stop, roundabout, and signal can be compared at an intersection using delay. For roadways on which many intersections are controlled by traffic signals, the capacity of the signalized intersections determines the capacity of the roadway to serve motor vehicles. Optimum capacities and levels of service for motor vehicles can be obtained when intersections include auxiliary lanes, appropriate channelization, and traffic control devices.

Intersection levels of service for motor vehicles at signalized intersections are defined to represent reasonable ranges in control delay and intersection conditions shown in Table 9-2. The values presented in Table 9-2 are typically used to characterize peak-hour traffic conditions. Designers may also choose to evaluate intersection level of service for periods adjacent to the peak period, and sometimes during off-peak periods, as well.

While motor vehicle level of service focuses on speed, delay, and space, these factors are not as important for nonmotorized users. The level of service procedures for bicyclists and pedestrians incorporate "quality of service" by accounting for measures such as comfort, potential for conflicts with motor vehicles, and ease of mobility. This quality of service procedure can help identify areas where bicyclist and pedestrian levels of service may be improved.

The *Highway Capacity Manual* (*49*) also provides detailed procedures for calculating level of service for both pedestrians and bicyclists on a variety of roadway elements, including signalized intersections and street segments. Refer to HCM Chapter 3 for more information.

Table 9-2—Motor Vehicle Level of Service Definitions for Signalized Intersections (*49*)

| Level of Service | Intersection Conditions |
|---|---|
| A | Very short delay and most vehicles do not stop as a result of favorable progression or short cycle length |
| B | Short delay and many vehicles do not stop or stop for a short time as a result of short cycle lengths or good progression |
| C | Moderate delay, many vehicles have to stop; occasional individual cycle failures as a result of insufficient capacity during the cycle |
| D | Longer delays; many vehicles have to stop; and a noticeable number of individual cycle failures as a result of long cycle lengths, high volume to capacity ratios, and/or unfavorable progression |
| E | Long delays and frequent individual cycle failures result from one or both of the following: long cycle lengths or high volume to capacity ratios, which, in turn, result in poor progression |
| F | Delays considered unacceptable to most drivers occur when the vehicle arrival rate is greater than the capacity of the intersection for extended periods of time |

## 9.2.6 Intersection Design Elements

The previous sections have provided an overview of general characteristics of intersections, objectives for intersection design, design considerations for user groups, and determining the size and physical features of an intersection. The remainder of this chapter describes types of intersections and provides guidance for each of the following physical elements of intersection design:

- Alignment and profile,
- Intersection sight distance,
- Turning roadways and channelization,
- Auxiliary lanes,
- Median openings and pedestrian refuge,
- Indirect left turns and U-turns,
- Roundabouts,
- Crossing distances and pedestrian exposure,
- Bicyclist treatments,
- Other intersection design elements, and
- Railroad–highway grade crossings.

## 9.3 TYPES AND EXAMPLES OF INTERSECTIONS

The basic types of intersections are three-leg (T), four-leg, multileg, and roundabouts. Further classification of the basic intersection types includes such variations as unchannelized, flared, and channelized intersections as shown in Figure 9-4. While this figure depicts only vehicle movements, pedestrian and bicycle accommodation could also be included. Roundabouts are described separately in Section 9.10. Additional variations include offset intersections, which are two adjacent T intersections that function similar to a four-leg intersection, and indirect intersections that provide one or more of the intersection movements at a location away from the primary intersection. At each particular location, the intersection type is determined primarily by the number of intersecting legs; the topography; right-of-way constraints; the needs of all users; the character of the intersecting roadways; the traffic volumes, patterns, and speeds; and the desired type of operation. These characteristics are also related to the type of traffic control (e.g., traffic signal, two-way or all-way stop, or yield on minor approach). Variations of these intersection types to improve capacity by providing indirect left-turn movements are addressed in Section 9.9, "Indirect Left Turns and U-Turns."

