian curb cut ramps or at-grade cut-throughs, in conformance with 521 CMR. At-grade cut-throughs should be sloped gently (maximum of 2 percent in the build condition and 1.5% in design)) to allow drainage.
- On multi-lane arterial streets, pedestrian call button-actuated traffic signals may be appropriate. When installed, such signal installations should have a supplementary call button at the median, as well as at either curb. The Federal Access Board's current draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-way* (not adopted at the time of this Guidebook) requires audible traffic signals wherever walk signals are installed. Although not yet required, these, along with detectable warnings, will provide strong cues for people with limited sight.
- Pedestrian call buttons should have locator tones for pedestrians with limited sight.
- Paths should be marked by white continental crosswalk markings (longitudinal stripes).
- On-street parking should be removed for a distance (typically 40 to 60 feet) adequate to assure sight distance for path users waiting on the curb.
- An alternative treatment where parking is present is to provide a curb extension, typically 6 feet deep for a 7 to 8 foot parking lane. Curb extensions reduce or eliminate the need for removing parking, and decrease the crossing distance for the path.
- At crossings with marginal sight distance, advance signing or even advance flashing indicators may be appropriate.

6.8.5 Railroad-Highway Grade Crossings

The following guidelines affect the horizontal alignment of streets at a railroad-highway grade crossing:

- Crossings should be avoided on both highway and railroad curves. Railroad curves present a problem of superelevated track crossing the roadway. A curve on the crossing highway prevents any superelevation on the highway, resulting in an awkward or unsafe curve.

- The highway should intersect tracks as near as possible to 90 degrees.
- Ideally, there should not be nearby intersections with streets or driveways. Where it is not possible to provide sufficient distance between the crossing and nearby intersections, traffic signals at the nearby intersection can be interconnected with the grade crossing signal, to enable vehicles to clear the grade crossing as a train approaches.
- The crossing should be wide enough to permit bicyclists to cross the tracks at right angles, while staying in their traffic lane.

The following guidelines apply to the vertical alignment of streets at railroad highway grade crossings:

- The street surface should be at the same plane as the cross-slope of the top of the rails (level for tangent rail and adopting the grade of super-elevated rail) for a distance of 2 feet outside either rail. Beyond this point (i.e., 2 feet from outside edge of rail), the grade should not be more than 1 percent greater than the grade across the tracks.
- Vertical curves should be used to make the transition from the street grade to the rail cross-slope plane described above.

Traffic control devices for railroad-highway grade crossings range from passive (signs, pavement markings) to active (flashing light signals) to restrictive (automatic gates). Consult the MUTCD for detailed criteria for the design and operation of these devices. At crossings protected by active signals or gates, the sight distance requirement is determined by the design speed of the crossing street (see Chapter 3 of this Guidebook).

At crossings without train activated warning devices, the sight distance must allow the driver or bicyclist to observe the approaching train at sufficient distance to permit stopping prior to reaching the crossing. The distance needed for this case depends on the speed of the vehicle and the speed of the train. Detailed sight distances are given for the WB-65 design vehicle in the AASHTO *Green Book.*

Where public sidewalks cross rail systems at-grade, the surface of the continuous passage shall be level and flush with the rail top at the outer edge and between the rails. As required by 521 CMR, the horizontal gap on the inner edge of each rail shall be the minimum necessary to allow passage of wheel flanges and shall not exceed 2½ inches. Where tracks cross a sidewalk, 24-inch wide detectable warnings, complying with 521 CMR, shall be placed on both sides of the tracks across the entire width of the sidewalk, at a sufficient distance from the tracks to allow clearance for the widest vehicle using those tracks. Where multiple tracks are part of the same level crossing, detectable warnings should be placed alongside the outermost track, and not within the sets of tracks.

6.8.6 Driveways

Driveways are points of access from public streets to private property, and are therefore not intersections, as defined in this chapter, although some large volume driveways should be designed as intersections. Guidelines for driveway design and spacing are offered in Chapter 15.

6.9 For Further Information

- *Manual on Uniform Traffic Control Devices for Streets and Highways,* American Traffic Safety Services Association (ATSSA), Institute of Transportation Engineers (ITE), American Association of State Highway and Transportation Officials (AASHTO), U.S. Department of Transportation, Federal Highway Administration (FHA), Washington, D.C., 2003 Edition.
- *Highway Capacity Manual*, Transportation Research Board, Washington, D.C., 2000.
- *A Policy on Geometric Design of Highways and Streets, Fourth Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2001.
- *Roundabouts: An Informational Guide*, Federal Highway Administration
- *Guide for the Planning, Design and Operation of Pedestrian Facilities*, American Association of State Highway and Transportation Officials (AASHTO), 2004.
- *Guide for the Development of Bicycle Facilities,* American Association of State Highway and Transportation Officials (AASHTO), 1999.
- *ADA Accessibility Guidelines for Buildings and Facilities*, The Access Board, amended through September 2002.
- *Guidelines for Driveway Location and Design,* Institute of Transportation Engineers (ITE), 1987.