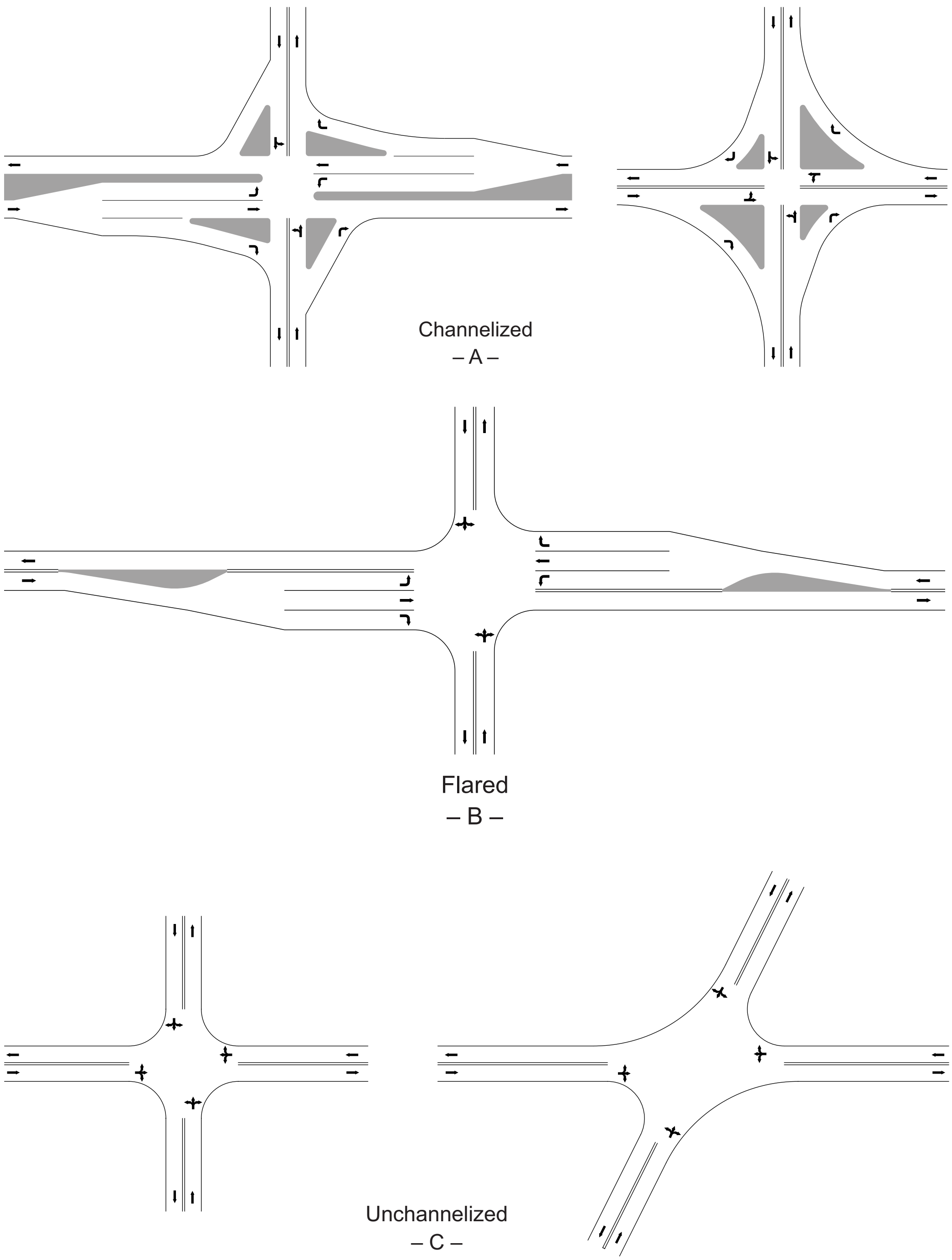



Figure 9-4. General Types of Intersections

Any of the basic intersection types can vary greatly in scope, shape, flaring of the pavement for auxiliary lanes, and degree of channelization. Channelization is the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings to facilitate the orderly movements of both motor vehicles, bicycles, and pedestrians.

Once the intersection type is established, the design controls and criteria discussed in Chapter 2 and the elements of intersection design presented in Chapter 3, as well as in this chapter, should be applied to arrive at a suitable geometric plan. In this section, each type of intersection is discussed separately, and likely variations of each are shown. It is not practical to show all possible variations, but those presented are sufficient to illustrate the general application of intersection design. Many other variations of types and treatment may be found in NCHRP Report 279, *Intersection Channelization Design Guide* (*30*), which presents detailed examples that are not included in this policy.

Although many of the intersection design examples are located in urban areas, the principles involved apply equally to design in rural areas. Intersection design needs a balanced approach to accommodate the modes of transportation that are anticipated while considering the context and community in which the project is located. Some minor design variations occur with different kinds of traffic control, but all of the intersection types shown lend themselves to cautionary or non-stop control, stop control for minor approaches, four-way stop control, and both fixed-time and traffic-actuated signal control. Right-turn roadways without stop or yield control are sometimes provided at channelized intersections. Such channelized right-turn lanes should be used only where an adequate merge is provided. Where motor vehicle conflicts with pedestrians or bicyclists are anticipated, provisions for pedestrians and bicycle movements should be considered in the design. Channelized right-turn lanes have a definite role in improving operations and reducing crashes at intersections. Installation of channelized right-turn lanes in many cases provides opportunities for multi-stage crossings by pedestrians, since raised corner islands are typically provided as part of their implementation. However, pedestrians with vision disabilities may have difficulty at channelized right-turn lanes perceiving the intended pedestrian crossing route. At locations with high pedestrian or bicycle volumes, the use of channelized right-turn lanes should be considered only where traffic capacity limitations or crash patterns may occur without them and where appropriate pedestrian crossings can be provided.

Simple intersections are presented first, followed by more complex types, some of which are special adaptations. In addition, conditions for which each intersection type may be suited are discussed in the following sections. In all cases, the approach roadway may include dedicated bicycle facilities and the designer should consider the need to provide adequate mixing zones so drivers and bicyclists can properly interact.

A brief introduction to each intersection type is presented below. Sections 9.4 through 9.11 then present guidelines to be used in intersection design. Design of roundabouts is described separately in Section 9.10.

## 9.3.1 Three-Leg Intersections

### 9.3.1.1 Basic Types of Intersections

Basic forms of three-leg or T intersections are illustrated in Figures 9-5 and 9-6. The most common type of three-leg conventional intersection, as shown in Figure 9-5A, has the normal pavement width of both roadways maintained except for the paved corner radii or where widening is needed to accommodate the selected design vehicle. This type of unchannelized intersection is generally suitable for junctions of minor or local roads and junctions of minor roads with more important roadways where the angle of intersection is not generally more than 15 degrees from perpendicular (i.e., from approximately 75 to 105 degrees). In rural areas, this intersection type is usually used in conjunction with two-lane roadways carrying light traffic. In suburban or urban areas, it may be satisfactory for higher volumes and for multilane roads. Where speeds or turning movements, or both, are high, an additional surface width or flaring may be provided for maneuverability, as shown in Figure 9-5B and 9-5C, but such provision should consider the effects of widening on pedestrian crossing distances.

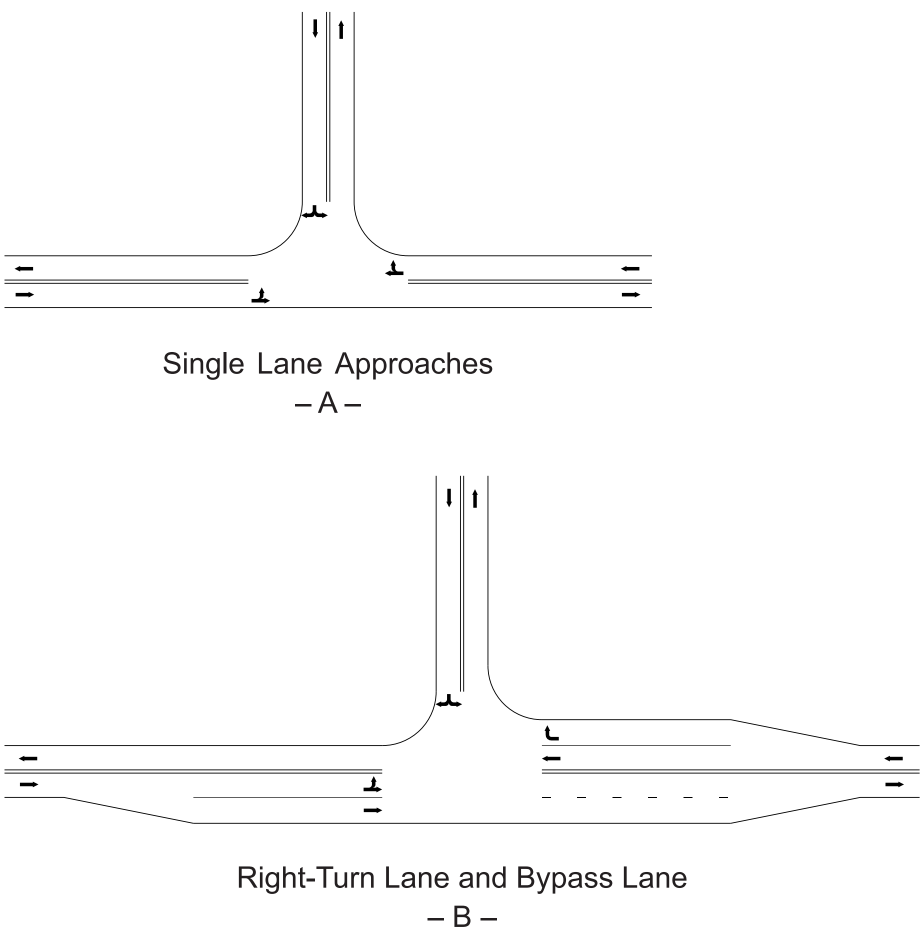
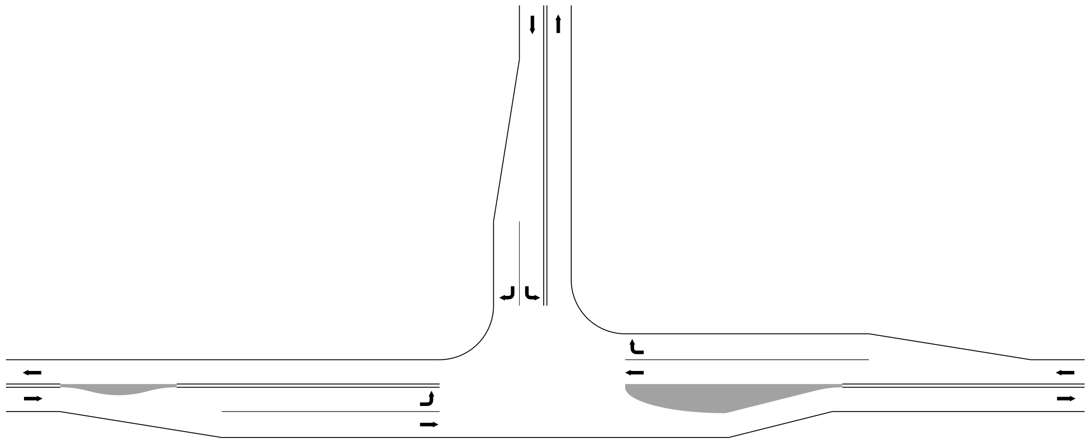



Figure 9-5. Three-Leg Intersections



Designated Lanes for Each Movement
– C –

Figure 9-5. Three-Leg Intersections (Continued)

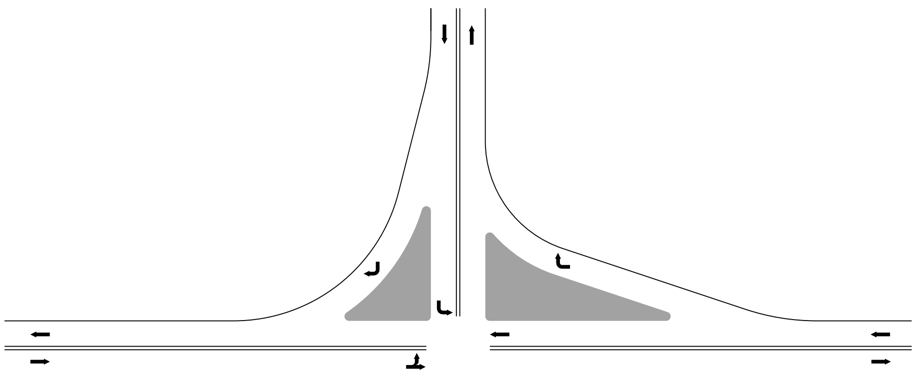
The use of auxiliary lanes, such as left- and right-turn lanes, can reduce crash frequency, increase capacity create better operational conditions for turning vehicles, provide a sheltered storage area for queued vehicles, and reduce speed differentials between through and turning traffic . Left turns from the through roadways are particularly difficult because vehicles need to slow down and perhaps stop before completing the turn. Existing intersections can have an auxiliary lane added with minimal difficulties to provide the intersection types shown in Figure 9-5B to allow through vehicles to bypass a vehicle slowing or stopped to turn left. Additional protection for queued vehicles from the risk of rear-end collisions can be gained by marking a separate lane exclusively for left-turning vehicles as shown in Figure 9-5C.

Where the right-turning movement from the through roadway is substantial, a right-turn lane for vehicles turning right from the major roadway can be added as shown in Figure 9-5B.

Where the left-turning movement from the through roadway and the through movement are substantial, a left-turn lane as shown in Figure 9-5C or a right-hand passing lane as shown in Figure 9-5B can be added on the side of the through roadway opposite the intercepted road. The right-hand passing lane affords an opportunity for a through driver to pass to the right of a slower moving or stopped vehicle preparing to turn left.

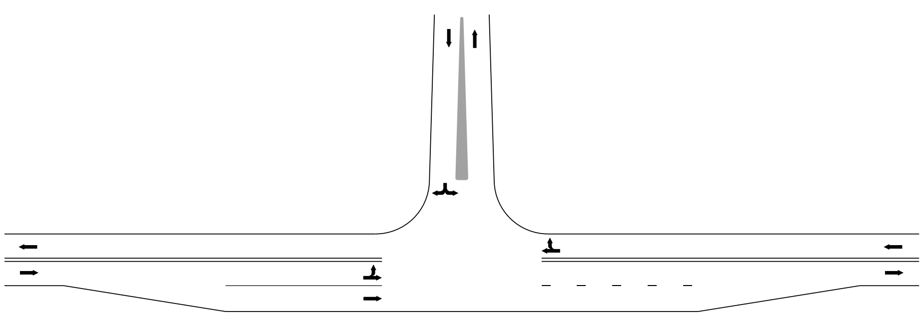
### 9.3.1.2 Channelized Three-Leg Intersections

Channelization is often desirable for a number of reasons, as described in Section 9.6.2. Where channelization is provided, islands and turning roadways should be designed to accommodate the wheel tracks of each vehicle movement while providing optimum crossing paths and storage for pedestrians within the proposed intersection. The simplest form of channelization is accomplished by increasing the corner radius between the two roadways sufficiently to permit a separate turning roadway that is separated from the normal traveled ways of the intersecting approaches by an island as shown in Figure 9-6A and 9-6C. The approach roadway may include a separate right-turn lane leading to the turning roadway for the accommodation of right-turn traffic. Often the provision for a separate lane for left turns or for through movements to bypass left-turning traffic is appropriate on two-lane roadways where right-turning roadways are justified. Left-turning traffic can be accommodated by the flaring of the through roadway as shown in Figure 9-6B and 9-6C. The right-turning roadways should be designed to discourage wrong-way entry while providing sufficient width for anticipated turning trucks.



With a Pair of Right-Turn Islands

– A –



With Divisional Island and Right Passing Lane

– B –

Figure 9-6. Channelized Three-leg Intersections

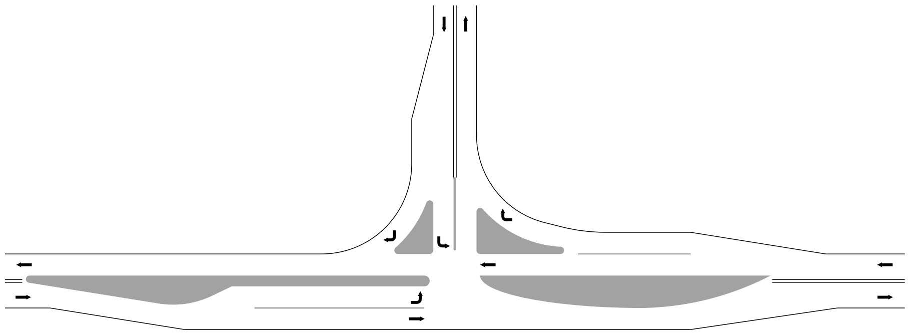



Figure 9-6. Channelized Three-leg Intersections (Continued)

Figure 9-6B depicts a channelized intersection incorporating one divisional island on the crossroad. Space for this island is made by flaring the pavement edges of the crossroad and by using larger-than-minimum pavement edge radii for right-turning movements. Figure 9-6C shows an intersection with a divisional island and right-turning roadways, a desirable configuration for intersections on important two-lane highways carrying intermediate to heavy traffic volumes (e.g., peak-hour volumes greater than 500 vehicles on the through roadway with substantial turning movements). All movements through the intersection are accommodated on separate lanes.

Where the traffic demand at an intersection approaches or exceeds the capacity of a two-lane roadway and where signal control may be needed in rural areas, it may be desirable to convert the two-lane roadway to a divided section through the intersection, as shown in Figure 9-6C. In addition to adding auxiliary lanes on the through roadway, the intersecting road (i.e., the stem of the three-leg intersection) may be widened on one or both sides for better maneuverability and increased capacity on the crossroad. The right-turn lane in the upper right quadrant accommodates a non-restricted exit from the major route.

Figures 9-5B and 9-6B provide examples of bypass lanes, which are added to the outside edge of the approach, allowing through vehicles to pass left-turning vehicles on the right, while Figures 9-5C and 9-6C show traditional left-turn lanes. Regardless of the treatment, consideration of traffic demand, delay savings, crash reduction and construction costs are all key factors in determining whether to install a left-turn lane or a bypass lane.

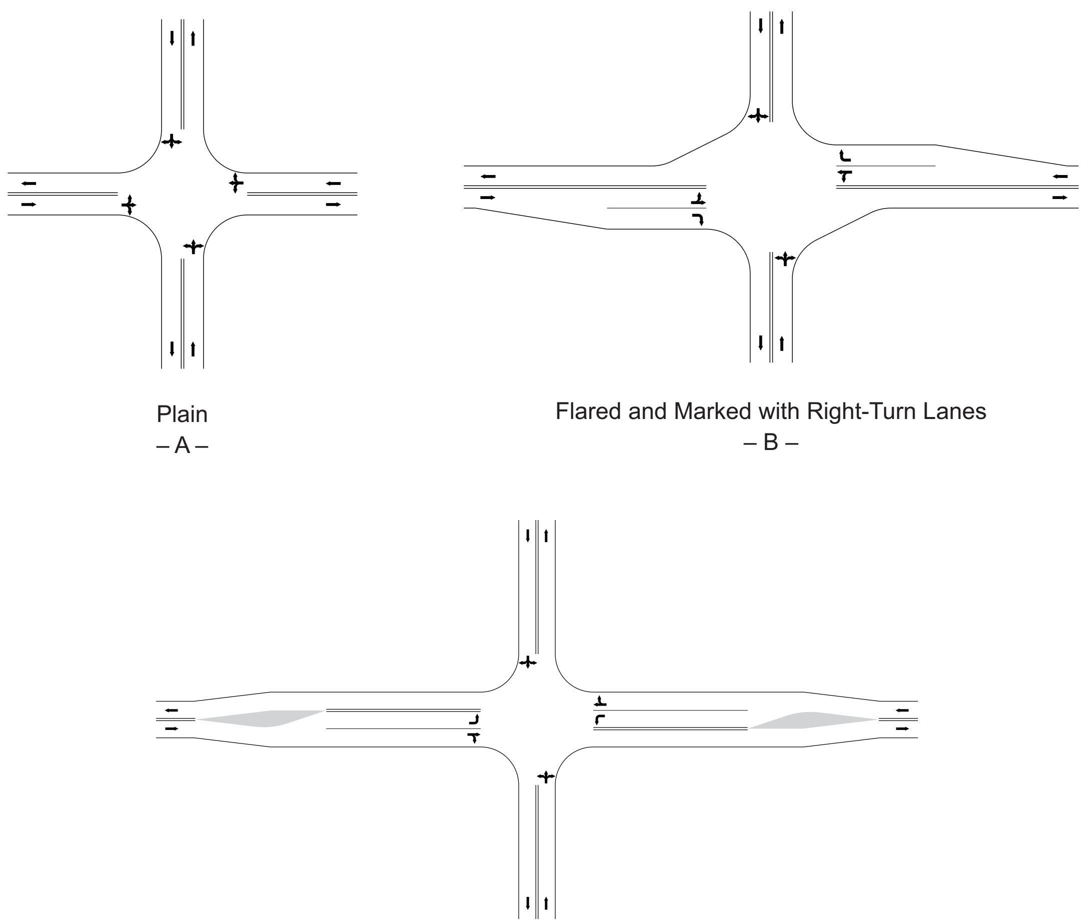
Dimensions for turning roadways (e.g., lane width, taper length, lane change and deceleration length, and storage length) are provided in Section 9.7. Bypass lanes for through traffic should be designed with the same lane width as the width of the travel lane upstream and downstream of the intersection; the taper rate recommended in Section 9.7.2 for turning roadways can also be used for bypass lanes. Guidance on installing bypass lanes and left-turn lanes are provided in Section 9.7.3.

The design of roundabouts at three-leg intersections is presented in Section 9.10.

## 9.3.2 Four-Leg Intersections

### 9.3.2.1 Basic Types

The overall design principles, island arrangements, use of auxiliary lanes, and many other aspects of the previous discussion of three-leg intersection design also apply to four-leg intersections. Basic types of four-leg intersections are shown in Figures 9-7 and 9-8.



Plain
– A –

Flared and Marked with Right-Turn Lanes
– B –

Flared and Marked with Left-Turn Lanes
– C –

Figure 9-7. Unchannelized Four-Leg Intersections, Plain and Flared

The simplest form of an unchannelized four-leg intersection suitable for intersections of minor or local roads and often suitable for intersections of minor roads with major roadways is illustrated in Figure 9-7A. A skewed intersection leg should not be more than 15 degrees from perpendicular (i.e., from approximately 75 to 105 degrees). Approach pavements are continued through the intersection, and the corners are rounded to accommodate turning vehicles.

A flared intersection, illustrated in Figures 9-7B and 9-7C, has additional capacity for through and turning movements at the intersection but may create concerns for pedestrians due to higher turning speeds and longer crosswalks. Therefore, provision of raised medians that serve as a pedestrian refuge may be considered. Auxiliary lanes on each side of the normal pavement at the intersection illustrated in Figure 9-7B enable through vehicles to pass slow-moving vehicles preparing to turn right. Depending on the relative volumes of traffic and the type of traffic control used, flaring of the intersecting roadways can be accomplished by parallel auxiliary lanes, as on the roadway shown horizontally, or by pavement tapers, as shown on the crossroad. Flaring generally is similar on opposite legs. Parallel auxiliary lanes are essential where traffic volume on the major roadway is near the uninterrupted-flow capacity of the roadway or where through and cross traffic volumes are sufficiently high to warrant signal control. Auxiliary lanes are also desirable for lower volume high-speed conditions. The length of added pavement should be determined as it is for speed-change lanes, as shown in the subsection on Auxiliary Lanes in Section 9.7, and the length of uniform lane width, exclusive of taper, should normally be greater than 150 ft [45 m] on the approach side of the intersection. The length of the lane-addition and lane-drop tapers needed to accomplish the flaring can be determined from Equations 3-38 and 3-39 in Section 3.4.4.

A flared intersection that makes provision for a median lane for left-turn movements is shown in Figure 9-7C. This configuration incorporates a median lane suitable for two-lane roadways where speeds are high, intersections are infrequent, and the left-turning movements from the roadway could create a conflict.

The configuration in Figure 9-7C affords better protection for vehicles turning left from the major highway than does the arrangement in Figure 9-7B and is better suited for intersections with signal control.

### 9.3.2.2 Channelized Four-Leg Intersections

Typical configurations of four-leg intersections with simple channelization are shown in Figure 9-8. Right-turning roadways as shown in Figure 9-8A are often provided at major intersections for the more important turning movements, where large vehicles are to be accommodated, and at minor intersections in quadrants where the angle of turn is substantially below 90 degrees as shown in Figure 9-9A.